Appendix 8

Evaluating Best Management Practices and their Potential in Reducing Greenhouse Gas Emissions from Soils – Estimates of N_2O Emissions and Agronomic Data Base.

Report submitted to

Ontario Greenhouse Gas Mitigation Committee
OSCIA/IFAO/SCCC

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Project Activities:

Agronomic data for the following three projects have been received and have been organized into the data base.

A. Demonstration of the impact of the rate of fertilizer N and date of N application on N_2O emissions and N use efficiency in wheat production.
B. Advancing N use efficiency in livestock farms.
C. Cover crops for carbon sequestration and N management in field crops.

The data include: grain yield, pre-plant and post harvest soil NO_3-N content, basic soil fertility, N inputs, residue dry mass and protein content (wheat sites only). In addition, complete weather data were also received for the Halton winter wheat site.

These data were used as input parameters in a new model, named 'GHG Farm' (developed by Agriculture and Agri-Food Canada) to generate estimates of N_2O emissions. The 'GHG Farm' is a simple ecosystem model that estimates net greenhouse gas emissions from Canadian farms (Helgason et al., 2005). It describes best understood biophysical processes and their interactions and utilizes several mathematical equations that combine expert knowledge and findings from experiments. Importantly, it considers soil and environmental conditions for Canadian farms. Some examples for the parameters and coefficients used in the model are presented in Table 1.

The estimated N_2O emissions for the wheat projects and the livestock projects have been completed and presented in this report. Estimated N_2O emissions for the cover crop projects are currently being done. Estimated N_2O emissions for the horticultural projects will be done when the agronomic database is completed.

Estimates of N_2O emissions at wheat sites:

The objectives of this project were "*to study N use efficiency in winter wheat and spring wheat production in response to different rates and timing of N application and to demonstrate management opportunities for reducing the risk of N_2O losses to the environment while improving wheat production and grain quality (protein content)*".

Two hub sites, one at Halton and another at Middlesex were established for winter wheat and one hub site at Ottawa was established for spring wheat.

For winter wheat, three application target times: 'Early' (~March 31st), 'Optimum' (~April 25th) and 'Late' (~May 10th) in combination with three N rates: 60, 90, 125 lb ac^{-1} (67, 101 and 140 kg N ha^{-1}, respectively) were included in the experiment. The resulting nine treatment combination was replicated twice. In addition, a split application of 90 lb ac^{-1} (30 lb N on the date of Early application and 60 lb N on the date of 'Late' application) and a 30 lb ac^{-1} (34 kg ha^{-1}) applied 'Early' were also included in the experiment. At the Middlesex wheat site, a replicated 0 N treatment was also included.

For spring wheat, three application times: (a) at panting, (b) at ‘node’ - applied at ‘tillers formed’ (Zadoks 22) to ‘first node visible’ (Zadoks 30), and (c) a split application (at planting and at ‘node’) in combination with three rates of N (67, 101 and 140 kg N ha^{-1}) were included. In addition, a 0 N treatment was also included. All treatments were replicated twice.

The estimated N_2O emissions for the winter wheat sites at Halton and Middlesex and spring wheat site at Ottawa for all three years are presented in Tables 2 and 3. The GHG Farm model estimates direct N_2O emissions due to fertilizer N and indirect N_2O emissions due to leaching and volatilization of fertilizer N used at a given site separately. It also calculates the N_2O emissions due to crop residue N using the same emission factor used for direct emissions for fertilizer N, but using measured residue N inputs at the site. In Tables 2 and 3, the combined estimates from direct and indirect emissions due to fertilizer N and emissions due to residue N returned are presented. The estimated baseline N_2O emissions for wheat, which was based on the residue N returned in the zero N plots, ranged from 0.25 – 0.36 kg N_2O-N ha^{-1} for different sites (Tables 2 and 3). The differences between sites and years are essentially due to differences in the N returned from residue dry mass. For the fertilized plots, the estimated N_2O emissions increased linearly due to the increasing rates of N and ranged from 0.86 kg N_2O-N ha^{-1} for the lowest N rate (34 kg N ha^{-1}) at Halton to 3.1 kg N_2O-N ha^{-1} for the highest N rate (140 kg N ha^{-1}) at Middlesex.

In the GHG Farm model there are two separate coefficients for spring and fall applied N (Table 1). However, the effect of a split application of fertilizer N or application of fertilizer N in early in the spring vs. late in the spring on N_2O emissions is still not well defined. As a result, there were no differences in estimated N_2O emissions due to the different times of fertilizer N application for winter wheat (Table 2). For spring wheat, N_2O-N emissions due to residue N were significantly higher for N application at ‘node’ stage and for split application, when compared with N application at planting (Table 3). This is due to higher residue N returned with later N applications.

N_2O emissions from agricultural fields may be influenced by N fertilizer recovery efficiency and overall N balance at the site. In order to evaluate different N management treatments for their potential for reducing the risk of N_2O-N loss, two additional variables such as apparent fertilizer N recovery (AFNR) and N balance were also calculated. The procedures for calculating these variables are described here briefly.

Apparent fertilizer N recovery: AFNR in the above ground biomass was calculated from the difference in above ground N in the zero N control plot (in the corresponding block) and any N treatment as a proportion of the amount of fertilizer N applied. For the Halton site there was no zero N treatment in 2003 and 2004. Therefore, the intercept ‘*a*’ of the N response curve was used for the calculation in each year.

N balance: To gain an understanding of the status of N in the treatment of interest, an N balance was calculated.

N balance = products – sources

The measured sources or inputs to the system are initial NO_3-N in the 0-60 cm soil depth and N applied as fertilizer. The measured products or outputs of the system are total above ground N uptake and residual NO_3-N in the 0-60 cm soil depth.

An estimate of the total NO_3-N in the 0-60 cm depth was calculated as:

(kg NO_3-N ha^{-1} in 0-60 cm depth) = (kg NO_3-N ha^{-1} in 0-30 cm) * 1.62 (Kachanoski and Beauchamp, 1991).

Above ground N uptake and apparent fertilizer N recovery (AFNR) for winter wheat are presented in Tables 4 and 5. At Halton, AFNR for all fertilizer N rates was relatively low in 2005 (38%) than in 2003 (64%) and 2004 (43%). The same trend for AFNR was evident for the Middlesex site. The lowest AFNR (14%) for winter wheat was observed at this site in 2005 (Table 5). The reasons for this drastic reduction in AFNR in 2005 compared with other two years is unclear but need to be examined, once weather data for this site becomes available. Averaged over three years for Halton and for first two years for Middlesex, the AFNR for winter wheat was highest (55%) at 67 kg N ha^{-1} rate and lowest (40%) at 140 kg N ha^{-1} rate indicating potentially higher fertilizer N loss at higher application rates. Date of N application did not indicate any significant influence on N uptake and AFNR in winter wheat, except in 2003 at Middlesex (Table 4 and 5), when early application of fertilizer N significantly reduced both above ground N uptake and fertilizer N recovery in winter wheat.

The general trend of decreasing fertilizer N recovery with increasing N fertilizer rate was also evident for spring wheat, although only significant in 2004 (Table 6). Averaged over three years AFNR decreased from 35% at 67 kg N ha^{-1} to 26% at 140 kg N ha^{-1}. In contrast with the results for winter wheat, the date of N application indicated a significant effect on AFNR in spring wheat showing that application of N at ‘node’ stage or split has a positive influence when compared with application of N at planting. This indicates higher efficiency of applied N at later stages of spring wheat growth with potentially reduced opportunities for N losses.

Measured N inputs and outputs as well as N balance for winter wheat for 2003 and 2004 at Halton are presented in Table 7. For 2003, the N balance was negative for both higher N fertilizer rates indicating fertilizer N loss at these two N rates. It is also apparent that N losses were comparatively higher at the highest N rate. In 2004, N balance for all treatments was positive, indicating considerable net N mineralization from soil organic matter. Assuming similar amount of N mineralization for all three N treatments, estimated loss of soil N mineralized for the 101 kg N ha^{-1} treatment is 18.7 kg ha^{-1} (61.8-43.1). Similarly, the estimated loss of soil N mineralized for the 140 kg N ha^{-1} treatment is 59 kg N ha^{-1} (61.8-2.8). Time of N application did not indicate significant effect on the N balance for winter wheat in both years. Losses of N_2O-N when expressed as a ratio of grain produced showed a negative correlation with AFNR indicating the potential for reducing N_2O-N loss by management practices that will contribute to increased fertilizer recovery (Fig 1).

The results for this project indicated that the potential for N_2O-N loss from soils cultivated with wheat is higher with increasing rates of fertilizer application. Indirect evidence from AFNR and N balance showed increasing N loss with increasing rates of N application. Application of fertilizer N exceeding 101 kg N ha^{-1} (90 lb ac^{-1}) did not contribute to significant improvement in grain yield (interim reports for wheat sites for 2003 and 2004), while greatly increased the potential for N losses to the environment.

Estimates of N_2O emissions for livestock sites:

The purpose of these on-farm demonstration project was *"to assess overall N use efficiency on livestock farms and to evaluate technologies such as the soil nitrate test and lower stalk N-test as tools to advance nitrogen use efficiency and thereby reduce risk of N losses to the environment including N_2O emissions"*.

Each year, nine sites were included across the corn producing regions of Ontario. At all sites, different types of manure had been applied in the previous fall. At a few sites manure was applied at pre-plant or as a side-dress. Subsequent to manure application four rates of fertilizer N (0, 50, 100, 150 kg N ha^{-1}) were established by side-dressing corn with 28% UAN.

The information on types and rates of manure applied and amounts of N inputs through manure, along with the estimated N_2O emissions due to manure N for different livestock sites are presented in Tables 8A, 9A, and 10A. Over the three year period, N inputs from manure ranged from 59 to 278 kg N ha^{-1}. Accordingly, sites showed considerable differences for the estimates of N_2O emissions resulting from manure N. Estimated emissions due to manure N ranged from 1.34 to 5.59 kg N_2O-N ha^{-1} $year^{-1}$.

Estimated N_2O emissions due to fertilizer N and crop residue N returned for different livestock sites are presented separately in Tables 8B, 9B and 10B. As explained for wheat, estimated N_2O emissions increased linearly with increasing fertilizer N rate for corn. At the highest fertilizer N rate applied, estimated N_2O emissions due to fertilizer ranged from 2.86 to 3.78 kg N_2O-N ha^{-1}.

Apparent fertilizer N recovery for different livestock sites over the three year period is presented in Table 11. In 2003 and 2004, AFNR was below 40% for the majority of sites, even at the lowest fertilizer N rate. In 2005, AFNR increased slightly, to an average of 31% at the lowest N rate applied. This extremely low AFNR at the majority of livestock sites is a clear indication of inefficient use of fertilizer N. In general, additional fertilizer N used at these sites appeared not to be contributing significantly to the grain production and was at risk of being lost to the environment. One option for reducing potential N_2O emissions from these sites would be maximizing the utilization of manure N for corn production while minimizing the use of fertilizer N. As shown in Table 12, the most economic rate of N (MERN) for these sites were, on average, 55, 61, and 73 kg N ha^{-1} for 2003, 2004 and 2005, respectively. At these N fertilizer levels, estimated N_2O emissions were, on average, 52% lower than the estimated N_2O emissions due to fertilizer N at the highest side-dress N rate. Identification of correct economically optimum fertilizer N rate for these sites in a given year would therefore be a critical factor in reducing greenhouse gas emissions.

References:

1. Helgason, B.L. et al., (2005) GHG Farm – An assessment tool for estimating net greenhouse gas emissions from Canadian farms. Agriculture and Agri-Food Canada.
2. Kachanoski, R. G. and Beauchamp, E. G. (1991) Soil nitrogen test for corn in Ontario. Dept. of Land Resource Science, University of Guelph.

Table 1. Some selected factors and coefficients used to calculate N_2O-N emission estimates in the 'GHG Farm' model

Factor	Coefficient
Fraction of grain N (wheat)	0.026
Fraction of grain N (corn)	0.015
Fraction crop residue N (wheat)	0.006
Fraction of crop residue N (corn)	0.005
Harvest Index (wheat)	0.40
Harvest Index (corn)	0.55
EF_{fert} (Soil code 6/soil texture code 1) (kg N_2O-N/kg N applied)	0.0167
EF_{fert} (Soil code 6/soil texture code 1)) (kg N_2O-N/kg N applied)	0.0083
$EF_{tillage}$ (NT)	1.3
$EF_{tillage}$ (IT)	1.0
$EF_{application}$ (Spring)	1.3
$EF_{application}$ (Fall)	1.8
$R_{leaching}$ (Eastern Canada)	0.25
$EF_{leaching}$	0.0125
$R_{volatilization}$	0.1
$R_{volatilization\ manure}$	0.2
$EF_{volatilization}$	0.01

Table 2. Estimated N_2O-N emissions (kg N_2O-N ha^{-1} $year^{-1}$) from soils cultivated with winter wheat as affected by the rate of fertilizer N and the date of N fertilizer application at Halton and Middlesex.

Treatments†		Halton 2003	Halton 2004	Halton 2005	Middlesex 2003	Middlesex 2004	Middlesex 2005
Rate of N	0	NA¶	NA	0.29	0.36	0.33	0.22
(kg ha^{-1})	34	0.86	1.13	0.98	1.06	1.14	0.85
	67	1.54	1.69	1.59	1.88	1.72	1.45
	101	2.18	2.31	2.24	2.26	2.36	2.09
	140	2.89	3.03	2.97	2.79	3.09	2.80
Time of N	Early	2.20	2.36	2.29	2.30	2.40	2.13
application	Optimum	2.21	2.32	2.25	2.32	2.37	2.11
	Late	2.20	2.35	2.26	2.31	2.40	2.09
SE‡		0.124	0.011	0.016	0.004	0.005	0.005

† N_2O emission estimates for 0 and 34 kg N ha^{-1} rates were not included in the statistical analysis, since they were based on one or two observations. For rest of the treatments, rate*time interaction is not significant, thus means for N rates are averaged across different application times, means for time of N application are averaged across different fertilizer N rates.

¶ Not available.

‡ Standard error of the mean for equally replicated treatments within three higher fertilizer N rates or time of N application (n = 6).

Table 3. Estimated N_2O-N emissions (kg N_2O-N ha^{-1} $year^{-1}$) from soils cultivated with spring wheat as affected by the rate of fertilizer N and the time of N fertilizer application at Ottawa, Ontario.

Treatments†		2003	2004	2005
Rate of N	0	0.27	0.26	0.31
(kg ha^{-1})	67	1.53	1.57	1.55
	101	2.14	2.20	2.18
	140	2.88	2.93	2.90
Time of N	Planting	2.19	2.22	2.18
application	Node	2.15	2.24	2.22
	Split	2.20	2.24	2.23
SE‡		0.007	0.005	0.005

†N rate*time of N application interaction is not significant, thus means for N rates are averaged across different application times, means for time of N application are averaged across different fertilizer N rates.

‡ SE = standard error of the mean for equally replicated treatments within fertilizer N rates or time of N application (n = 6).

Table 4. Total above ground N uptake and apparent fertilizer N recovery (FNR) of winter wheat as affected by the rate of fertilizer N and date of N fertilizer application at Halton, Ontario.

Treatments†		2003		2004		2005	
		N uptake kg ha^{-1}	FNR %	N uptake kg ha^{-1}	FNR %	N uptake kg ha^{-1}	FNR %
N rate kg ha^{-1}	67	86.6	79.5	131.8	52.5	101.0	40.7
	101	96.9	63.2	139.6	42.7	112.7	38.6
	140	100.9	48.4	145.4	34.9	122.5	34.9
Time of N application	Early	91.9	61.3	144.1	49.0	117.7	44.8
	Optimum	96.2	63.9	133.3	39.0	108.7	33.8
	Late	96.3	66.0	139.5	42.0	109.8	35.7
SE‡		3.55	4.02	3.73	4.55	4.12	6.12

†N rate*time of N application interaction is not significant, thus means for N rates are averaged across different application times and means for time of N application are averaged across different fertilizer N rates.
‡SE = standard error of the means within fertilizer rates or time of N application (n = 6).

Table 5. Total above ground N uptake and apparent fertilizer N recovery (FNR) of winter wheat as affected by the rate of fertilizer N and date of N fertilizer application at Middlesex, Ontario.

Treatments†		2003		2004		2005	
		N uptake kg ha^{-1}	FNR %	N uptake kg ha^{-1}	FNR %	N uptake kg ha^{-1}	FNR %
N rate kg ha^{-1}	67	116.1	46.0	133.9	57.1	66.7	14.0
	101	126.5	47.8	144.0	47.8	73.0	15.4
	140	134.4	43.3	151.9	40.2	74.0	11.8
Time of N application	Early	118.1	37.9	144.6	48.8	76.5	19.3
	Optimum	128.1	48.5	146.5	51.9	71.0	12.8
	Late	130.8	50.6	138.7	44.5	66.2	9.1
SE‡		2.24	2.32	2.09	1.76	1.81	2.65

†N rate*time of N application interaction is not significant, thus means for N rates are averaged across different application times and means for time of N application are averaged across different fertilizer N rates.
‡SE = standard error of the means within fertilizer rates or time of N application (n = 6).

Table 6. Total above ground N uptake and apparent fertilizer N recovery (FNR) of spring wheat as affected by the rate of fertilizer N and date of N fertilizer application at Ottawa, Ontario.

Treatments†		2003		2004		2005¶	
		N uptake kg ha^{-1}	FNR %	N uptake kg ha^{-1}	FNR %		
N rate kg ha^{-1}	67	98.6	22.2	121.6	57.5		
	101	100.4	16.5	132.4	49.0		
	140	108.2	17.5	141.1	41.5		
Time of N application	Planting	90.5	6.3	125.3	42.0		
	Node	108.1	25.2	136.2	54.1		
	Split	108.6	24.8	133.6	52.0		
SE‡		1.74	2.99	1.65	2.15		

†N rate*time of N application interaction is not significant, thus means for N rates are averaged across different application times and means for time of N application are averaged across different fertilizer N rates.

‡SE = standard error of the means within fertilizer rates or time of N application (n = 6).

¶Not calculated.

Table 7. Measured N inputs (sources) and outputs (products) for the soil/winter wheat system as affected by the rate of fertilizer N and the date of N application at Halton, Ontario.

Table 7A: 2003

Treatment[1]		Inputs (sources): Fertilizer N	Inputs (sources): Spring soil NO_3[2]	Outputs (products): Plant N uptake	Outputs (products): Residual soil NO_3[2]	N balance[3]
		(kg ha^{-1})				
Rate of N ($kg\ ha^{-1}$)	67	67.2	23.9	86.6	12.8	8.4
	101	100.8	25.1	96.9	14.7	- 14.4
	140	140.0	28.1	100.9	17.1	- 50.1
Time of N application	Early	102.7	24.6	91.9	16.5	- 18.9
	Optimum	102.7	25.6	96.2	13.7	- 18.4
	Late	102.7	26.8	96.3	14.3	- 18.8
SE			1.69	3.54	2.11	4.20

Table 7B: 2004

Treatment[1]		Inputs (sources): Fertilizer N input	Inputs (sources): Initial soil NO_3[2]	Outputs (products): Plant N uptake	Outputs (products): Residual soil NO_3[2]	N balance
		(kg ha^{-1})				
Rate of N ($kg\ ha^{-1}$)	67	67.2	48.0	131.8	45.2	+ 61.8
	101	100.8	43.4	139.6	47.8	+ 43.1
	140	140.0	46.0	145.4	43.4	+ 2.8
Time of N application	Early	102.7	42.7	144.1	53.2	+ 51.9
	Optimum	102.7	44.6	133.3	41.6	+ 27.6
	Late	102.7	50.1	139.5	41.5	+ 28.3
SE			1.34	3.72	4.17	7.58

[1] Means for N rates are averaged across different application times, means for time of N application are averaged across different N rates.
[2] Initial and residual NO_3-N in the 0-60 cm depth.
[3] N balance = products – sources, (a positive balance indicates N additions through mineralization and a negative balance indicates N removal through immobilization or losses). If the change in soil organic N content is negligible a negative balance means losses from the system.
SE = standard error of the means within N rates or time of N application (n = 6).

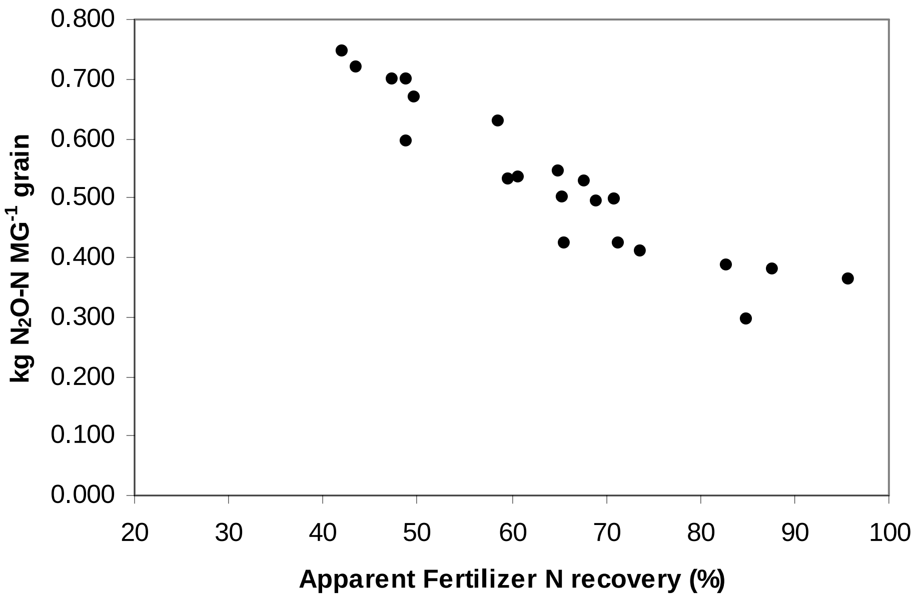

Fig 1. Estimated N_2O-N loss per mega gram of grain produced as influenced by the apparent fertilizer N recovery by winter wheat at Halton, Ontario – 2003.

Table 8A. N inputs from manure applications prior to corn and estimated N_2O emissions due to manure N at nine livestock sites – 2003.

Site	LASF	LBWB	LDKD	LJHS	LKBD	LLHB	LSBD	LTBD	LWJD
Country	Stormont, Dundas and Glengarry	Huron	Leeds and Grenville	Stormont, Dundas and Glengarry	Perth	Wellington	Stormont, Dundas and Glengarry	Bruce	Durham
Manure type	Liquid beef	Solid Poultry	Liquid dairy	Liquid hog	Liquid dairy	Solid poultry	Liquid dairy	Liquid dairy	Solid dairy
Time applied	Fall 02	Fall 02	Fall 02	Fall 01	Fall 02	Fall 02	Fall 02	Spring 02	Fall 02
Manure rate	56.0‡	4.5	74.7	32.7	60.7	11.2	46.7	23.3	56.0
N input (kg ha^{-1})	94.1	139.3	268.9	166.7	212.4	246.4	168.1	84.0	207.3
N_2O-N emissions (kg N_2O-N ha^{-1})	1.89	2.79	5.39	3.35	4.26	4.94	3.37	1.34	4.16

‡ Units are m^3 ha^{-1} for liquid manure, Mg ha^{-1} for solid manure.

Table 8B. Estimated N_2O emissions (kg N_2O-N ha^{-1} $year^{-1}$) due to fertilizer N and crop residue N as affected by different fertilizer N rates applied to corn at nine livestock sites – 2003.

Rate of fertilizer N (kg ha^{-1})	LASF	LBWB	LDKD	LJHS	LKBD	LLHB	LSBD	LTBD	LWJD
0	0.41	0.46	0.38	1.20	0.30	0.62	0.53	0.36	1.07
56	1.25	1.33	1.23	2.12	1.19	1.46	1.41	1.24	1.90
112	2.06	2.18	2.07	2.07	2.05	2.30	2.25	2.08	2.74
168	2.88	3.01	2.90	3.78	2.88	3.13	3.09	2.91	3.58
SE	0.004	0.006	0.004	0.005	0.011	0.005	0.009	0.002	0.005

Table 9A. N inputs from manure applications prior to corn and estimated N_2O emissions due to manure N at nine livestock sites – 2004.

Site	L2AS	L2CW	L2DC	L2HV	L2JK	L2KB	L2LH	L2SE	L2WJ
Country	Stormont, Dundas and Glengarry	Huron	Stormont, Dundas and Glengarry	Huron	Perth	Perth	Wellington	Wellington	Durham
Manure type	Liquid beef	Solid poultry	Liquid dairy	Liquid hog	Liquid hog	Liquid dairy	Solid poultry	Liquid hog	Solid dairy
Time applied	Fall 03	Fall 03	Fall 03	Summer 03	Fall 03	Fall 03	Fall 03	Fall 03	Fall 03
Manure rate	56.0‡	9.0	74.7	46.7	56.0	60.6	11.8	27.1	56.0
N input (kg ha^{-1})	190.5	278.6	268.8	186.7	268.9	218.5	246.4	137.8	229.7
N_2O-N emissions (kg N_2O-N ha^{-1})	3.82	5.59	5.39	3.75	5.39	4.38	4.94	2.76	4.61

‡ Units are m^3 ha^{-1} for liquid manure, Mg ha^{-1} for solid manure.

Table 9B. Estimated N_2O emissions (kg N_2O-N ha^{-1} $year^{-1}$) due to fertilizer N and crop residue N as affected by different fertilizer N rates applied to corn at nine livestock sites – 2004.

Rate of fertilizer N (kg ha^{-1})	L2AS	L2CW	L2DC	L2HV	L2JK	L2KB	L2LH	L2SE	L2WJ
0	0.40	0.81	0.35	0.35	0.30	0.31	0.55	0.28	0.83
56	1.24	1.69	1.20	1.26	1.18	1.19	1.41	1.15	1.67
112	2.07	2.54	2/03	2.13	2.03	2.04	2.24	1.99	2.51
168	2.92	3.38	2.86	2.97	2.89	2.87	2.91	2.83	3.34
SE	0.005	0.006	0.008	0.008	0.010	0.006	0.081	0.003	0.003

Table 10A. N inputs from manure applications prior to corn and estimated N_2O emissions due to manure N at nine livestock sites – 2005.

Site	L3AS	L3CW	L3GV	L3HV	L3KB	L3LH	L3SE	L3WJ
Country	Stormont, Dundas and Glengarry	Perth	Huron	Perth	Huron	Wellington	Wellington	Durham
Manure type	Liquid beef	Solid poultry	Liquid hog	Liquid hog	Liquid dairy	Solid poultry	Liquid hog	Solid dairy
Time applied	Fall 04	Fall 04	Fall 04	Fall 03	Late summer 04	Fall 04	Pre-plant 05	Fall 04
Manure rate	60.7‡	9.0	56.0	46.7	51.3	6.7	36.9	56.0
N input (kg ha^{-1})	206.3	59.1	152.6	186.7	184.9	196.2	84.6	246.5
N_2O-N emissions (kg N_2O-N ha^{-1})	4.14	1.19	3.06	3.75	3.71	3.94	1.35	4.95

‡ Units are m^3 ha^{-1} for liquid manure, Mg ha^{-1} for solid manure.

Table 10B. Estimated N_2O emissions (kg N_2O-N ha^{-1} $year^{-1}$) due to fertilizer N and crop residue N as affected by different fertilizer N rates applied to corn at nine livestock sites – 2005.

Rate of fertilizer N (kg ha^{-1})	L3AS	L3CW	L3GV	L3HV	L3KB	L3LH	L3SE	L3WJ
0	0.36	0.37	0.23	0.34	0.36	0.69	0.32	0.79
56	1.25	1.24	1.13	1.25	1.22	1.54	1.18	2.05
112	2.06	2.08	1.99	2.09	2.07	2.38	2.02	2.47
168	2.92	2.93	2.83	2.95	2.92	3.21	2.86	3.31
SE	0.009	0.012	0.008	0.017	0.003	0.004	0.003	0.202

Table 11. Apparent fertilizer N recovery of corn as affected by the rate of fertilizer N at different sites where animal manure had been applied in the previous fall.

2003

Rate of N (kg ha^{-1})	LASF	LBWB	LDKD	LJKS	LKBD	LLHB	LSBD	LTBD	LWJD
56	1.3	25.9	16.8	36.2	43.8	0.9	29.0	34.3	-1.2
112	2.1	18.4	8.7	17.4	31.4	3.0	20.4	16.8	-0.9
168	2.9	11.3	5.8	17.6	20.6	1.0	15.8	13.8	-0.7
SE									

2004

Rate of N (kg ha^{-1})	L2AS	L2CW	L2DC	L2HV	L2JK	L2KB	L2LH	L2SE	L2WJ
56	6.3	20.6	5.8	56.4	42.8	39.1	13.2	14.5	1.2
112	1.3	20.4	2.6	43.4	27.7	26.9	6.2	8.9	5.6
168	2.8	14.3	0.4	31.1	15.5	16.7	2.9	5.8	1.9
SE	2.7	0.8	1.8	1.0	4.5	3.2	1.2	4.8	1.2

2005

Rate of N (kg ha^{-1})	L3AS	L3CW	L3GV	L3HV	L3KB	L3LH	L3SE	L3WJ
56	49.8	31.9	58.7	59.0	19.5	5.6	22.9	3.0
112	14.0	20.5	46.0	33.5	14.0	5.0	12.1	1.8
168	18.8	17.0	29.2	31.4	12.5	1.9	8.1	2.2
SE	9.3	6.3	3.6	10.4	0.3	0.5	1.5	3.7

Table 12. Comparative estimates of N_2O emissions (kg N_2O-N ha^{-1}) at MERN and highest N rate for different livestock sites.

2003

Site	LASF	LBWB	LDKD	LJHS	LKBD	LLHB	LSBD	LTBD	LWJD	Average
MERN (kg N ha^{-1})	0	83	41	113	96	0	100	61	0	55
N_2O-N loss at MERN	0.40	1.54	0.96	2.03	1.78	0.31	1.91	1.22	0.36	1.17
N_2O-N loss at highest side-dress N	2.88	3.01	2.90	3.78	2.88	3.13	3.09	2.91	3.58	3.13

2004

Site	L2AS	L2CW	L2DC	L2HV	L2JK	L2KB	L2LH	L2SE	L2WJ	Average
MERN (kg N ha^{-1})	0	132	0	122	84	85	52	72	0	61
N_2O-N loss at MERN	0.39	2.32	0.31	2.18	1.60	1.60	1.10	1.39	0.36	1.25
N_2O-N loss at highest side-dress N	2.92	3.38	2.86	2.97	2.89	2.87	2.91	2.83	3.34	2.63

2005

Site	L3AS	L3CW	L3GV	L3HV	L3KB	L3LH	L3SE	L3WJ	Average
MERN (kg N ha^{-1})	81	102	109	140	82	20	54	0	73
N_2O-N loss at MERN	1.59	1.94	1.95	2.42	1.59	0.62	1.14	0.31	1.45
N_2O-N loss at highest side-dress N	2.92	2.93	2.83	2.95	2.92	3.21	2.86	3.31	2.99