Paper No. 004079
An ASAE Meeting Presentation

NITROUS OXIDE EMISSION FROM LAND APPLICATION, COMPOSTING AND STORAGE OF MANURE

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Written for presentation at the
2000 ASAE Annual International Meeting
Sponsored by ASAE

Midwest Express Center
Milwaukee, Wisconsin
July 9-12, 2000

Abstract:

Emissions of nitrous oxide were determined following three to four annual applications of fertilizer, dairy cattle liquid manure and liquid hog manure on grassland; during composting of dairy cattle feedlot manure in turned windrows and in passively aerated static windrows; during vermicomposting of a 1:1 mixture of separated solids from dairy cattle and swine manure in bins; and from hog manure slurry stored in concrete tanks. Most emissions occurred during the 3-4 week period immediately following land application of manure, assembly of windrows and filling of slurry in storage tanks. Emission rate increased with rate of N application on grassland and during warm weather conditions. Total annual emissions from grassland ranged from about 0.2 to 4.5 kg N_20-N per ha. Peak emission rates from manured grassland, turned windrows, static windrows, vermicompost bins and stored swine manure slurry were about 600, 180, 270, 2200 and 2 ng N_20-N m^{-2} s, respectively.

Keywords: nitrous oxide, greenhouse gas, manure slurry, grassland, composting

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ABSTRACT

Emissions of nitrous oxide were determined: following three to four annual applications of fertilizer, dairy cattle liquid manure and liquid hog manure on grassland; during composting of dairy cattle feedlot manure in turned windrows and in passively aerated static windrows; during vermicomposting of a 1:1 mixture of separated solids from dairy cattle and swine manure in bins; and from hog manure slurry stored in concrete tanks. Most emissions occurred during the 3-4 week period immediately following land application of manure, assembly of windrows and filling of slurry in storage tanks. Emission rate increased with rate of N application on grassland and during warm weather conditions. Total annual emissions from grassland ranged from about 0.2 to 4.5 kg N_20-N per ha. Peak emission rates from manured grassland, turned windrows, static windrows, vermicompost bins and stored swine manure slurry were about 600, 180, 270, 2200 and 2 ng N_20-N m^{-2} s, respectively.

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INTRODUCTION

Nitrous oxide (N_20) is one of the three major agriculture related greenhouse gases (GHGs), carbon dioxide ($C0_2$) and methane (CH_4) being the other two. Anthropogenic activities are estimated to account for 24% of the global total emissions of N_20, and 92% of these come from agricultural sources (Duxbury et al., 1993). The Global Warming Potential (GWP) of N_20 in terms of $C0_2$ equivalents is 321 compared to 21 for CH_4, over a 100-year time horizon. Although most of the anthropogenic N_20 emission is from agricultural activities, the factors which control N_20 emissions are poorly understood (Robertson, 1993). For Canada, it is estimated that agriculture contributes 10% of the total GHG emission, and about 60% of this total is N_20 emission (Janzen et al., 1999). However, of the three main GHGs, the uncertainty in emission estimates is greatest for N_20. The study reported here was conducted in response to a need to quantify and better understand agricultural emissions of N_20, particularly under the relatively cool humid climatic conditions of south coastal British Columbia. The objectives of our study were:

1. Determine N_20 emission rates from:
   a) land-applied dairy cattle liquid manure (DCLM) and liquid hog manure (LHM)
   b) during composting of dairy cattle feedlot manure (DCFM) in turned windrows and in passively aerated static windrows
   c) during vermicomposting of a 1:1 mixture of separated solids from DCLM and LHM in indoor bins
   d) LHM stored in partially below grade, open-top concrete manure storage tanks in a roofed shed.

2) Estimate the total N_20 emissions from land-applied manure slurry.

STUDY PROCEDURE

The study was conducted at the Pacific Agri-Food Research Centre of Agriculture and Agri-Food Canada in Agassiz, which is located about 100 km east of Vancouver, British Columbia. The region is characterized by mild winters and about 1650 mm of average annual precipitation, about two-thirds of which occurs in the winter. Daily weather data are recorded at a weather station on site.

Nitrous oxide emission was determined in 1997, 1998 and 1999 in tall fescue *(Festuca arundinacea* Schreb.) fields to which DCLM was applied. Emissions from tall fescue fields receiving LHM, from windrow composting, vermicomposting and from LHM in concrete storage tanks were determined in 1999, only.

Air sample collection and analysis

The method of air sample collection for N_20 determination was common for all systems studied. A 10 mL sample of air was collected during a 30 minute period at 0, 15 and 30 minutes, using pre-evacuated "vaccutainer" tubes using a two-way needle valve. Samples were analysed for N_20 concentration using a Varian Gas Chromatograph equipped with a ^{63}Ni electron capture detector. The emission rate was determined from the slope calculated from the increase in concentration of N_20.

Emission from DCLM application on grassland

Manure and fertilizer treatments, with four replications each in a complete randomized block, were initiated at the study site in 1994 (Table 1). Nitrous oxide emissions were determined from nine treatments in 1997 and 1998, and from five of the nine treatments in 1999. The plots, 3.0 m x 125 m in area, were located on a silt loam soil (Monroe Series) described as Eluviated Eutric Brunisol of moderate to good drainage, derived from medium-textured, stone free Fraser River flood plain deposits overlying coarse textured deposits (Kowalenko, 1991).

Table 1. Treatments used for land application of dairy cattle liquid manure.[a]

Treatment [b]	Inorganic-N nominal appln. rate (kg/ha/appln.)	Nutrient source: fertilizer or manure					
		1994	1995	1996	1997	1998	1999
Control	0	C	C	C	C	C	C
Low-fertilizer	50	F	F	F	F	F	F
Low-manure 1	50	F	F	F	M	M	F
-manure 2	50	F	F	M	M	M	F
-manure 4	50	M	M	M	M	M	M
High-fertilizer	100	F	F	F	F	F	F
High-manure 1	100	F	F	F	M	M	F
-manure 2	100	F	F	M	M	M	F
-manure 4	100	M	M	M	M	M	M

[a] Treatments for which nitrous oxide emission was determined are shown in bold;
C = control; F = fertilizer; M = manure.

[b] Numbers following manure in "Treatment" indicate the number of successive years of DCLM application up to and including 1997 when the study was initiated.

Four times a year, fertilizer was applied by broadcast application, and DCLM was applied in bands (23 cm apart), using a drag shoe applicator (also called sliding foot or sleighfoot), at two nominal rates, 50 and 100 kg inorganic-N/ha/application, which were termed as "low" and "high" rates, respectively. The inorganic-N was considered to be equal to the total-N in the fertilizer (ammonium nitrate), and to the ammonia-N in the DCLM. An Agros Nitrogen Meter (AGROS, Kallby, Sweden) was used initially to determine the ammonia-N concentration in well-mixed DCLM. This concentration value was used to calculate the volumetric application rate of DCLM that was used on the plots. DCLM samples were collected during application for analysis later in the laboratory for ammonia and total Kjeldahl nitrogen. The ammonia-N content of the DCLM was about 50% of the total (Kjeldahl) N content. The control treatment received neither manure nor fertilizer. The actual application rates of inorganic-N under the different treatments on the different application dates during the study period are shown in Table 2.

Table 2. Inorganic-N application rates for the dairy cattle liquid manure study.

Year and day of application	Application rate under different treatments (kg inorganic-N ha^{-1}) [a]						
	Control	Low fed	Low manure 1& 2	Low manure 4	High fed	High manure 1& 2	High manure 4
1997							
Mar. 11	0	60	58	59	120	113	115
May 30	0	50	36	36	100	74	74
Jul 14	0	55	50	52	110	106	109
Aug 13	0	52	50	49	104	99	97
Total	0	217	194	196	434	392	395
1998							
Mar 10	0	50	54	56	100	101	103
May 20	0	50	50	50	100	103	100
Jul 02	0	50	43	43	100	78	75
Aug 24	0	60	34	33	120	65	67
Total	0	210	181	182	420	347	345
1999[b]							
Apr 06	0	60	-	71	120	-	117
May 31	0	58	-	62	116	-	131
Jul 13	0	54	-	54	108	-	109
Sep 07	0	58	-	56	116	-	104
Total	0	230	-	243	460	-	461

[a] Inorganic-N = total-N for fertilizer or NHx-N for manure; NH_x-N = (NH_3 + NH_4^+)-N. See text and Table 1 for explanation of treatments.

[b] Fertilizer instead of manure was used in 1999 on manure 1 and manure 2 treatments for both low and high rate plots.

A closed chamber system was used for N_20 emission rate determination. On the day after the application of treatments, 0.7 m x 0.7 m x 0.15 m deep stainless steel collars were inserted into each plot. Air-tight vented covers were placed on the collars for 30 minutes and air samples were collected from the chambers at 0, 15 and 30 minutes. In 1997 and 1998, air samples were collected twice per week for four weeks, and weekly for the additional five weeks. It was observed that most emission of N_20 occurred only in the initial 3-4 weeks after application of manure and fertilizer. In 1999, the sampling frequency was decreased to twice per week for the initial three weeks and weekly for an additional four weeks.

Emission from LHM application on grassland

The site for LHM application was about 100 m from the DCLM site described above. Treatments, with four replications, in a complete randomized block were initiated at this site in 1998, and N_20 emission measurements were made in 1999. The soil at this site was similar to that at the DCLM application site described above. The plot size was 3.0 m x 34.0 m. Seven treatments including a control were studied (Table 3).

Table 3. Treatments used for land application of liquid hog manure.

Treatment	Inorganic-N nominal appln. rate (kg/ha/appln.)	Nutrient source: fertilizer or manure	
		1998	1999[a]
Control	0	C	C
Fertilizer 1 x	40	F	F
Manure 1 x	40	M	M
Fertilizer 2x	80	F	F
Manure 2x	80	M	M
Fertilizer 3x	120	F	F
Manure 3x	120	M	M

[a] Treatments for which nitrous oxide emission was determined are shown in bold; C = control; F = fertilizer; M = manure. x represents 40 kg inorganic-N/ha/appln.

The nominal application rates used for inorganic-N were 40, 80 and 120 kg N/ha/application. Five applications were made per year, with the last application in late fall being made at half the nominal rate. Ammonium nitrate fertilizer was applied by broadcast application. Manure (LHM) was applied by the conventional splashplate applicator. As with DCLM, the volumetric application rate for LHM was calculated from an initial determination of LHM ammonia-N with the Agros Nitrogen Meter. The actual application rates were determined later from laboratory analysis of applied LHM samples (Table 4). The air sample collection method, was the same as described above for DCLM.

Table 4. Inorganic-N application rate for the liquid hog manure study.

Year and day of application	Application rate under different treatments (kg inorganic-N ha^{-1})[a]						
	Control	FERT1 x	MAN1 x	FERT2x	MAN2x	FERT3x	MAN3x
1998							
Feb 24	0	42	3 7	84	75	126	112
May 17	0	40	37	80	75	120	112
Jul 01	0	40	42	80	83	120	125
Aug 19	0	60	38	120	68	180	103
Oct 27	0	27	21	54	42	81	64
Total	0	209	175	418	343	627	516
1999							
Mar 31	0	50	40	100	80	150	119
Jun 02	0	50	40	100	81	150	121
Jul 15	0	40	42	80	84	120	125
Sep 04	0	43	40	86	80	129	120
Oct 28	0	21	26	42	53	63	79
Total	0	204	188	408	378	612	564

[a] Inorganic-N = total-N for fertilizer or NH_x-N for manure; NH_x-N = (NH_3 + NH_4^+)-N. See text and Table 3 for explanation of treatments.

Emission from compost windrows and vermicomposting bins

Four 9.1 m long, 2.7 m wide (at base) and 1.2 m high trapezoidal-shaped windrows were set up in a roofed shed using dairy cattle feedlot manure which had an initial moisture content of 75 %. Two windrows were laid on open-ended perforated pipes (3.0 m long, 10 cm diameter), at right angles to the windrow length, for passive aeration of the static compost biomass. A 5 cm thick layer of wood shavings was used for insulation at the base and on the surface of the static windrows. Aeration of the other two windrows was by turning once a week using a Sittler turner which has a rotary drum with flails. The windrows were assembled on October 14, 1999, and N_20 emission was monitored on 20 days during the following three months, approximately every three days for the initial six weeks and weekly thereafter. Four replicate air samples, two from each long side of the windrows, were collected at 0, 15 and 30 minutes from 16 cm diameter, 7 cm high, vented PVC pipe caps placed on the surface of the composting biomass. The samples were collected in vaccutainer tubes as described earlier.

The vermicomposting system consisted of a 9 m x 4 m x 0.76 m deep wooden bin filled with a 1:1 mixture of separated solids from DCLM and LHM. Earthworms, *Eisenia fetida* were used for vermicomposting. Air samples from the surface of the vermicompost were collected weekly for 10 weeks at four locations in the bin. The sampling system was the same as the one used for the windrow composting.

Emission from stored swine manure slurry

Three adjacent concrete tanks in a roofed shed, each 2.2 m x 2.7 m x 2.7 m deep, were filled with fresh grower/finisher swine manure slurry to a 2.4 m depth. The slurry had an initial total solids and total (Kjeldahl) nitrogen content of about 10%, and 0.6%, respectively. Two PVC pipes, each 2.5 m long x 0.3 m in diameter, were then lowered vertically into the tanks, so as to fill the pipes with slurry. The pipes were anchored with wooden planks to hold them in place. The tanks were open to the atmosphere but had a wire-mesh cover to keep out insects.

Nitrous oxide emission from the stored slurry was determined by placing airtight vented covers on each of the two pipes in each tank, and sampling the air below the covers at 0, 15 and 30 minutes as described above. Emission rate was determined from the volume of the air between the cover and the slurry surface in the pipes, and the increase in concentration of N_20 during the 30 minute period. Six samples (2 per tank x 3 tanks) were collected at 0, 2, 4, 9, 18 and 25 weeks of slurry storage.

RESULTS AND DISCUSSION

Precipitation and atmospheric temperatures

The monthly total precipitation during 1997, 1998 and 1999 and the long term average value at the study site is given in Figure 1. The daily maximum and minimum temperatures recorded at the site in 1998 are shown in Figure 2. Similar temperature values were recorded in 1997 and 1999. The lowest precipitation and highest temperatures occurred mostly during July and August. Temperature and moisture content of soil influence nitrous oxide emissions.

Emissions from grassland treated with DCLM

Table 5. Nitrous oxide emission following application of fertilizer and dairy cattle liquid manure.

Year and day of application	Emission rate under different treatments (g N_2O-N ha^{-1})[a]								
	Control	Low application rate				High application rate			
		fert	manure			fert	manure		
			1	2	4		1	2	4
1997									
Mar 11	-	-	-	-	-	-	-	-	-
May 30	52	662	342	161	1274	1641	2331	1505	1308
Jul 14	55	383	291	284	202	1503	723	486	849
Aug 13	66	139	246	236	278	436	1147	698	595
Total	173	1185	878	680	1753	3580	4201	2689	2751
1998									
Mar 10	69	188	21	44	62	425	504	262	131
May 20	61	65	99	120	60	212	341	550	923
Jul 02	67	50	350	338	435	865	2113	3246	3375
Aug 24	60	18	19	54	9	53	115	53	89
Total	257	792	489	557	567	1555	3073	4111	4517
1999[b]									
Apr 06	18	29	-	-	87	27	-	-	87
May 31	5	27	-	-	12	11	-	-	12
Jul 13	-	-	-	-	-	-	-	-	-
Sep 07	31	57	-	-	74	34	-	-	74
Total	54	113	-	-	174	72	-	-	174

[a] See text and Table 1 for explanation of treatments.

[b] Fertilizer instead of manure was used in 1999 on manure 1 and manure 2 treatments for both low and high rate plots.

Table 6. Nitrous oxide emission following application of fertilizer and liquid hog manure.

Year and day of application	Control	Emission rate under different treatments (g $N0_2$-N ha^-)[a]					
		fert1 x	man1 x	fert2x	man2x	fert3x	man3x
1999							
Mar 31	36	21	34	46	76	52	35
Jun 02	-	-	-	-	-	-	-
Jul 15	46	39	74	47	58	92	91
Sep 04	29	90	74	128	185	139	187
Oct 28	28	37	9	56	38	24	34
Total	139	188	190	278	358	307	348

[a] See text and Table 3 for explanation of treatments.

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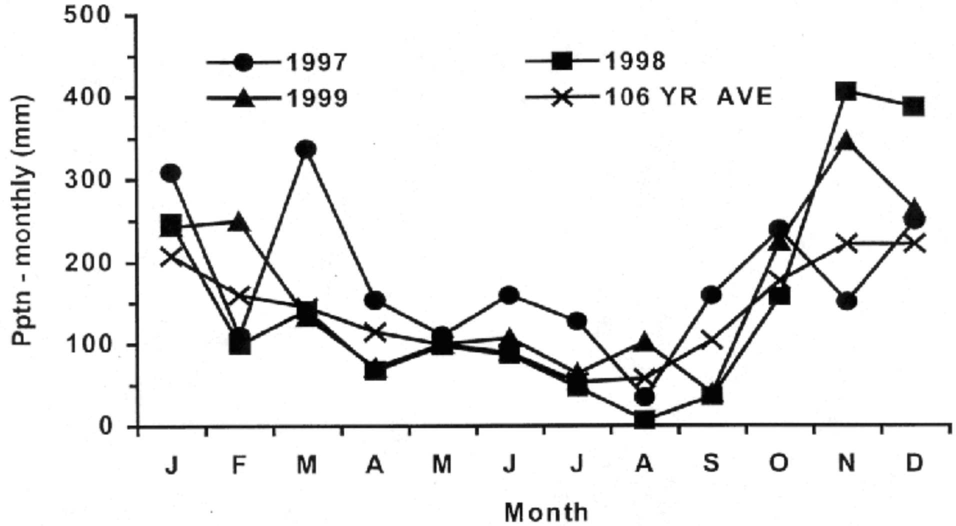

Fig. 1. Monthly total precipitation during 1997, 1998 and 1999 and the long-term average precipitation at the study site.

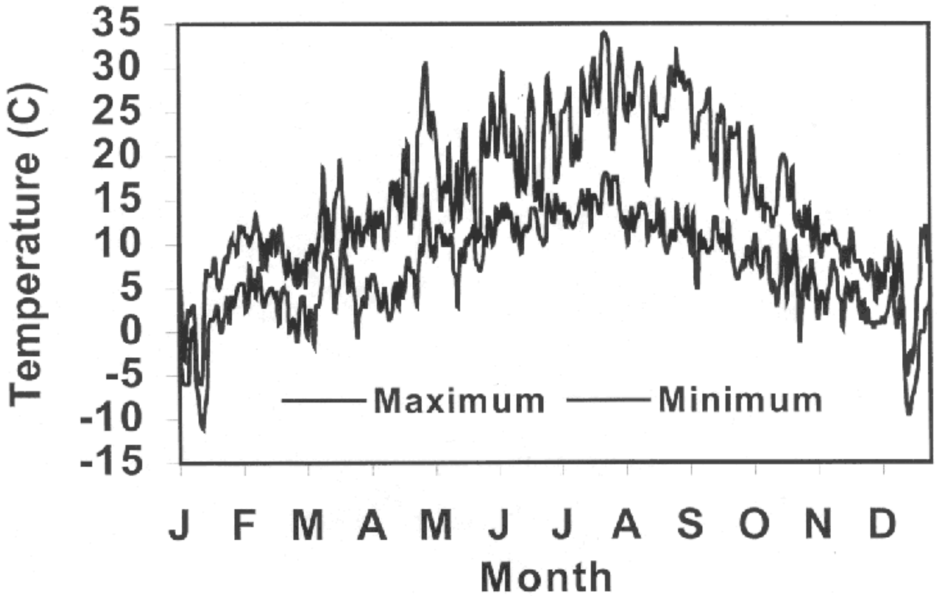

Fig. 2. Minimum and maximum daily temperatures at the study site in 1998. The range of temperatures was similar in 1997 and 1999.

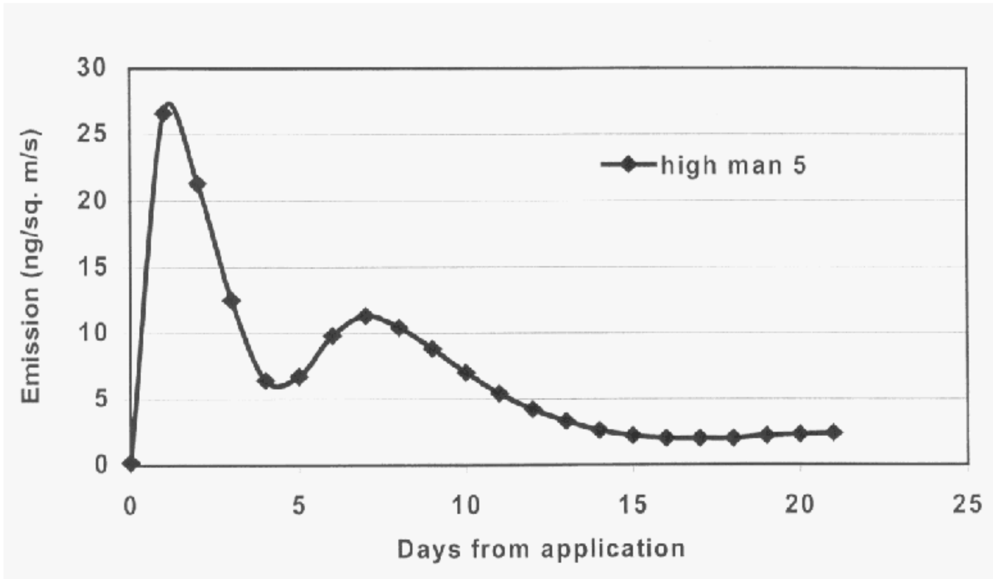

Fig. 3. Pattern of nitrous oxide emission rate following application of dairy cattle liquid manure (DCLM) on grassland. Generally, emissions decreased with time after application with possibly one or more additional peaks in subsequent days, depending on local conditions.

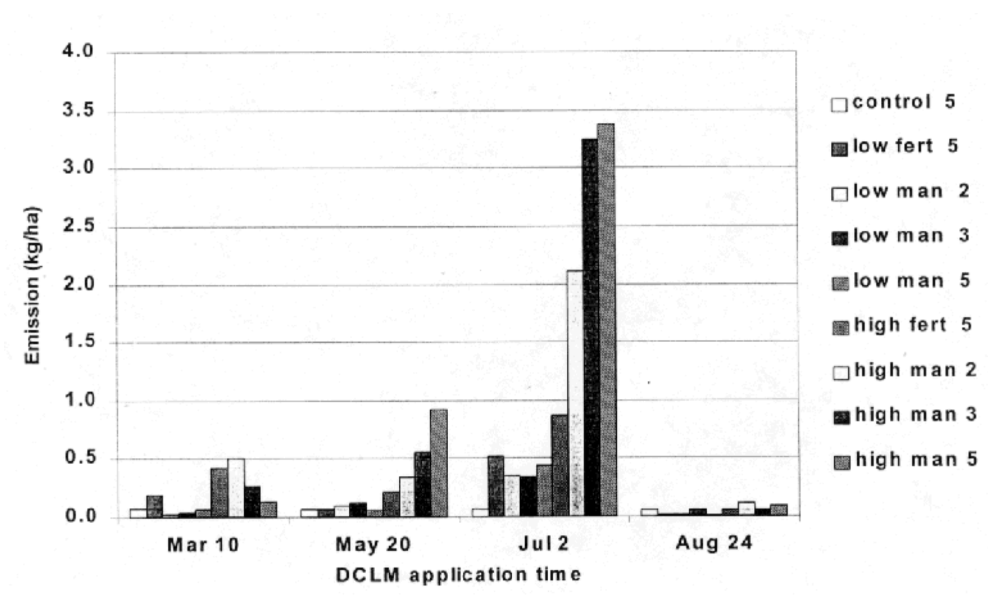

Fig. 4. Total emission of nitrous oxide following DCLM and fertilizer applications at four different times during 1998. Numbers following treatments in the legend indicate total years of that treatment (See table 1).

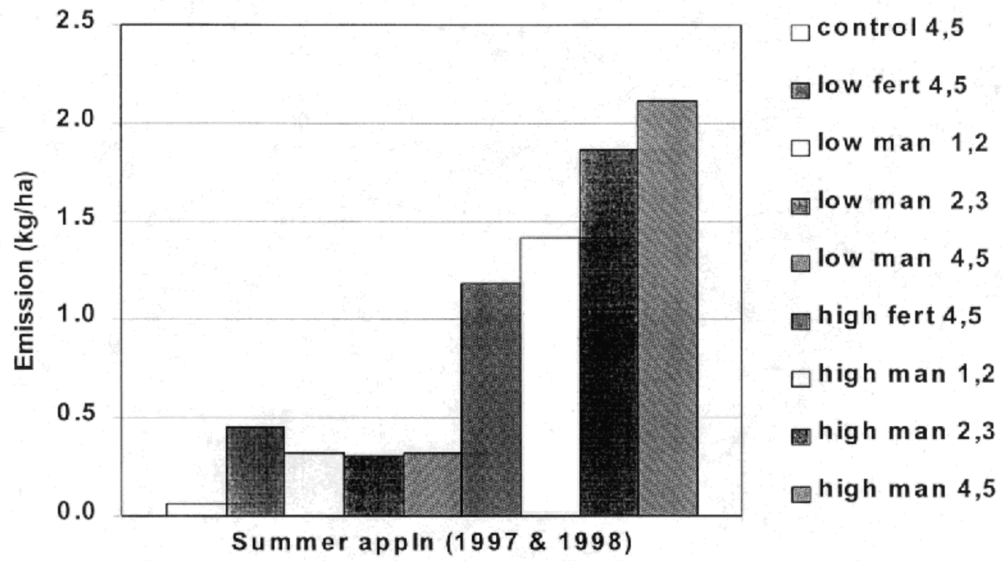

Fig. 5. Average of 1997 and 1998 emission of nitrous oxide under different treatments following July application of DCLM and fertilizer.

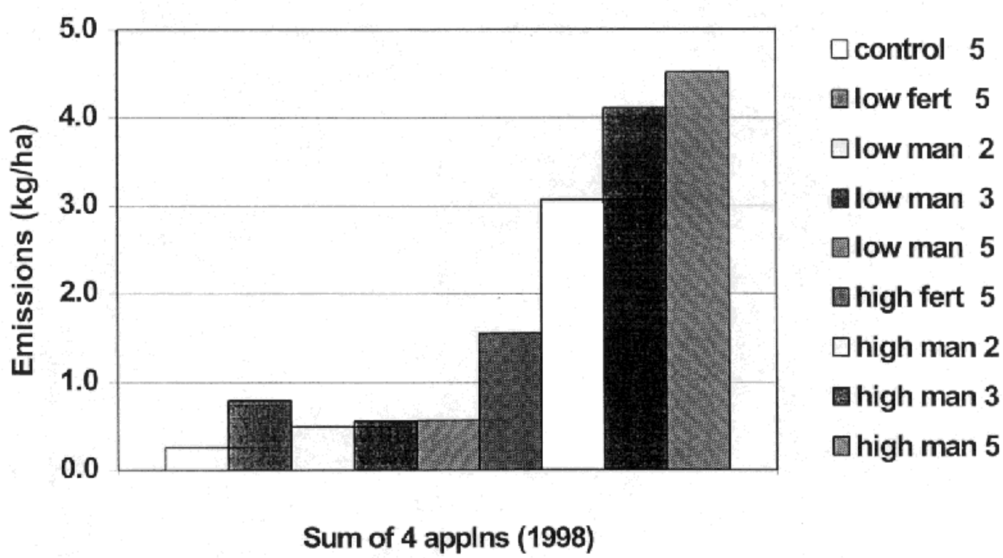

Fig. 6. Total annual emission of nitrous oxide under different treatments following DCLM and fertilizer application in 1998.

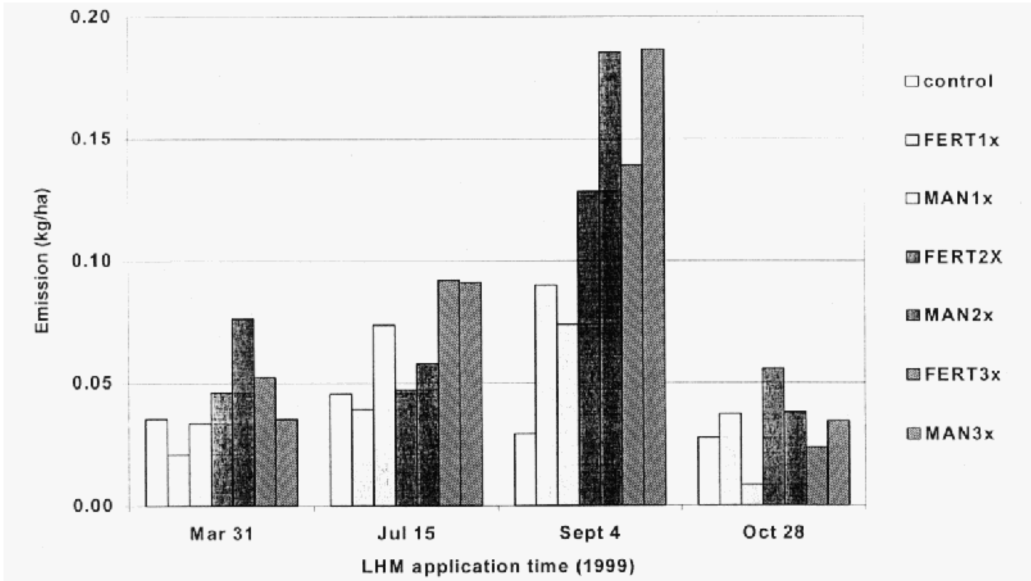

Fig. 7. Total emission of nitrous oxide under different treatments following LHM and fertilizer application at four different times during 1999. Emission following a June 2 application of LHM was not determined

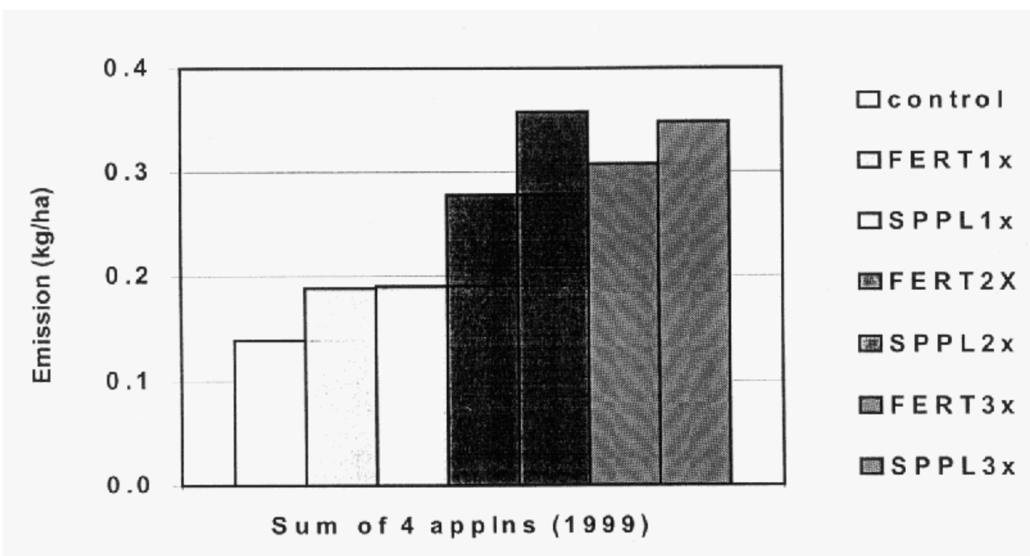

Fig. 8. Total emission of nitrous oxide from four applications of LHM and fertilizer in 1999. Total annual emissions would be higher because emissions following a June application were not determined.

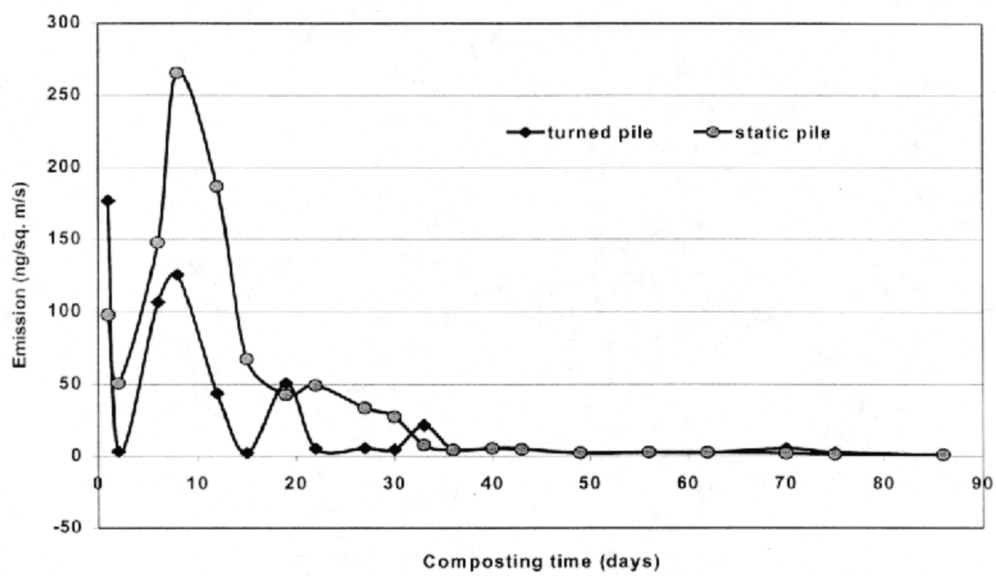

Fig. 9. Nitrous oxide emission rate from dairy cattle feedlot manure during composting in turned and passively aerated static windrows. Day 1 was October 15, 1999.

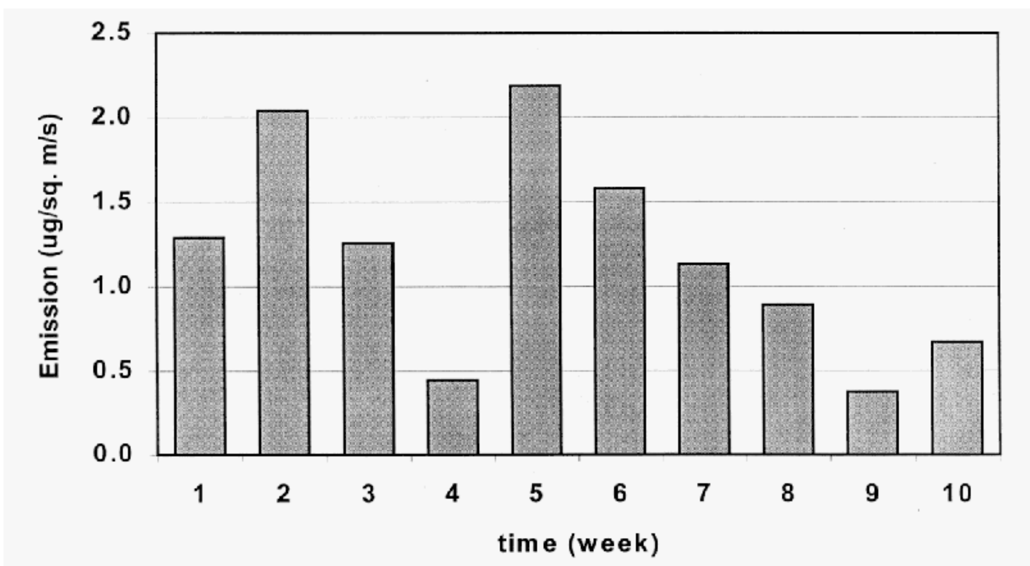

Fig. 10. Nitrous oxide emission rate during vermicomposting of 1:1 mixture of separated solids from dairy cattle and hog manure slurries.

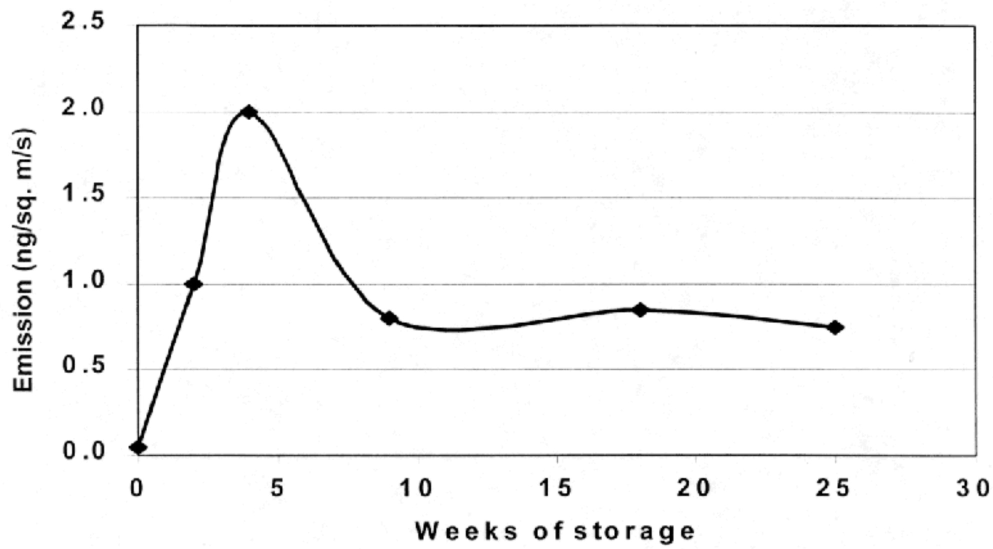

Fig. 11. Nitrous oxide emission rate from swine manure slurry stored to 2.4 m depth in concrete tanks. The tanks were filled on November 2, 1999 (day 0).