Winter and early spring losses ᴏᶠ ᴨᵢᵗᵣᴏᵍᵉᴨ following late fall application of hog manure

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Gangbazo, G., Pesant, A.R., Cluis, D., Couillard, D. and Barnett, G.M. 1995. **Winter and early spring losses of nitrogen following late fall application of hog manure**. Can. Agric. Eng. 37:073-079. Runoff and drainage losses of ammonium, nitrate, and total nitrogen during winter and early spring following hog manure application in late fall were simulated using disturbed Coaticook clay loam soil (Humic Gleysol) contained in 0.26 m^2 boxes. A factorial treatment combination of three hog manure application rates (0, 27.3, and 54.6 $m^3 \cdot ha^{-1}$, which represented 0, 150, and 300 kg TKN$\cdot ha^{-1}$, or 0, 115, and 230 kg NH4-N$\cdot ha^{-1}$) and two application methods (with and without incorporation) were studied. During the freezing period (winter), the soil in the boxes remained frozen and runoff was the major hydrologic process accounting for 99% of the total water collected. Total Kjeldahl-N (TKN) and ammonium-N (NH4-N) loads in runoff water increased linearly with surface application rates. Loads were 3.2, 8.0, and 12.7 kg TKN$\cdot ha^{-1}$ and 1.7, 5.3, and 9.0 kg NH4-N$\cdot ha^{-1}$ for increasing application rates, respectively. Incorporation did not affect drainage water loads since infiltration in the frozen soil was low. During the thawing period (early spring), snowmelt produced both runoff and drainage water until the soil had thawed completely at which time infiltration increased sharply. Drainage then accounted for 80% of the total amount of water collected. Loads of TKN in drainage water increased linearly regardless of application methods whereas NH4-N loads increased linearly for incorporation only. Loads were 5.4, 6.3, and 7.3 kg TKN$\cdot ha^{-1}$ and 1.0, 1.4, and 2.0 kg NH4-N$\cdot ha^{-1}$ for increasing application rates, respectively. Rate of manure application without incorporation did not affect the loads of any form of N during the thawing period, probably due to losses which occurred during the freezing period. Leaching produced NO3-N loads of 60 kg$\cdot ha^{-1}$ regardless of application rate and methods indicating that the possible source of NO3-N was the soil itself. Total loads were 9.5, 15.1, and 20.8 kg TKN$\cdot ha^{-1}$; 3.2, 6.7, and 10.4 kg NH4-N ha^{-1} for the three surface spreading rates, respectively. Losses due to surface-spreading were therefore 3.7 and 3% of TKN and NH4-N applied, respectively. For incorporation, total loads were less; 9.5, 10.5, and 11.5 kg TKN$\cdot ha^{-1}$; 3.2, 3.7, and 4.3 kg NH4-N$\cdot ha^{-1}$, representing only 0.7% of TKN and 0.5% of NH4-N applied. Incorporation was therefore less damaging than surface spreading.

Key words: hog manure, runoff and drainage water, freezing period, thawing period, snowmelt, nitrogen

Les pertes d'azote nitrique, ammoniacal et total par ruissellement et drainage pendant l'hiver et tôt au printemps, suite à l'épandage du lisier de porc tard à l'automne, ont été simulées sur sol tamisé (loam sablo argileux Coaticook) d'un Gleysol humique contenu dans des caissettes de 0,26 m^2 de surface. Une combinaison factorielle de trois taux d'épandage (0, 27.3 et 54.6 $m^3 \cdot ha^{-1}$, soit 0, 150, et 300 kg NTK$\cdot ha^{-1}$, ou 0, 115 et 230 kg N-NH4$\cdot ha^{-1}$) et deux modes d'épandage (surface et enfouissement) a été utilisée. Au cours de l'hiver, le

ruissellement était le processus le plus important représentant 99% de la quantité totale d'eau récoltée, le sol dans les caissettes étant gelé en bloc. Le lisier épandu à la surface du sol a été érodé. Les charges d'azote ammoniacal (1,7 à 5,3 et 9,0 kg N-NH4$\cdot ha^{-1}$) et d'azote total Kjeldahl (3,2, 8,0 et 12,7 kg NTK$\cdot ha^{-1}$) ont suivi une tendance linéaire, augmentant avec le taux d'épandage en surface. L'incorporation du lisier n'a pas affecté les charges dans l'eau de drainage puisque l'infiltration d'eau dans le sol était faible à cause du gel. Par contre, tôt au printemps, le ruissellement et le drainage de l'eau ont eu lieu en même temps jusqu'à ce que le sol dégèle complètement. Puis l'infiltration de l'eau s'est accélérée de sorte que l'eau drainée représentait 80% de la quantité totale évacuée. Les charges d'azote ammoniacal (1,0 1,4 et 2,0 kg N-NH4$\cdot ha^{-1}$) ont suivi une tendance linéaire, augmentant avec le taux d'épandage par enfouissement. Les charges n'ont pas varié selon le taux d'épandage en surface probablement à cause des pertes subies en hiver. Les pertes de nitrates par lessivage se sont élevées à 60 kg N-NO3$\cdot ha^{-1}$, peu importe le taux et le mode d'épandage, indiquant que la source possible du NO3-N est le sol même. Les charges totales étaient de 9,5, 15,1 et 20,8 kg NTK$\cdot ha^{-1}$; 3,2, 6,7 et 10,4 kg N-NH4$\cdot ha^{-1}$ pour les trois taux d'épandage en surface respectivement. Les pertes dues à l'épandage du lisier représentaient donc 3,7 et 3% du NTK et du N-NH4 appliqué. Pour l'incorporation, les charges totales étaient plus faibles: 9,5, 10,5 et 11,5 kg NTK$\cdot ha^{-1}$; 3,2, 3,7 et 4,3 kg N-NH4$\cdot ha^{-1}$, ne représentant donc que 0,7 et 0,5% du NTK et du N-NH4 appliqué. L'incorporation semble donc moins dommageable que l'épandage en surface.

INTRODUCTION

Spring thawing constitutes one of the most important phases of the hydrologic cycle in northern countries, often producing sudden rises in river levels (Davar 1972). Nitrogen losses accounting for 5 to 10% of the total amount of manure-N applied in winter have been reported, due to runoff during the snowmelt period (Young and Mutchler 1976; Steenvoorden 1981; Steenhuis et al. 1981). Because of reduced nutrient requirement in the fall, much residual-N results from late-fall manure applications and thereby increases the potential for water pollution during the winter and spring. Although the time lapse between initial thawing temperatures and active plant growth is relatively short, this period may be critical in terms of nitrate leaching to groundwater because nitrification rates increase with soil temperature (Walter 1974). More information is needed on the environmental impacts of large hog manure applications under late fall conditions.

Most research conducted on the environmental impact of fall application of animal wastes has not reported infiltration-drainage losses (Converse et al. 1976; Tokarz et al. 1979).

Some have reported both runoff and drainage water (Pesant et al. 1993) but did not give complete information on the effects of uncontrollable climatic factors on N losses by these two processes.

The objective of this research was to simulate the effects of late fall-applied hog manure to soil with or without incorporation on N losses in runoff and drainage water under winter and early spring conditions by using boxes filled with soil.

MATERIALS AND METHODS

Experimental design and sampling

The experiment was conducted on the Experimental Farm of the Agriculture and Agri-Food Canada Research Station in Lennoxville (southeastern Québec, Canada) during the winter of 1989-1990. The experimental unit consisted of two $0.26 \, m^2$ boxes placed one on top of the other. The boxes were constructed of plywood, tongue and grooved to fit together. The joint between the two boxes was caulked with silicone to prevent any leakage. The lower box was 0.30 m wide, 0.88 m long, 0.40 m high and contained 0.40 m depth of soil. It was equipped with a gutter of 50 mm width by 300 mm length by 50 mm height to collect runoff from rainfall and snowmelt and with a 15mm diameter pipe to collect drainage water. The upper box which had no bottom, was used to contain the natural snowfall during the winter. It was 0.30 m wide, 0.88 m long, and 0.50 m high.

The top layer (0-200 mm) of a Coaticook clay loam (Humic Gleysol) site which had been under grassland for more than 5 years was collected in late fall (Table I) and screened with a 12.5 mm mesh sieve. The initial water content of the soil was near field capacity as determined by a method developed by Richards (1954). Undisturbed soil was not used because manure incorporation would have disturbed the topsoil (0-200 mm) anyway. A 50 mm layer of water-washed crushed rock (3-6 mm diameter) was placed in the bottom of each box followed by four 100 mm-layers of soil compacted to the apparent volumic mass of the undisturbed soil.

The hog manure contained 950 $g•L^{-1}$ of water, 50 $g•L^{-1}$ of solids, an average of 5495 $\mu g•L^{-1}$ of TKN, 4175 $\mu g•L^{-1}$ of NH4-N and 8 $\mu g•L^{-1}$ of NO3-N. The treatments consisted of the factorial combination of hog manure rates and methods of application replicated three times which required 18 sets of experimental units. The independent variables were:

- three application rates: 0, 27.3, and 54.6 $m^3•ha^{-1}$ which correspond to 0, 150, and 300 kg $TKN•ha^{-1}$, respectively, (including 0, 115, and 230 kg $NH_4-N•ha^{-1}$) and 0, 0.2, and 0.4 kg $NO_3-N•ha^{-1}$, respectively.

- two application methods: surface (application on the soil surface of the top layer without incorporation) and incorporation (application on the surface of the 200-300 mm layer before adding the two top 100 mm soil layers).

The hog manure was applied in late fall (9 December 1989) when the probability of rainfall was low. The side walls of the experimental apparatus were insulated with 50 mm rigid styrofoam to induce soil freezing from the top down. Five thermocouples were installed as follows: one at 500 mm above the soil and one each at the 0, 50, 150, and 350 mm depths in the

Table I. Characteristics of the Coaticook clay loam soil used for the experiments (0-200 mm)

Parameters	Units	Values[a]	
		Mean	S.D.
Textural composition			
- sand	%	43	-
- silt	%	28	-
- clay	%	29	-
Apparent volumic mass[b]	$Mg•m^{-3}$	1.2	-
Initial water content	% D.B	25	2.0
Water content (Field capacity)	% D.B	25	2.0
Organic matter	% D.B.	4.1	-
Organic carbon	% D.B.	3.1	-
Total Kjeldahl-N (TKN)	$\mu g•g^{-1}$	300.0	110.0
Ammonia-N (NH4-N)	$\mu g•g^{-1}$	4.4	0.4
Nitrate-N (NO3-N)	$\mu g•g^{-1}$	20.0	4.5

[a] S.D. = standard deviation; number of samples: 12
[b] Undisturbed soil
[c] D.B. = Dry basis
- Not available

soil of three boxes. The thermocouples were connected to a data logger. The experimental units were placed outside for about three months (87 days) under natural atmospheric conditions on a concrete platform having 3% slope. Precipitation (rain and snow) data were recorded at the farm weather station located about 500 m from the experimental site.

During the winter (freezing period), runoff water from each snowmelt event was sampled and the amount measured. Snow depth in the boxes was measured periodically. The mean concentration of nutrients in the snow were 0.15 ppm TKN, 0.03 ppm NH4-N, and 0.04 ppm NO3-N.

In early spring (5 March 1990), when only traces of snow remained in the boxes, the latter were transported to an unheated barn and placed on a platform with a 3% slope to simulate snowmelt on frozen soil. The upper boxes were filled with 500 mm of snow and an infra-red lamp was installed at 300 mm above the snow surface. Five hundred millimeters of snow is approximately the maximum expected depth of snow (370 ± 200 mm) at Lennoxville in March (MENVIQ 1984). The snow used for this purpose can be described as fresh, firm, and partly consolidated into ice since its density was 0.45 $kg•L^{-1}$ (McKay 1972; Pesant 1987). To evaluate the snow contribution to the nitrogen budget, three boxes closed at the bottom, insulated, and filled with snow as described previously were placed randomly among the other boxes. Infra-red bulbs were turned on in the day and off at night. The runoff and/or drainage water was measured and sampled each day for one week, corresponding to the end of the thawing period. The soil in the boxes was then sampled at 50 mm intervals to evaluate the amount of residual N.

Laboratory analysis

Soil TKN was determined by a procedure proposed by Schu-

man et al.(1973); NH4-N and NO3-N analytical methods were described by McKeague (1977).

All N forms in water, hog manure, and snow were determined using automatic colorimetric methods (MENVIQ 1986, 1987, 1989).

Statistical analysis

The SAS PC 6.03 GLM procedure (SAS 1988) was used to determine treatment effects on TKN, NH4-N, and NO3-N loads in runoff and drainage water. Data collected during the freezing (9 December 1989 to 5 March 1990) and thawing (5-12 March 1990) periods were analyzed separately. Tabular (P) probabilities are reported and the equals sign means "significant at" the given probability level.

RESULTS AND DISCUSSION

Nitrogen supply comparison

Nitrogen loads in hog manure, in rainfall, in snowfall during the winter, in snow used to simulate the snowmelt period, and in the pre-treatment soil were determined (Table II). Results showed that N loads applied through precipitation during the winter (freezing period) or by snow during the spring (thawing period) were much smaller than those contained in hog manure or in soil. Hog manure TKN was 3% and 6% of that in the soil and NO3-N was 0.2% and 0.4% of that in the soil. However, NH4-N in hog manure was 5 and 10 times that in the soil. Thus, except for NH4-N, hog manure N represented only a small percentage of soil N content.

Freezing period

During the winter, the experimental site received 29.2 mm of rain and 1.25 m of snow for a total of 154.1 mm of water-equivalent precipitation with a mean snow density of 0.1 (Garstka 1964). Due to rainfall and relatively high temperatures, the snow melted frequently, producing many runoff events although the soil remained frozen. The mean quantity of runoff water due to snowmelt was relatively high (120 mm) while infiltration into frozen soil was less than 1 mm.

There was therefore no drain flow during the winter.

Surface application rates had significant effects on TKN and NH4-N loads in runoff water (P = 0.01) while there was no rate effect with incorporation (P > 0.10); (Table III; Fig. 1). Because the soil was frozen, runoff was the sole hydrologic process and affected only the surface layer. Loads of 3.2, 8.0, and 12.7 kg TKN•ha^{-1} were linearly dependant (P = 0.01) on surface application rates of 0, 27.3, and 54.6 m^3•ha^{-1} respectively. Similarly, NH4-N loads of 1.7, 5.3, and 9.0 kg NH4-N•ha^{-1} increased linearly (P = 0.01) with application rates. Losses of NH4-N were relatively low accounting for only 3% of the quantities applied, which were 5 to 10 times pre-treatment soil levels. This is due to the initial infiltration of hog manure in the soil at the time of application before the soil had frozen. Nitrate-N loads were affected only by application rates (Table III) but unlike TKN and NH4-N, the effect was quadratic (P = 0.01). Loads were 1.50, 1.01, and 2.11 kg NO3-N•ha^{-1} for increasing rates of 0, 27.3, and 54.6 m^3•ha^{-1}. Nitrate-N loads almost doubled with application rates, exceeding the amount supplied by manure and winter precipitation. This indicates that NO3-N losses during the winter comes in part from the hog manure applied in late fall and in part from the soil.

Thawing period

Even though the boxes were insulated, the soil thawed quickly (Fig. 2). The mean temperature of the soil profile was in the order of -10 °C when the boxes were moved to the barn and increased to -3 °C at the end of the first day. The temperature remained around 0 °C until the fourth day and increased rapidly to 14 °C at the end of the seventh day. During that period, the ambient temperature in the barn increased from 8.5 to 15.5 °C. The snow in the boxes thawed progressively until the sixth day.

Runoff and infiltration-drainage processes occurred simultaneously (Fig. 3). In terms of cumulative amounts, runoff water increased faster than drainage water during the first day only. During the second day, cumulative amounts were still higher for runoff but were increasing faster for drainage. During the second day, runoff ceased and drainage continued until the seventh

Table II. Comparison of N applied with amounts available in the pre-treatment soil

Parameters[a]	Pre-treatment[b] (kg•ha^{-1})		Fall hog manure (m^3•ha^{-1})				Freezing period (rainfall + snow)[c]		Thawing period[d] (snow)	
			27.3		54.6					
	Mean	S.D.[e]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
TKN	5280.0	446.0	150	7	300	14	0.23	0.14	0.34	0.20
NH4-N	20.2	1.6	115	6	230	12	0.05	0.02	0.07	0.02
NO3-N	97.4	16.2	0.2	0.0	0.4	0.0	0.06	0.02	0.09	0.02

(Loads applied (kg•ha^{-1}))

[a] TKN=Total Kjeldahl nitrogen; NH4-N=Ammonium nitrogen; NO3-N=Nitrate nitrogen.

[b] Total load in 400 mm of soil.

[c] Winter (9 Dec. 1989 to 5 Mar. 1990).

[d] Snowmelt simulation period in early spring (5 to 12 Mar. 1990).

Table III. Effects of hog manure on N loads in runoff and drainage water, (F values and their significance)

Sources of variation[a]	df	Freezing period[b] (natural precipitation) Runoff water			Thawing period[c] (added snow) Runoff water			Drainage water		
		TKN	NH$_4$-N	NO$_3$-N	TKN	NH$_4$-N	NO$_3$-N	TKN	NH$_4$-N	NO$_3$-N
Rate (R)	2	30.88**	22.82**	6.61**	1.58^{ns}	0.90^{ns}	11.01**	5.74**	5.81**	2.43^{ns}
Method (M)	1	57.34**	52.36**	1.45^{ns}	0.21^{ns}	0.12^{ns}	0.02^{ns}	3.75^{ns}	21.59**	0.00^{ns}
R x M	2	15.20**	14.58**	1.27^{ns}	0.38^{ns}	0.22^{ns}	0.11^{ns}	2.58^{ns}	12.38**	0.00^{ns}
Error	13									
Simple effects										
Rates: linear	1			2.75^{ns}			3.79*	6.57**		
Rates: quadratic	1			9.66**			18.94	1.48^{ns}		
R x M										
Rate (surface)	2	86.80**	71.86**						2.0^{ns}	
Rate (surface) linear	1	77.23**	70.18**						1.22^{ns}	
Rate (surface) quadratic	1	1.33^{ns}	0.56^{ns}						8.08^{ns}	
Rate (incorporated)	2	3.29^{ns}	1.05^{ns}						26.86**	
Rate (incorporated) linear	1	3.51^{ns}	1.21^{ns}						27.22**	
Rate (incorporated) quadratic	1	1.03^{ns}	0.70^{ns}						0.12^{ns}	
Error mean square		1.58	1.10	0.05	0.20	0.06	0.02	1.08	0.07	96.98

[a] Rate (R) = Application rates (0 m$^3 \cdot$ha^{-1}, 27.3 m$^3 \cdot$ha^{-1} and 54.6 m$^3 \cdot$ha^{-1}).

M = Application methods (with and without incorporation).

[b] Freezing period (9 Dec. 1989 to 5 Mar. 1990).

[c] Thawing period (5 to 12 Mar. 1990).

** Significant at 1% level; * Significant at 5% level; ^{ns} nonsignificant at 5% level.

day (Fig. 3). Eighty-one percent of the total quantity of water collected was from drainage and 19% from runoff.

The effect on the total quantity of runoff or drainage water was nonsignificant for all of the independent factors and their interaction (P > 0.10). This was because the amount of water supplied by manure (2.6 and 5.2 mm for 27.3 and 54.6 m$^3 \cdot$ha^{-1}, respectively) was much lower than that supplied by snow (225 mm). The mean quantities were 53 ± 19 mm and 220 ± 22 mm for runoff and drainage water, respectively.

Nitrogen losses in runoff water Unlike during the freezing period, there were no treatment effects on TKN and NH$_4$-N loads during thawing (P > 0.10, Table III). Therefore, runoff from a thawing, snow-covered soil surface does not have the same effect on N losses as on a frozen bare soil. In winter, frozen bare soils are more subject to erosion than thawing snow-covered soils. Mean N loads in runoff water were 0.78 ± 0.44 kg TKN$\cdot$ha^{-1} and 0.61± 0.22 kg NH$_4$-N$\cdot$ha^{-1} regardless of application rates and methods. However, the effects of application rates on the NO$_3$-N loads was quadratic (P = 0.01) but unlike during the freezing period, the effect of the application method was not significant (P > 0.10). The loads were 0.8, 0.4, and 0.6 kg NO$_3$-N$\cdot$ha^{-1} for 0, 27.3, and 54.6 m$^3 \cdot$ha^{-1} treatments, respectively. It was not possible to explain this result since the largest source of nitrates was the soil itself, the amount supplied by snow being low (0.09 kg NO$_3$-N$\cdot$ha^{-1}, Table II).

Nitrogen losses in drainage water Nitrogen losses in drainage water increased linearly with application rate (P = 0.01). Loads were 5.4, 6.3, and 7.3 kg TKN$\cdot$ha^{-1} for 0, 27.3, and 54.6 m$^3 \cdot$ha^{-1} treatments, respectively, regardless of the application method (Table III). By contrast, the effect of application rates on NH$_4$-N loads varied significantly with application method (Table III; P = 0.01). When hog manure was incorporated at the 200 mm depth, loads increased significantly (P = 0.01) with application rates from 1.0 to 1.4 and 2.0 kg NH$_4$-N$\cdot$ha^{-1} but remained nonsignificant (P > 0.10) for surface application with a mean load of 0.8 ± 0.1 kg NH$_4$-N$\cdot$ha^{-1}. Thus, during the snowmelt period, drainage water originating from fields where large quantities of hog manure were applied in late fall is likely to contain significant amounts of NH$_4$-N. It is known that NH$_4$-N has adverse effects on the environment even at low concentrations (McNeely et al. 1980). This form of nitrogen is often responsible for taste and odour problems in potable water and reduces the treatment efficiency of chlorine thereby increasing the risks for public health safety (Boucher 1985).

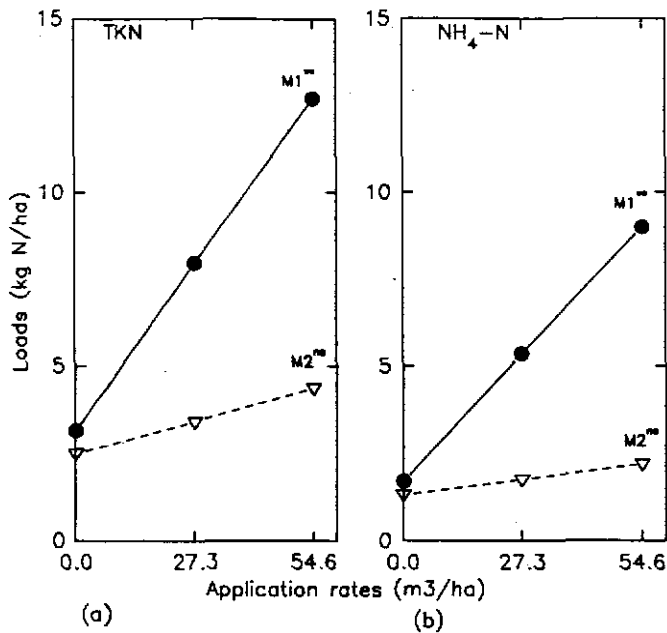There were no treatment effects on NO$_3$-N loads (P > 0.10).

Fig. 1. Effect of hog manure application rate on TKN and NH₄-N loads in runoff water during the freezing period (M1: application without incorporation; M2: application with incorporation at 200 mm depth).
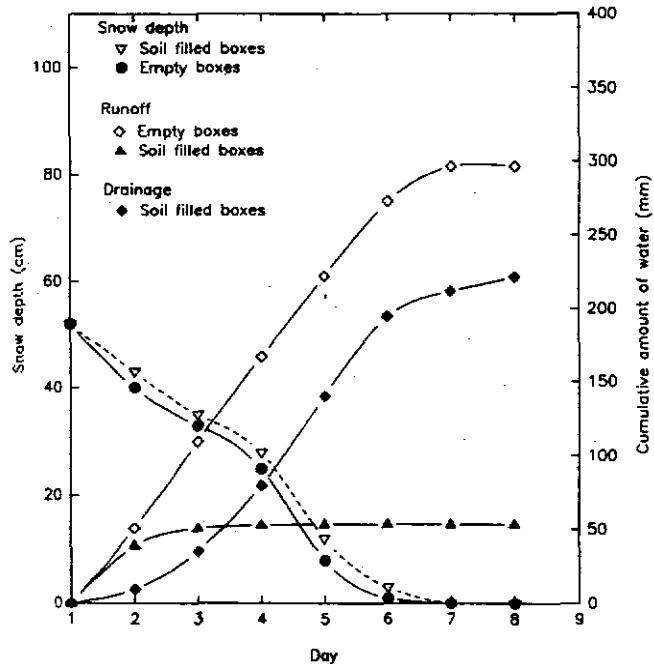
** Significant at 1% level; ns: nonsignificant.

Fig. 2. Pattern of soil temperature and snow depth during the thawing period (5 to 12 March 1990).

Fig. 3. Cumulative amounts of runoff and drainage water during the thawing period (5 to 12 March 1990).

Fig. 4. Cumulative amounts of drainage water and nitrate loads during the thawing period (5 to 12 March 1990).

The mean load was 62 ± 9.8 kg NO₃-N•ha⁻¹ which was much higher than the amount present in added snow (0.09 kg NO₃-N•ha⁻¹) but lower than the amount present in the soil during the previous fall (97.4 kg NO₃-N•ha⁻¹, Table II), suggesting that nitrate-N was leached by infiltrating water. Although by the fourth day, 50% of the snow had melted, it contained only 30% of total NO₃-N load. However, losses increased sharply to 80% of the total load at the end of the fifth day (Fig. 4).
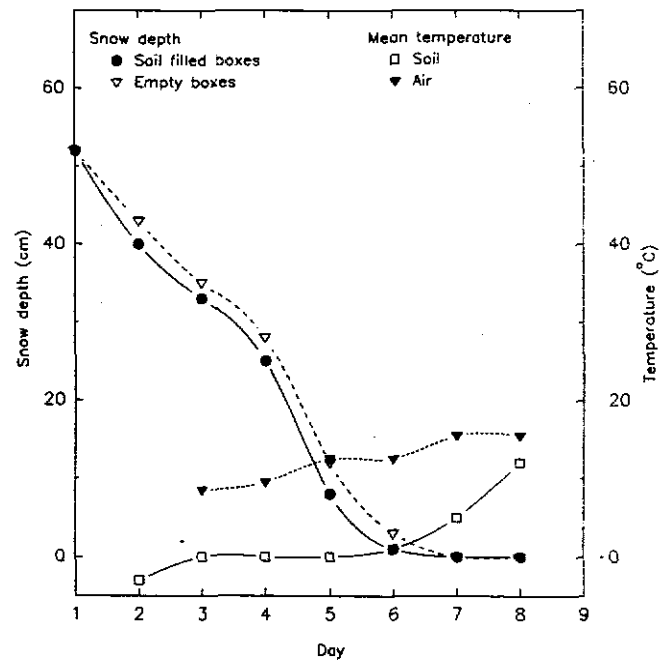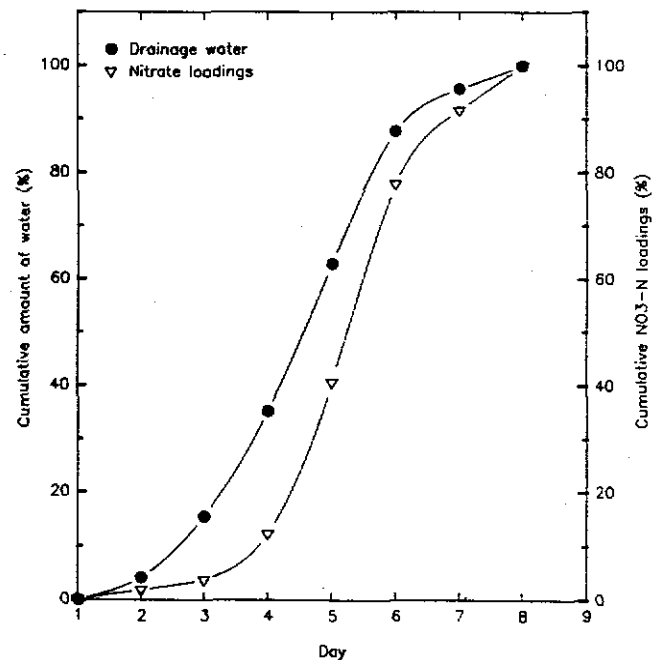
During the thawing period, drainage water loads of TKN. NH₄-N, and NO₃-N were respectively 7, 3, and 70 to 150 times those in runoff water because drainage was the prevailing hydrologic process. Since the effect of application rates was not significant, natural soil NO₃-N exceeded and hid any treatment effects. Moreover, at the end of the thawing period,

Table IV. Nitrogen losses budget

| Application methods | Hydrologic processes | Nitrogen loads ($kg•ha^{-1}$) | | | | | | | | |
| | | Control | | | $27.3\ m^3•ha^{-1}$ | | | $54.6\ m^3•ha^{-1}$ | | |
		TKN	NH₄-N	NO₃-N	TKN	NH₄-N	NO₃-N	TKN	NH₄-N	NO₃-N
Surface	Runoff[a]	3.2	1.7	1.5	8.0	5.3	1.0	12.7	9.0	2.1
	Runoff[b]	0.8	0.5	0.5	0.8	0.6	0.4	0.8	0.6	0.6
	Drainage[c]	5.5	1.0	62.0	6.3	0.8	62.0	7.3	0.8	62.0
	Total:	9.5	3.2	64.0	15.1	6.7	63.4	20.8	10.4	64.7
Incorporation	Runoff[a]	3.2	1.7	1.5	3.4	1.7	1.0	3.4	1.7	2.1
	Runoff[b]	0.8	0.5	0.5	0.8	0.6	0.4	0.8	0.6	0.6
	Drainage[c]	5.5	1.0	62.0	6.3	1.4	62.0	7.3	2.0	62.0
	Total:	9.5	3.2	64.0	10.5	3.7	63.4	11.5	4.3	64.7

[a] Runoff water during freezing period.
[b] Runoff water during thawing period.

there was as much NO₃-N in the soil as there was when the boxes were filled in the fall. For example, the mean quantity of NO₃-N was 110.6 kg N•ha⁻¹ in boxes having received hog manure at rates of 27.3 m³•ha⁻¹. These results suggest that soil N nitrified rapidly when the soil temperature increased over 0 °C thus confirming observations (Walter 1974) which indicated that soil-N nitrification increased rapidly with soil temperature.

This may appear contradictory because at low temperature (< 30 °C) nitrification is slow (Buchanan and Brady 1969; Loehr 1984). However, information on low temperature (1 to 10°C) nitrification is contradictory (Loehr 1984). Moreover, Mack (1963) showed that freezing speeded up the mineralisation of organic nitrogen (transformation to NH₄-N). Therefore, if there is a large NH₄-N pool at the end of winter, accelerated nitrification may result from rapid soil temperature increase. For this reason, the NO₃-N leaching potential may be high between the first thawing period and the start of the growing season. Field experiments conducted in northern Alberta (Canada) by Malhi and Nyborg (1986) also demonstrated an increase in the mineral-N (NH₄-N and NO₃-N) contents of the soil which were as high as 48 kg•ha⁻¹ in the top 600 mm of the soil between fall and the end of the winter, followed by a sharp decrease in the nitrate content of the soil in spring. The generation and fate of early spring NO₃-N needs further elucidation.

Nitrogen losses budget A nitrogen budget (Table IV) indicated that mean total losses by the control treatment were 9.5 kg TKN•ha⁻¹, 3.2 kg NH₄-N•ha⁻¹, and 64.0 kg NO₃-N ha⁻¹. For surface application, total losses were 15.1 and 20.8 kg TKN•ha⁻¹ for 27.3 and 54.6 m³•ha⁻¹, respectively, and 6.7 and 10.4 kg NH₄-N•ha⁻¹ for the same application rates, respectively. Therefore, 3.7 and 3% of the TKN and NH₄-N applied as hog manure in late fall were lost in winter and early spring runoff and drainage water. Moreover, 79 to 86% of total NH₄-N losses occurred in runoff during the freezing period.

When compared to surface application, TKN and NH₄-N losses were lower for incorporation. Mean values were 10.5 and 11.5 kg TKN•ha⁻¹, and 3.7 and 4.3 kg NH₄-N for the two application rates, respectively. Consequently, 0.7 and 0.5% of the TKN and NH₄-N applied as hog manure in late fall were lost.

Regardless of the application rates and modes, NO₃-N losses were similar to those from the pre-treatment (control) treatment .

SUMMARY

The relative importance of runoff and infiltration (drainage) processes varied according to the condition of the soil. Using a disturbed clay loam soil contained in boxes, runoff and drainage losses of nitrogen were simulated during winter and early spring following late fall hog manure application.

During the winter (freezing period), the soil was deeply frozen and the prevailing hydrologic process was surface runoff which accounted for 99% of the total amount of water collected. Runoff loads of TKN and NH₄-N increased linearly with surface application rates. Loads were 3.2, 8.0, and 12.7 kg TKN•ha⁻¹ and 1.7, 5.3, and 9.0 kg NH₄-N•ha⁻¹ for hog manure rates of 0, 27.3, and 54.6 m³•ha⁻¹, respectively. Nitrate-N loads in runoff were very low varying from 1.0 to 2.1 kg NO₃-N•ha⁻¹.

During the early spring snowmelt and thawing period, runoff and infiltration occurred simultaneously, runoff accounting for only 19% of the total amount of water collected. Consequently, N losses by runoff were lower than those by drainage water. Drainage TKN losses increased linearly with application rates, but did not vary with application method. Loads were 5.4, 6.3, and 7.3 kg TKN•ha⁻¹ for the three application rates, respectively. Unlike TKN, NH₄-N drainage loads increased linearly with application rates, but only for incorporation. Loads were 1.0, 1.4, and 2.0 kg NH₄-N•ha⁻¹, respectively. No effect was observed for surface application probably due to the losses which occurred in winter. Nitrate-N losses by drainage water increased sharply when the soil

thawed with a mean load of about 62 kg NO_3-N•ha^{-1}, regardless of application rates and methods.

Of the nutrients in late fall-applied hog manure, total losses accounted for only 3.7 and 3% of the TKN and NH_4-N surface-applied, and 0.7 and 0.5% of the TKN and NH_4-N incorporated. Thus, in a short term context, incorporation produced less pollution than surface application. It is important to note that although these loads represent a small proportion of the quantities applied in hog manure, late fall hog manure application to a significant percentage of the land in a watershed would result in surface water pollution.

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