Disposing hog manure on inorganically-fertilized corn and forage fields in southeastern Quebec

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Gangbazo, G., Barnett, G.M., Pesant, A.R., and Cluis, D. 1999. **Disposing hog manure on inorganically-fertilized corn and forage fields in southeastern Quebec**. Can. Agric. Eng. **41**:001-012. In Québec, manure has often been considered as a valueless by-product. Hog (*Sus scrofa domestica* L.) manure has frequently been applied to soils at high rates within a disposal philosophy. This 5-year study was conducted to evaluate the effect of high-rate hog manure (HM) applications, in addition to the normal inorganic fertilizer (IF), on water quality, soil fertility, and crop growth. Two crops were fertilized (IF) according to N requirement (kg/ha): silage corn (*Zea mays* L.)-180, and a timothy-red and white clover mixture (*Phleum pratense* L.-*Trifolium repens* L.): 55. In addition, HM was applied at twice these rates to each crop on separate plots in three ways: all in the fall, all in the spring, or split equally between these two seasons. Control plots for each crop received only IF. In contrast to forage, relatively more total N, NH_4-N, and NO_3-N was lost in runoff and drainage from corn when HM was applied in addition to IF, the degree of difference depending on the year. Although there were no fall-spring or split-whole differences for total N or NO_3-N for either crop, there was frequently much more NH_4-N lost from fall applications to corn (as compared to spring), the effect being year dependent. Hog manure in addition to IF generally did not affect water P consistently. However, fall application often produced higher runoff P losses for both crops. Whole (vs split) applications sometimes increased runoff P for both crops. Drainage P was little affected except for a decrease sometimes when HM was added. In comparison to forage, there was much more NO_3-N in the top two layers of corn soil (0-200 and 200-400 mm). There was no treatment effect on soil P. Yield increases were much higher for forage when compared to corn. Therefore, applying high rates of HM in addition to IF caused water pollution by nitrogen and phosphorus and nitrate-N accumulation in soil, but generally to a greater degree for corn than for forage for the same level of overfertilization. Treatment effects were often crop and year dependent. **Keywords**: hog manure, inorganic fertilizer, corn, forage, runoff water, drainage water, nitrogen, phosphorus.

Les fumiers ont souvent été considérés comme des sous-produits sans valeur au Québec. Le lisier de porc (*Sus scrofa domestica* L.) a fréquemment été épandu à forte dose sur les sols aux seules fins d'élimination. Cette étude de cinq ans a été réalisée pour évaluer l'effet des fortes doses de lisier de porc (HM) en plus des doses normales de fertilisants inorganiques (IF), sur la qualité de l'eau, la fertilité du sol, et la productivité des cultures. Deux cultures étaient fertilisées (IF) conformément aux besoins azotés (kg/ha): du maïs ensilage (*Zea mays* L.)-180, et du fourrage-55, ce dernier étant constitué d'un mélange de mil (*Phleum pratense* L) et de trèfle rouge et blanc (*Trifolium repens* L.). De plus, HM était appliqué au double de ces doses à chaque culture, sur des parcelles séparées selon trois scénarios: tout à l'automne, tout au printemps, ou fractionné en quantité égale entre ces deux saisons. Les parcelles témoin pour chaque culture recevaient des IF uniquement. Contrairement au fourrage, une quantité relativement plus élevée de N total, NH_4-N, et NO_3-N était perdue dans l'eau de ruissellement et de drainage des parcelles de maïs lorsque HM était épandu en plus des IF, l'ampleur de la différence dépendant de l'année. Bien qu'il n'y avait pas de différence automne-printemps ou application fractionnée-application en une seule fois pour N total ou NO_3-N pour chacune des deux cultures, il y avait fréquemment beaucoup plus de NH_4-N perdu pour les épandages d'automne sur le maïs (comparativement aux épandages du printemps), l'effet dépendant des années. L'épandage du lisier de porc en plus des IF n'a pas toujours influencé la perte de P dans l'eau. Toutefois, les épandages d'automne ont produit souvent des pertes plus élevées de P dans le ruissellement pour les deux cultures. L'application en une seule fois (par rapport à l'application fractionnée) a augmenté quelquefois la perte de P dans le ruissellement pour les deux cultures. La perte de P dans le drainage a été peu influencée, sauf à quelques occasions, où elle a diminué lorsque HM était utilisé en plus des IF. Comparé au fourrage, il y avait beaucoup plus de NO_3-N dans les deux couches de surface du sol des parcelles de maïs (0-200 et 200-400 mm). Les traitements n'ont pas influencé la quantité de P dans le sol. Les augmentations de rendement étaient beaucoup plus élevés pour le fourrage que pour le maïs. Par conséquent, l'épandage de grandes quantités de lisier de porc en plus des IF a causé la pollution de l'eau par l'azote et le phosphore et l'accumulation de nitrates dans le sol, mais généralement plus pour le maïs que pour le fourrage pour le même niveau de surfertilisation. Les effets des traitements dépendaient de la culture et des années.

INTRODUCTION

In Québec, hog (*Sus scrofa domestica* L.) production has expanded rapidly since 1975. With 32% of total Canadian hog production, Québec is a major producer in the country. Within the Québec farm sector, hog production generates some 6 x 10^6 m^3 of liquid manure or approximately 24% of the total manure produced (Thériault 1983). Hog farms are geographically concentrated along some of the tributaries of the St. Lawrence River (Yamaska, Richelieu, L'Assomption, Chaudière), where hay and corn are the main crops. Culley and Barnett (1984) reported that 83% of hog manure was produced on farms with insufficient land base for application. Many producers believe that manure has little or no nutrient value and therefore apply inorganic fertilizers in addition to high rates of manure. Gangbazo and Buteau (1985) reported that in watersheds with manure surpluses, application rates could be as high as three times the agronomic N requirements of crops. Present hog manure management practices are often identified as the main cause for the lack of overall improvement in surface water quality. This is in spite of the construction of municipal wastewater treatment plants and manure storage systems across Québec. It is well documented that manure and/or inorganic fertilizer applications in excess of crop requirement lead to detrimental effects: greater N and P loads and concentrations in runoff and drainage waters (Phillips et al. 1981; Evans et al. 1984) and accumulation and downward migration of N and P in soils (Chang et al. 1991; Liang and MacKenzie 1994). However, under humid temperate climatic conditions found in Quebec, where annual precipitation totals about one metre, there is little information on the water loss of nutrients when inorganic fertilizers are applied at recommended rates in addition to hog manure spread primarily for disposal purposes. Therefore, the objective of this study was to assess the impact of this scenario under these climatic conditions on runoff and drainage water quality, soil N and P content, silage corn and forage yields, and N and P uptake.

MATERIAL and METHODS

The 5-year experiment (1989-1994) was conducted at the Agriculture and Agri-Food Canada experimental farm near Lennoxville, 150 km east of Montréal, QC (45° 21' N, 71° 51' W) in a region with an average annual precipitation of 1033 mm. The soil is a Coaticook silty loam (Typic Fragiaquept) developed on lacustrine material. Physical and chemical characteristics of the surface (0-200 mm) horizon were as follows: sand 30 g/kg, silt 800 g/kg, clay 170 g/kg, organic matter 53 g/kg, total P 845 mg/kg, Mehlich III extractable-P 81 mg/kg.

The plots (each 3 m wide and 15 m long), which were established on a site with 6% slope, were separated from each other at the head and along both sides by a black polyethylene plastic sheet installed to a depth of 1.2 m and on the surface by a sodded dike 500 mm wide by 250 mm high. Therefore, the plots were isolated from the surrounding environment, thereby preventing runoff and leaching contamination from other sources. For each plot, two water collection systems were installed: a trough at the foot to collect runoff and a 100-mm diameter perforated plastic drain installed at a depth of 900 mm (normal for hilly regions) in the center to collect leachate. Each runoff and each drainage collection system was connected by its own pipe to separate barrels ensuring independent, year-round volume measurements and water samples for each plot. The experiment was composed of the factorial combination of four treatments and two crops arranged in a completely randomized plot design. The four treatments applied to the plots were: (1) inorganic N fertilizer (IF) as NH_4NO_3 applied in the spring (May 21 to 25) according to crop N requirement; (2) inorganic fertilizer as described plus hog manure (HM) applied at twice the crop N requirement in the fall (October 1 to 30); (3) inorganic fertilizer plus hog manure applied at twice the crop N requirement in the spring (May 21 to 25); and (4) inorganic fertilizer plus hog manure applied at twice the crop N requirement, but split (HM only) equally between the spring and the fall (same dates as above). The treatments were replicated twice to give a total of 16 plots (four N inputs X two crops x two replicates).

The test crops included silage corn (*Zea mays* L.; 'Funk's G-4082') and a mixture of timothy (*Phleum pratense* L.), and red and white clover (*Trifolium pratense* L.). Corn was planted after the spring-manure application at 750 mm inter- and 150 mm intrarow spacing. The average population density at harvest was 6 plants/m^2.

Recommended annual IF rates of application were 180 and 55 kg N/ha for corn and forage respectively (Association des fabricants d'engrais du Québec-AFEQ 1987). All IF was broadcast and spring-applied. Corn and forage treatments received total N applications of 360 and 110 kg/ha, respectively, from hog manure (manually-applied with a watering can equipped with a splash plate) each year. Thus, total annual N applications for corn and forage were 540 and 165 kg/ha, except for the plots receiving only IF. The manure rate was adjusted for total N and varied from year to year. Supplemental inorganic fertilizer P and K were broadcast in the spring on all plots at rates adjusted to the soil test as recommended (AFEQ 1987). Hog manure and fertilizer were incorporated in the corn plots by rototilling but left on the surface for forage plots. Basing manure applications on crop N needs resulted in average annual P applications (IF+HM) of 116 kg/ha for corn and 47 kg/ha for forage, thus exceeding crop requirements (corn 2.4-times; forage 1.2-times). Plots receiving only IF had average annual P applications of 34 kg/ha for corn and 21 kg/ha for forage.

Two 125 mL water samples were collected after each rainfall or snowmelt event and from each barrel (runoff or drainage): one for N and total P (0.5 mL of sulfuric acid added) and the other for PO_4^--P (no preservative). The sediments were not sampled, because the objective of this study involved only the soluble nutrients in the water. All water samples were refrigerated at 4°C for subsequent analyses. Soil samples were collected from each plot at the beginning and the end of the project (in October, after corn harvest) using a Giddings sampler (50 mm inner diameter). Samples were taken to one metre in depth and one metre from the sides of each plot at two locations, the maximum distance between samples being 13 m. Each soil core was cut at 200 mm intervals and sections corresponding to each depth were pooled and conserved in plastic bags for subsequent analyses. Forage was cut twice each year (in June and in August), while the two central rows of each corn plot were harvested in September. Yields were calculated for each plot and crop samples were taken and dried at 37 °C and conserved for subsequent analyses.

The water samples were filtered through 1.2 µm Whatman GF/C glass microfibre filters. The filtrate was then analyzed for total N, NH_4-N, NO_3-N, total P, and PO_4-P by standard automated colorimetric methods (Ministère de l'Environnement et de la Faune-MEF 1987). Soil samples were analyzed for total Kjeldahl N-TKN (Schuman et al. 1973), NO_3^--N (McKeague 1977), total P (Page et al. 1982), and Mehlich III extractable-P (Mehlich 1984). Plant samples were analyzed for TKN (Schuman et al. 1973), NH_4^+-N and NO_3^--N (Commission of the European Communities-CEE 1979), and total P (Walsh 1971). Because of budget restrictions, all chemical analyses of water samples could not be performed every year: nitrogen analyses were done the first, second, third, and fifth years, while phosphorus analyses were done only the first three years of the project (1989-1992). However, all fertilization treatments were applied to the plots every year, but water quality results are presented for 3 and 4-year periods.

Table I: Precipitation (mm water) during experimental period.

Form	Year	Season*				
		Fall	Winter	Spring	Summer	Total
Rainfall	1	170.2	35.2	245.7	361.0	812.1
	2	305.2	137.9	241.0	281.4	956.5
	3	238.0	69.0	118.9	332.8	758.7
	4	187.5	34.2	186.1	378.2	786.0
	5	269.2	22.2	264.4	331.1	886.9
	29 yr mean	197.9	60.7	213.0	320.1	791.7
Snow	1	33.9	124.2	24.0	0.0	182.1
	2	29.3	145.0	15.4	0.0	189.7
	3	30.6	98.1	36.9	0.0	165.6
	4	25.6	154.4	25.2	0.0	205.2
	5	35.2	174.0	32.5	0.0	241.7
Total	29 yr mean	63.7	148.4	37.0	0.0	249.1
	1	204.1	159.4	269.7	361.0	994.2
	2	334.5	282.9	256.4	281.4	1155.2
	3	268.6	167.1	155.8	332.8	924.3
	4	213.1	188.6	211.3	378.2	991.2
	5	304.4	196.2	296.9	331.1	1128.6
	29 yr mean	258.5	202.9	249.4	320.1	1031.0

*Fall: September 15 - December 14; Winter: December 15 - March 14; Spring: March 15 - June 14; Summer: June 15 - September 14

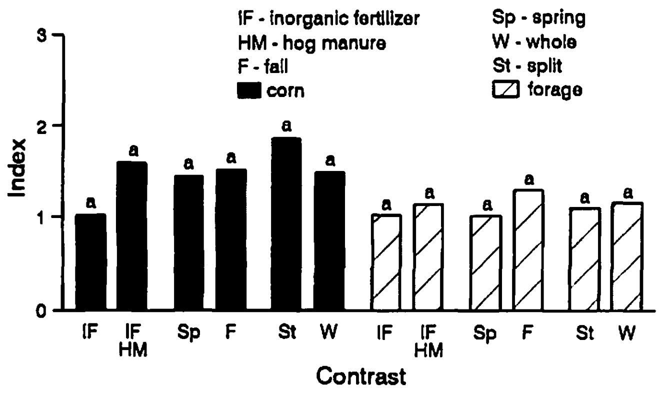

Fig. 1. Crop by treatment interaction for total-water N index (treatment values divided by IF value for each crop). Columns within a contrast capped by unlike letters are significantly different (P ≤ 0.10) by the F-test. Total-water = runoff + drainage. N =total N.

Nitrogen and phosphorus loads in runoff and tile drain water were calculated weekly for each plot as the product of volume of water collected by the respective mean weighted concentrations. The chi-square (Bartlett) test was used to test the homogeneity of variance of the raw data. Because variances were not always homogeneous, the transformation $\log_{10}(X + 1)$ was used to normalize the data where necessary (Gomez and Gomez 1984). To make the corn and forage effects directly comparable, all data for each variable were divided by the respective control value (IF, mean of the two replicates) for each crop. These "standardized" data or indexes (N and P loads in water, accumulation in soil, crop uptake, and yields) were subjected to repeated measures analysis of variance using SAS PC 6.04 (SAS Inst. 1990). Interactions ($p \leq 0.10$) were decomposed into their constituent simple effects which were evaluated for significance. Significant ($p \leq 0.10$) treatment differences were located by the use of contrasts [inorganic fertilizer (IF) vs IF + hog manure(HM), spring (Sp) vs Fall (F), split (St) vs single (W) applications]. Because of the inherent high variability of runoff and drainage data, effects were declared significant when the calculated probability (p) was less than or equal to the tabulated probability (P) of 10%.

RESULTS and DISCUSSION

Weather conditions

Total annual precipitation (rain plus snow) for the first 3- and 5-year periods varied from 924 to 1155 mm (Table I). These values are comparable to the 1031 ± 135 mm 29-year average for the district. Total precipitation in the wetter second and fifth years was 1155 and 1129 mm, respectively, while the third year was drier with 924 mm. Fall plus spring rainfall amounted to 440 mm (3-year average) and 445 mm (5-year average), representing about 42% of the total annual precipitation. Winter snowfall accounted for 12% of the total annual precipitation (3 or 5-year average) and the mean daily winter temperature for the district was -9.1 °C (29-year average).

Water loss

Total annual water loss (runoff plus drainage combined) was unaffected by crop ($p > 0.10$, data not shown); mean values were 267 mm (26% of total mean annual precipitation) for the first three years and 307 mm (30% of total mean annual precipitation) for the 5-year period. However, total annual runoff (leaching not considered) was greater for corn plots (3-year : 110 mm; 5-year : 122 mm) than for forage plots (3-year : 72 mm; 5-year: 89 mm); ($p \leq 0.10$), but leaching losses were unaffected by crop ($p > 0.10$) and averaged 159 mm for the 3-year and 187 mm for the 5-year periods.

Table II. Statistical analyses of indexes for water variables. F values and significance.

Source of variation	df	Variable				
		Total N	NH_4-N	NO_3-N	Total P	PO_4-P
Total water						
Crop (C)	1	28.59**	0.77	35.49**	3.29	2.83
Treatment (T)	3	9.35**	6.61*	9.25**	2.06	2.30
CxT	3	6.02*†	0.51	**9.18****	0.94	0.78
Error (between)	8	0.2739	4.2965	0.2896	1.1086	2.1750
Year (Y)	3	1.83	3.17*	1.73	9.01**	3.75*
Y×C	3	**5.15****	3.88*	**5.52****	14.60**	6.36**
Y×T	9	0.97	1.69	0.85	3.74*	2.01
Y×C×T	9	0.94	**2.30**$^{+}$	1.16	**4.74****	**3.61***
Error (year)	24	0.4359	2.5443	0.4893	0.3362	0.5210
Runoff						
Crop (C)	1	5.44*	**4.30**$^{+}$	6.98*	2.37	5.63*
Treatment (T)	3	0.78	5.79*	0.15	11.12**	15.96**
CxT	3	1.02	1.56	1.28	1.90	2.73
Error (between)	8	0.2576	0.5512	0.3156	0.1482	0.2808
Year (Y)	3	2.59^{+}	1.34	6.11**	33.56**	13.89
Y×C	3	**3.44***	1.81	4.43*	12.02**	2.36
Y×T	9	0.83	**4.17****	1.41	10.65**	3.58
Y×C×T	9	1.34	0.53	**1.91**$^{+L}$	**7.49****	**2.54**$_{+}$
Error (year)	24	0.0909	0.1183	0.1226	0.0506	0.2100
Drainage						
Crop (C)	1	7.26	0.02	7.92*	1.36	0.89
Treatment (T)	3	**5.52***	**2.82**$^{+L}$	6.37*	0.34	0.36
CxT	3	2.21	0.16	2.94^{+L}	0.24	0.16
Error (between)	8	0.3593	4.5613	0.3747	1.2745	1.6807
Year (Y)	3	1.35	1.95	1.26	2.23	2.10
Y×C	3	**3.66***	**2.65**$^{+}$	**3.27***	5.76*	10.08**
Y×T	9	0.69	0.79	0.60	0.91	1.62
Y×C×T	9	0.49	1.82	0.42	**2.39**$^{+L}$	**2.77**^{*L}
Error (year)	24	0.3000	3.0933	0.3302	0.3822	0.0051

$^{+,*,**}$ Significant at P = 0.10, 0.05, 0.01 levels, respectively
^{L} - Significant with log transform
df - degrees of freedom
† Bolded F values indicate that all information for the variable is contained in this effect.

being no difference for forage (Table II, Fig. 1). There were no differences for the other two contrasts for either crop. These effects were year-independent as well. However, total-water N indexes were much higher for corn than for forage in two years, there being no difference in the other two (Fig. 2). Thus, in some years, applying hog manure in addition to fertilizer did increase total N losses for corn much more than for forage for the same degree of over-fertilization (three times crop requirement). Yearly effects were not correlated with annual precipitation because there was less total precipitation in years one and three than in two and five (Table I). This was also generally true for other effects involving "year" in this paper.

Runoff N The year by crop interaction (Table II) was very similar (data not shown) to that for total-water N (Fig. 2). Losses were much higher for corn than for forage in years one and three, there being no difference in the other two years.

Drainage N There was also a year by crop interaction (Table II) for drainage N (data not shown) similar in pattern to total-water (Fig. 2) and runoff N. The treatment effect was related to the fact that hog manure in addition to mineral fertilizer increased N losses substantially (Table II, Fig. 3), neither of the other contrasts being significant ($p > 0.10$). This same treatment effect was found for total-water N but only for corn (Fig. 1).

Consequently, hog manure in addition to fertilizer substantially increased total water N for corn but not for forage; a similar effect occurred for both crops for drainage N. Corn caused more total N loss in total-water, drainage, and runoff than forage but only in two of the four years. Therefore, hog manure applied above crop needs did indeed increase water N losses and corn caused relatively higher losses than forages for the same level of excess (three times). There were no seasonal or splitting effects on total-water N losses.

Total-water (runoff + drainage), runoff, and drainage N

Total-water N (total) There were two significant interactions: crop by treatment and year by crop (Table II). When hog manure was applied to corn in addition to fertilizer, total (runoff plus drainage) water N losses increased greatly, there

Total-water NH_4-N The treatment effect for this variable depended on the crop and the year (Table II, Fig. 4). Although hog manure in addition to fertilizer always produced more NH_4-N loss than IF-alone for corn, the difference was only significant ($p \leq 0.10$) in the first year. The same was true for forage, but in the second year and the magnitude was of the

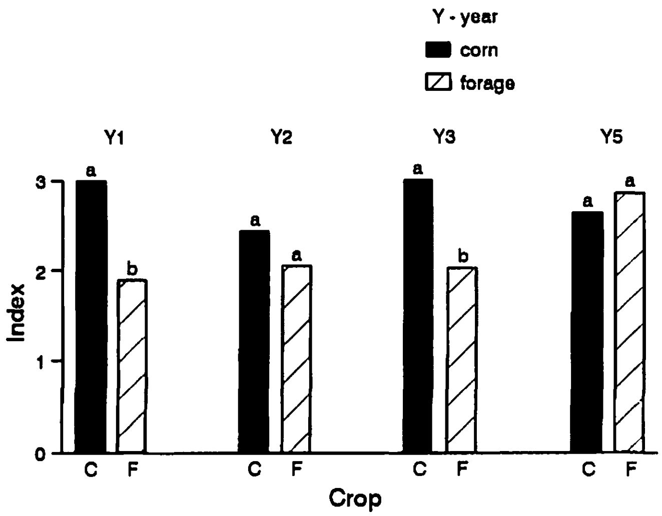

Fig. 2. Year by crop interaction for total-water N index (treatment values divided by IF value for each crop). a, b - see Fig. 1. Total-water = runoff + drainage. N = total N.

same order. Thus, hog manure in addition to IF can increase total-water NH_4-N loss. For corn, the fall application always produced more NH_4-N loss compared to spring (significant in three of four years). The same was true for forage but significant in only one year. Although there was no difference between split and whole applications for corn in all years, a difference did occur in one year for forage where the "whole" treatment caused more NH_4-N loss. Consequently, splitting applications generally had little impact on total-water NH_4-N loads.

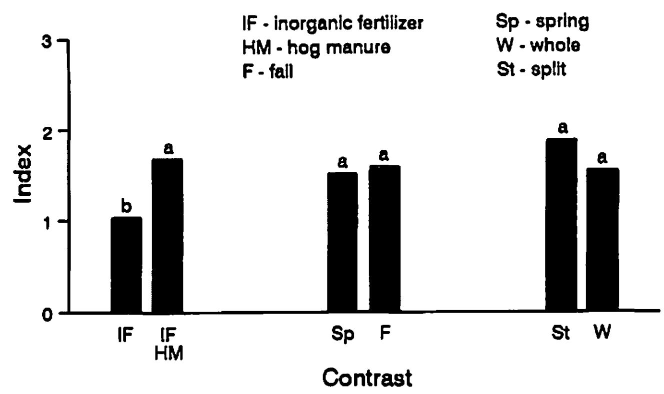

Fig. 3. Treatment contrasts for drainage N index (treatment values divided by IF value for each crop). a, b - see Fig. 1. N = total N.

In hog manure, at least 75% of total N is in the NH_4^+-N form. Because of higher temperatures, nitrification is higher for spring applications resulting in more NO_3^--N and less NH_4^+-N, while the reverse is true for late fall applications. For this reason, fall spreading of large amounts of hog manure on corn plots (less frequent for forage) had a great impact on NH_4^+-N loads and concentrations, particularly at spring snowmelt (Gangbazo et al. 1995). Thus, fall application of large amounts of hog manure is likely responsible for surface water contam-

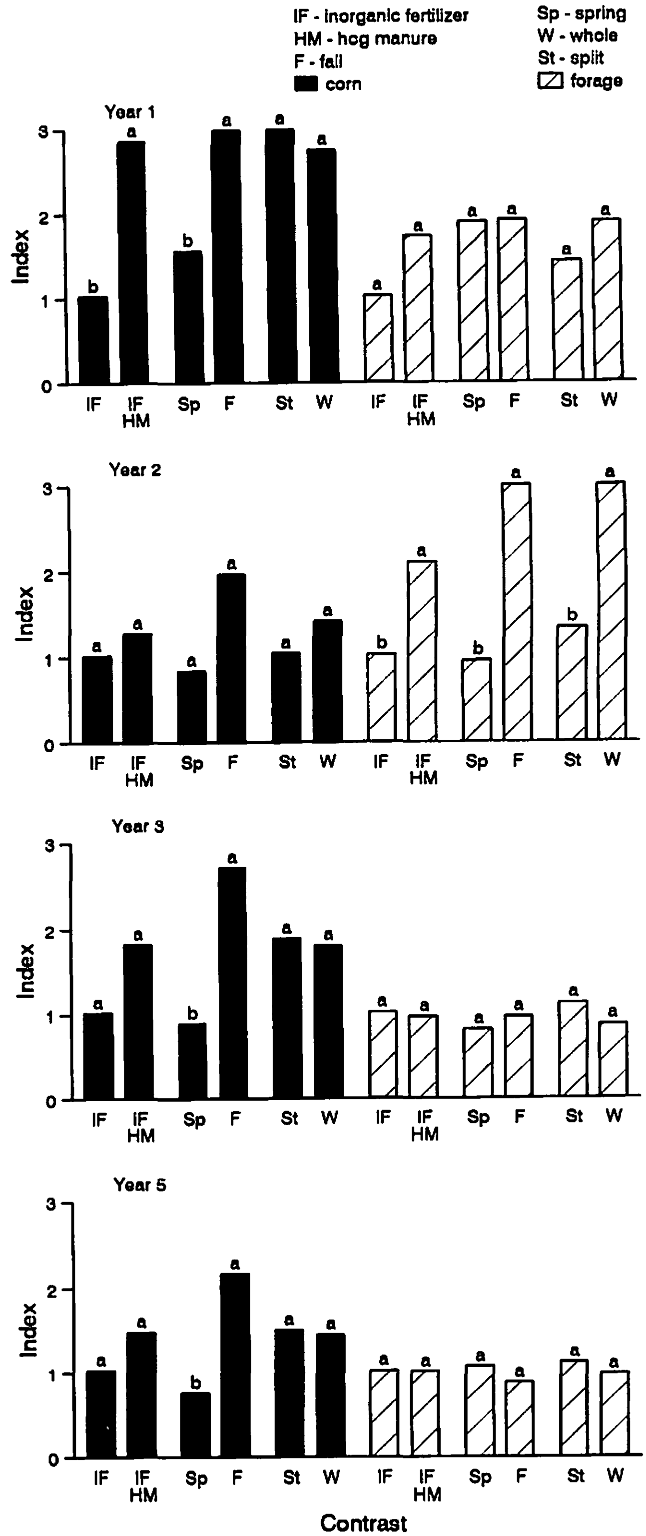

Fig. 4. Year by crop by treatment interaction for total-water NH_4-N index (treatment values divided by mean IF value). a, b - see Fig. 1. Total-water = runoff + drainage.

ination by NH_4^+-N during spring runoff events from snowmelt. This has been observed in the L'Assomption river which drains a watershed with large manure surpluses (Boucher 1985).

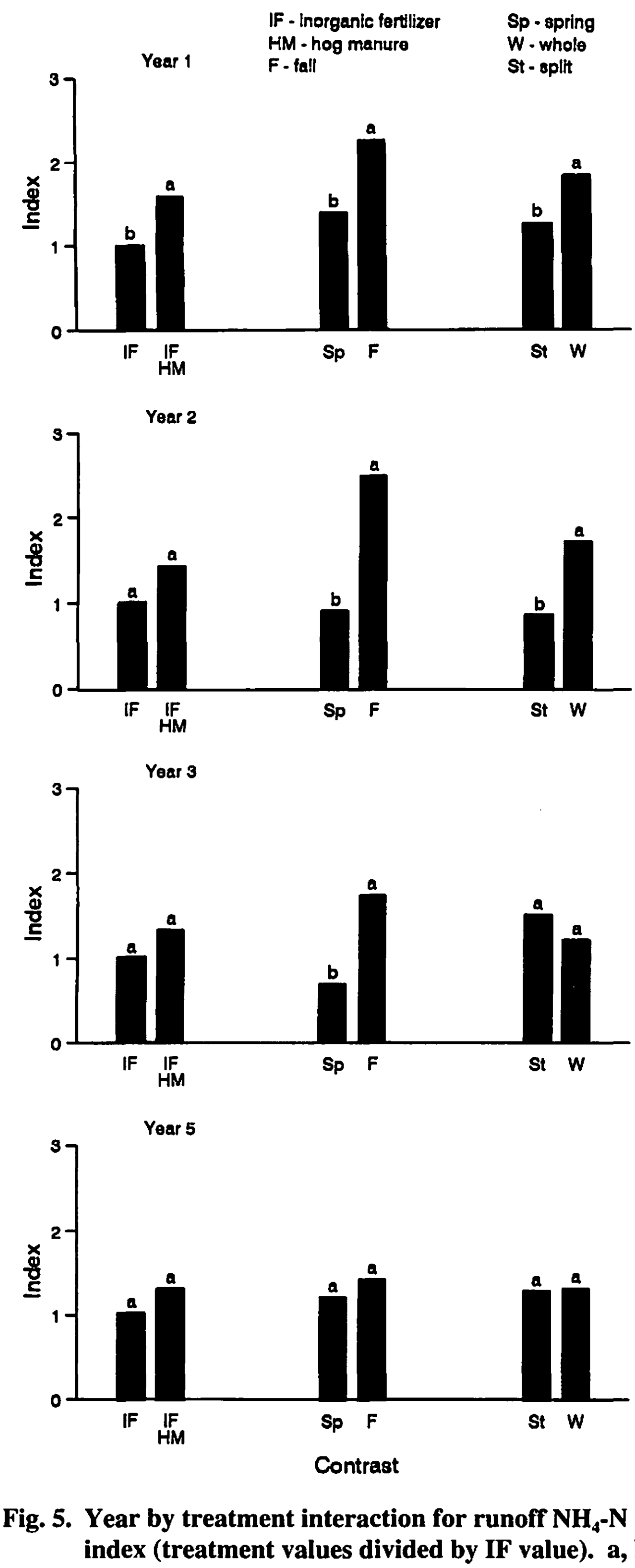

Fig. 5. Year by treatment interaction for runoff NH_4-N index (treatment values divided by IF value). a, b - see Fig. 1.

Runoff NH_4-N All information was contained in the crop and year by treatment effects (Table II). Corn produced more runoff NH_4-N than forage (1.48 vs 1.10, $p \leq 0.10$). This was due mainly to the greater NH_4-N load for corn; the higher application rate for corn would result in slower disappearance,

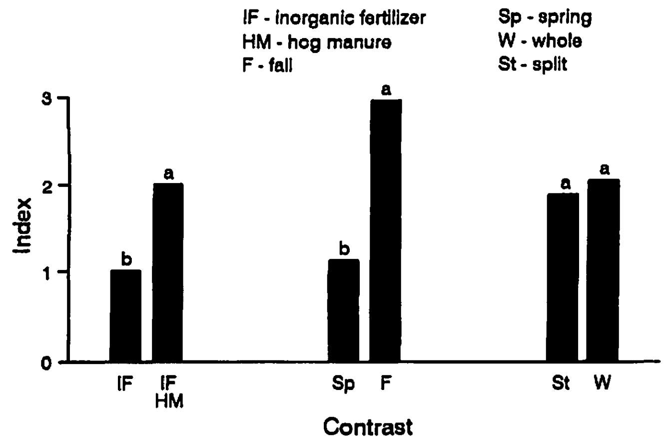

Fig. 6. Treatment contrast for drainage NH_4-N index (treatment values divided by mean IF value). a, b - see Fig. 1.

because the soil conversion rate would be more or less fixed. Runoff volume was also higher for corn.

Hog manure in addition to IF and application in one shot versus two both resulted in much more NH_4-N loss in two of the four years (Table II, Fig. 5). Fall application resulted in much more NH_4-N loss compared to "spring" in three of the four years, for the above reasons. Thus, manure applied once in the fall, and in addition to fertilizer, resulted in higher runoff NH_4-N losses but not in all years. Furthermore, forage produced significantly less NH_4-N loss compared to corn, for the same degree of overfertilization (three times crop need).

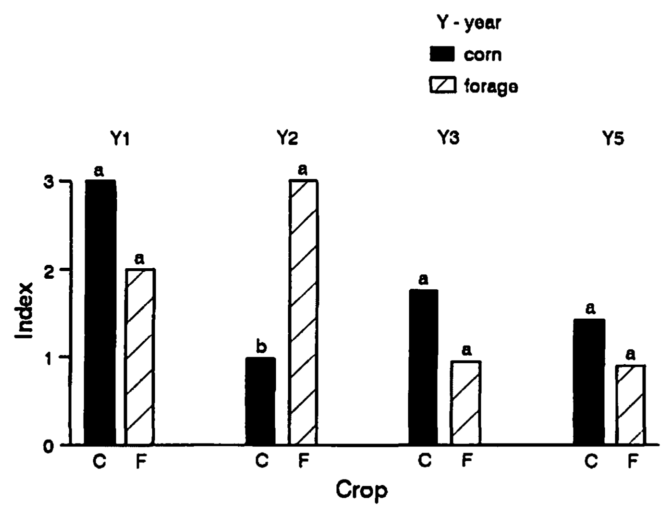

Fig. 7. Year by crop interaction for drainage NH_4-N index (treatment values divided by mean IF value). a, b - see Fig. 1.

Drainage NH_4-N The treatment effect (Table II) was explained by the much higher losses when hog manure was applied either in addition to IF or in the fall, there being no difference between one or two applications (Fig. 6). These effects were crop-independent. Although there was a tendency for increased NH_4-N in corn drainage compared to forage (Fig. 7);

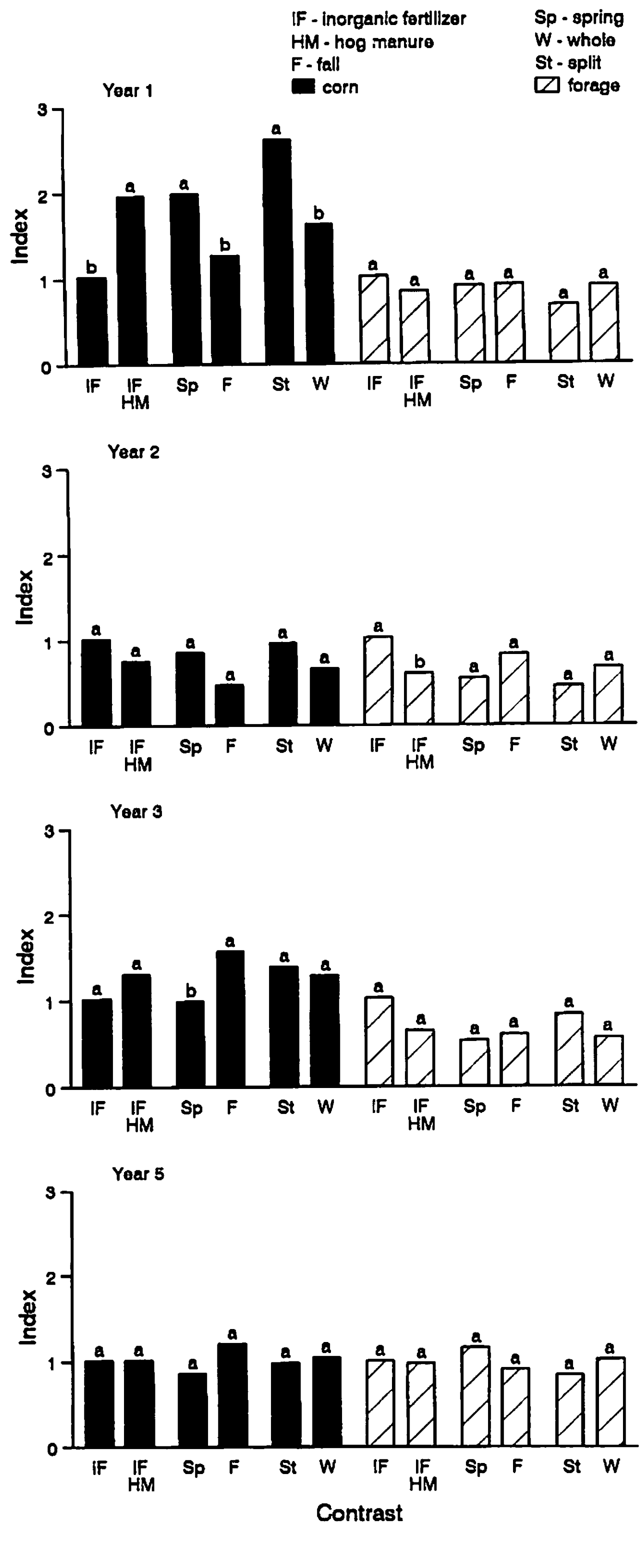

Fig. 8. Year by crop by treatment interaction for runoff NO_3-N index (treatment values divided by mean IF value). a, b - see Fig. 1.

this was not significant ($p > 0.10$) in three of four years, the effect being the reverse in the other year ($p < 0.10$).

Total-water NO_3-N All information was contained in the crop by treatment and crop by year interactions (Table II). The crop by treatment interaction (data not shown) was very similar in pattern to total-water N (Fig. 1) and was explained by the increased NO_3-N load for corn when manure was added to IF and when split applications were practiced, there being no difference ($p > 0.10$) for the forage contrasts. There was no difference between fall and spring applications for either crop.

The crop by year interaction (Table II) was produced by the higher NO_3-N loads for corn in two of the four years. The pattern (data not shown) was very similar to that for total-water N (Fig. 2). Thus, total-water NO_3-N loads for corn, but not for forage, were higher when hog manure was applied in addition to fertilizer and when applications were split. Although year-dependent, corn produced higher NO_3-N loads than forage for the same magnitude of excess. The patterns were similar to those of total-water N, likely because nitrate N constitutes a large part of the former.

Runoff NO_3-N The effect depended on the treatment, crop, and year (Table II). Only in one of the four years did manure in addition to fertilizer increase NO_3-N for corn (Fig. 8), the reverse occurring for forage, also in only one year (Fig. 8). Spring application increased NO_3-N load in the first year, the opposite being true in the third for corn. For the forage contrast spring-fall, there was no difference. Splitting manure application increased NO_3-N load only in one year for corn and not at all for forage.

Thus, manure in addition to fertilizer did increase NO_3-N loads for corn, but not consistently. Similarly, neither season of application nor splitting had consistent effects on corn NO_3-N loss. When there were effects (first and third years), the NO_3-N index was higher for corn than for forage, indicating greater losses for the same degree of excess.

Drainage NO_3-N The information was contained in the crop by treatment and crop by year interactions (Table II). The crop by treatment interaction (data not shown) was similar in pattern to total-water N (Fig. 1). Manure in addition to IF increased NO_3-N loads greatly for corn, there being no other differences. Similarly, the crop by year effect closely resembled the Fig. 2 pattern, there being higher NO_3-N loads in the first and third year from corn. Therefore, applying manure in addition to fertilizer increased drainage NO_3-N for corn but not for forage. Corn did cause higher NO_3-N losses, at least half the time.

Most NO_3^--N (90% on corn plots and 84% on forage plots) was lost through drain tiles; whereas, most NH_4^+-N (85% on corn or forage plots) was lost in surface runoff. This reconfirms the fact that drainage is the most important pathway for NO_3^--N while NH_4^+-N is lost mainly through runoff (Gangbazo et al. 1995).

Total-water, runoff, and drainage P

Total-water P (total) The effect depended on treatment, crop, and year (Table II). Applying hog manure in addition to fertilizer had no effect on total-water P for corn but increased loads in one year and reduced them in another for forage (Fig. 9). Fertilizer and manure were surface-applied for forage, but incorporated for corn, and this would explain the more frequent effect for forage. The contradictory effect was probably due to rainfall intensity, quantity, and length of time after application until rainfall. Fall applications increased P loads both for corn

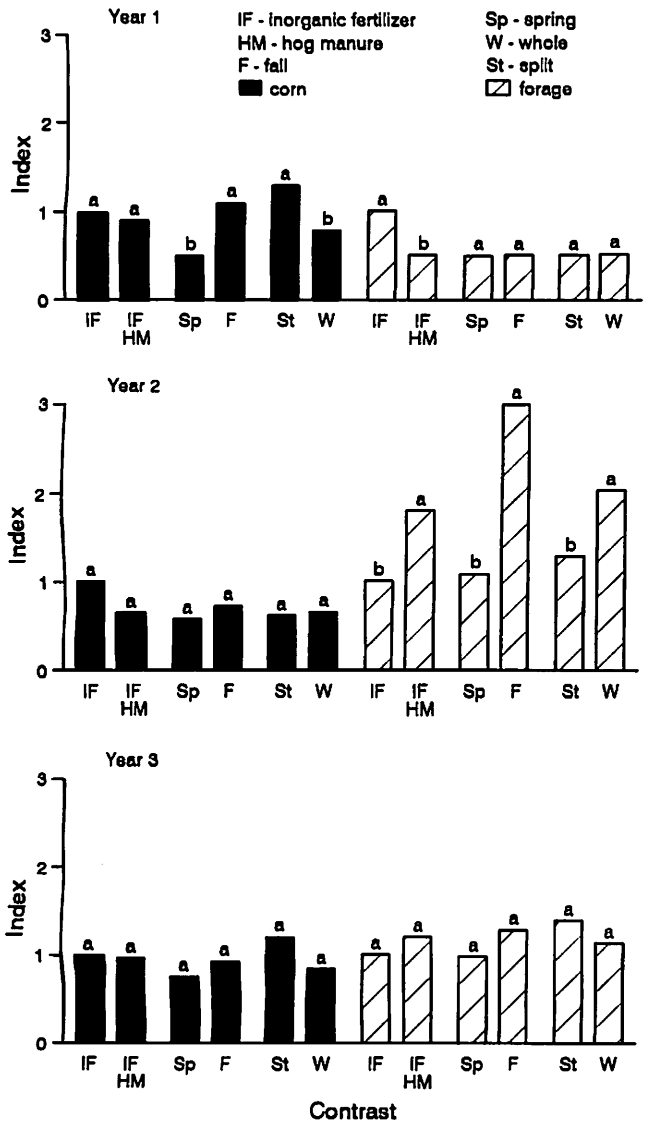

Fig. 9. Year by crop by treatment interaction for total-water P index (treatment values divided by IF value for each crop). a, b - see Fig. 1. Total-water = runoff + drainage. P = total P.

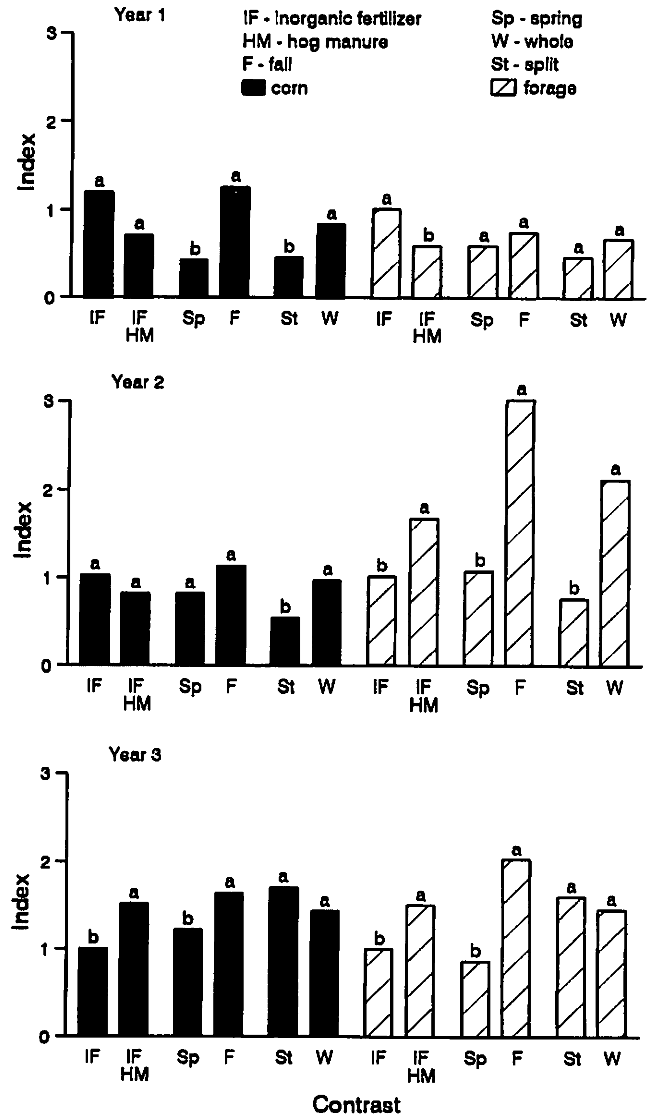

Fig. 10. Year by crop by treatment interaction for runoff P index (treatment values divided by IF value for each crop). a, b - see Fig. 1. P = total P.

and forage, in only one of three years (not the same year). Split applications increased P loads for corn and reduced them for forage but only in one (different) year for each crop.

Runoff P The effects depended on the treatment, crop, and year (Table II) as for total-water P (Fig. 9) but differed in pattern (Fig. 10). When manure was applied in addition to IF, runoff P increased (compared to IF) in only one of the three years for corn and in two of the three years for forage, the reverse being true for the other forage year (Fig. 10). Forage likely caused P loss more frequently, because manure was surface-applied, whereas, it was incorporated for corn.

Fall HM applications resulted in a little over one to about three times as much P as spring applications in two of the three years for both crops (Fig. 10) with the same tendency ($p > 0.10$) in the other year. Forage exported somewhat more P (about three times) more frequently than corn because of the surface applications.

A single HM application resulted in more P loss than split applications in two of the three years for corn (double) and one of three for forage (triple). This is because of the greater difficulty in covering a single application for corn and the fact that HM was surface-applied for forage. Consequently, applying HM in addition to fertilizer in the fall and in single applications increased P in runoff sometimes.

Drainage P Crop and year both influenced the treatment effect (Fig. 11); the pattern of which differed from the total-water P (Fig. 9) and runoff P (Fig. 10).

Applying HM in addition to IF caused less P loss in two of three years for corn, which was the reverse of runoff P in one of those years. More P in runoff would result in less drainage P. For forage, the effect was the same as for corn in one year but the reverse in the other; these effects were similar to those

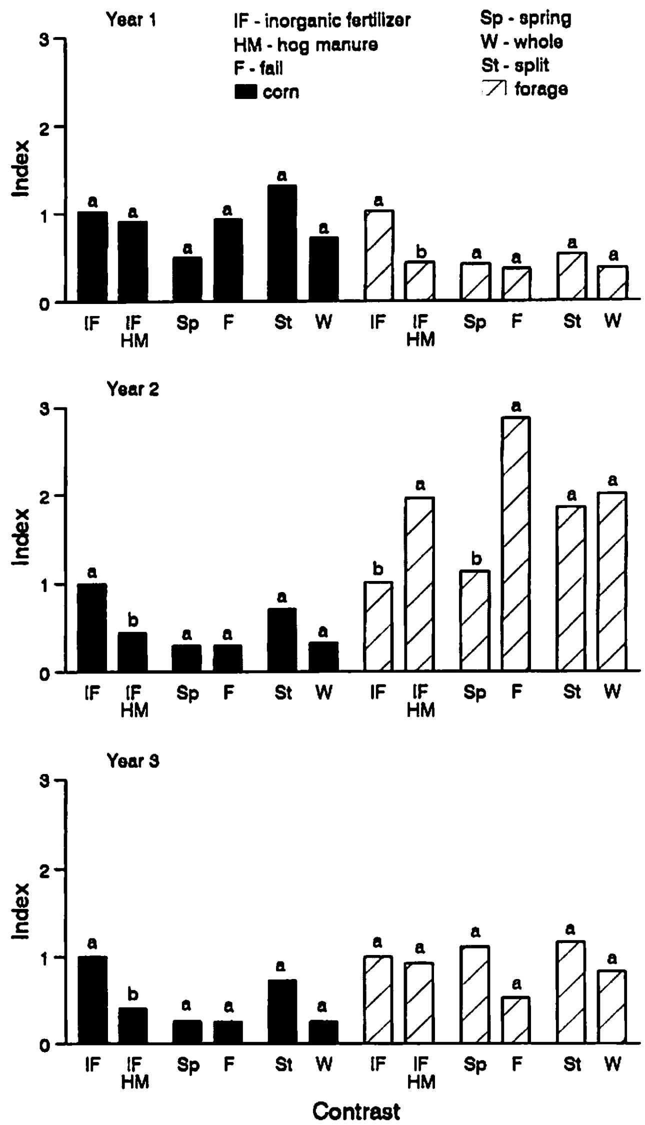

Fig. 11. Year by crop by treatment interaction for drainage P index (treatment values divided by IF value for each crop). a, b - see Fig. 1. P = total P.

for runoff P (Fig. 10) and total-water P (Fig. 9). Consequently, for forage, the treatment effect depended on the year and was not consistent in contrast to corn. The magnitude of the differences were similar for the two crops in two of three years but higher for forage in the other.

Fall application resulted in more P loss than spring-applied HM but in only one year for forage (Fig. 11). The indexes for the forage data tended to be relatively higher than for corn in two of the three years.

There were no differences between whole or split applications (Fig. 11), although there was a tendency ($p > 0.10$) for higher split losses which was contrary to runoff P (Fig. 10). Consequently, applying HM in addition to IF did not result in consistent effects. There was an indication that less P occurred in the drainage for corn when HM was applied and that fall and split applications resulted in more P loss.

Total-water PO_4-P The treatment effects depended on the crop and year (Table II), as for total-water P. The pattern (data not shown) was also very similar to that of total-water P (Fig. 9), except for the contrasts Sp vs F in year three for corn and forage, IF vs IF+HM for corn in three, and St vs W in years one and three all being significant ($p \leq 0.10$) for total-water PO_4-P; whereas, they weren't for total-water P. The differences were often greater for forage because of surface application.

Runoff PO_4-P There was a year by crop by treatment interaction for this variable as well (Table II). The pattern (data not shown) was very similar to that for runoff P (Fig. 10). The differences were as follows: the St vs W contrast was not significant for years one and two for corn but with the same tendency, and IF vs IF+HM was not significant for year one forage. The magnitude of the differences for significant ($p \leq 0.10$) effects was similar for both crops.

Drainage PO_4-P The year by crop by treatment interaction (Table II) was very similar in pattern to drainage P (Fig. 11) except for the following details: the Sp vs F corn year one, St vs W corn year one, and three, and Sp vs F forage year three contrasts were all significant ($p \leq 0.10$); IF vs IF+HM forage years one and two and IF vs IF+HM corn year two were not ($p > 0.10$). These effects were not significant for drainage P.

Consequently, split applications resulted in more PO_4-P loss for corn, but not for forage, likely because precipitation would leach relatively more P from several small applications than a single large one. Since HM was all surface-applied for forage, this phenomenon would not apply.

For corn and forage, most P (total P: 70% for corn and 65% for forage; PO_4-P: 61% for corn or forage) was exported by surface runoff. Manure PO_4-P was found more in surface runoff than in drainage because hog manure was incorporated in the corn plowlayer by rototilling and left on the soil surface in forage plots. Much of the manure P is in the PO_4-P form as well which would not move into the soil (and hence drainage) because of soil fixation. This would favor surface runoff of P.

Soil effects

There was no effect for the total soil N index (Table III). Mean actual values were 5.0, 3.3, 1.7, 1.4, and 1.1 Mg/ha, respectively, in the 0-200, 200-400, 400-600, 600-800, and 800-1000 mm depths. In Wisconsin, Motavalli et al. (1985) observed a migration of total N to a depth of 600 mm the first year that liquid cattle manure was spread on sandy or silty loam soil plots at rates of 250 to 500 kg total N/ha. In Alberta, Chang et al. (1991) showed that when high rates (480 to 2880 kg total N/ha) of liquid cattle feedlot manure were spread on a clay loam soil for eleven years, total N accumulation was observed to a depth of 500 mm. The lack of a significant accumulation of total N in this study could be attributed to the large spatial variability in total N content in the soil at the onset of the study: coefficients of variation were 49 and 63% in the 0-200 and 200-1000 mm soil layers, respectively.

The principle effect for NO_3-N resided in the depth by crop interaction (Table III); there was a much higher increase for corn than for forage in the first two depths (Fig. 12). Consequently, for the same degree of over-fertilization, the increase in forage soils was much less, perhaps due to relatively more N uptake (data not shown) because of greater yield

Table III. Statistical analyses of indexes for soil variables. F values and significance.

Source of variation	df	Variable		
		Total N	NO_3-N	Mehlich-3 P
Crop (C)	1	0.03	1.18	0.47
Treatment (T)	3	0.86	1.37	1.50
CxT	3	0.65	0.18	0.56
Error (between)	8	0.0691	3.3433	0.2099
Depth (D)	4	1.80	0.54	**2.50**$^{+}$
DxC	4	0.46	**3.09***†	1.07
DxT	12	0.93	0.84	1.14
DxCxT	12	0.69	1.40	0.35
Error (depth)	32	0.0275	0.4034	0.2459

df = degrees of freedom
$^{+}$,* Significant at P = 0.10 and 0.05 levels, respectively
† Bolded F values indicate that all information for the variable is contained in this effect.

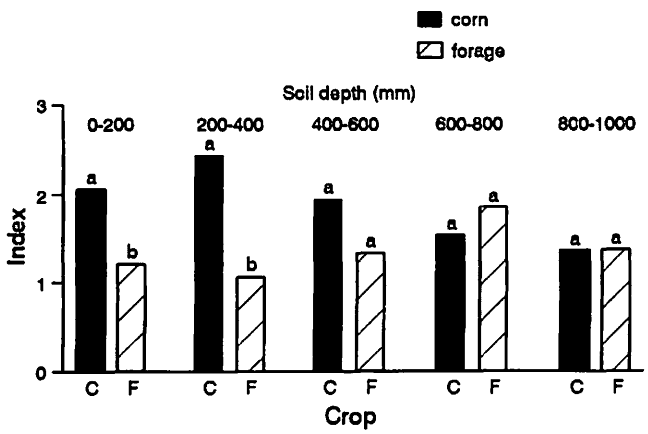

Fig. 12. Depth by crop interaction for soil NO_3-N index (treatment values divided by IF value for each crop). a, b - see Fig. 1.

increase (Fig. 13). This also resulted in less NO_3-N in the water (Fig. 2). Nitrate-N accumulation in soil would be expected, because many studies have demonstrated this with overfertilization (Chang et al. 1991; Liang and MacKenzie 1994).

The only soil P effect was related to depth (Table III, data not presented). It is well known that P generally accumulates in the top soil layer (Chang et al. 1991; Sutton et al. 1986). Although though there was no significant treatment effect on P accumulation index in soils in spite of the fact that the manured plots annually received substantially more than crop requirement, Mehlich III-P content in the 0-200 mm soil layer averaged over treatments increased from 195 to 335 kg/ha (70%) under corn but only from 195 to 218 kg/ha (12%) under forage over the five years. During this period, the P rating of the top 200 mm of the soil remained rich (151-250 kg P/ha) under forage plots, but changed from rich (151-250 kg P/ha) to excessively rich (> 251 kg P/ha) under corn plots according to the current classification (CPVQ 1994).

Yield and uptake

The crop by year interaction (Table IV) for yield was explained by the relatively greater increase for forage (Fig. 13), the difference varying according to the year. Normally, if IF was applied at the recommended rate, no yield increases would be expected with HM applied in addition to fertilizer. Forage may have responded more to HM applications (in addition to IF) than corn because of greater N uptake (data not shown; pattern was very similar to Fig. 13). This could have led to increased forage growth, if the recommended N requirement was actually below the real need. There were no other yield effects. Nitrogen uptake was greater for IF+HM treatments independent of crop, there being no other contrast effect (Fig. 14).

The P uptake effect (data not shown) was contained in a crop by year interaction (Table IV) which was similar in pattern to that of yield and N uptake (Fig. 13). Greater P uptake resulted when HM was added to IF and when a single application was applied (Fig. 15).

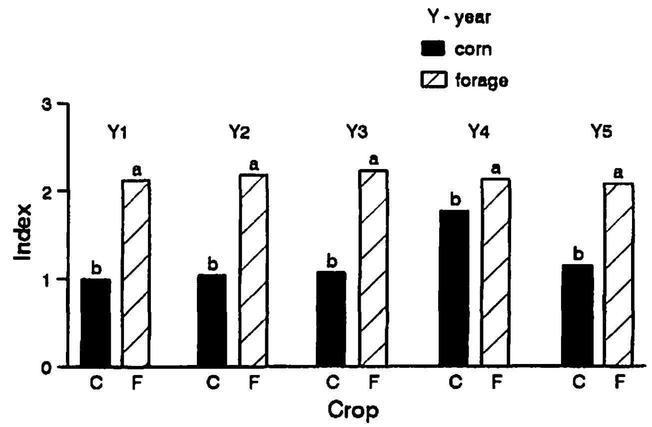

Fig. 13. Year by crop interaction for yield index (treatment values divided by IF value for each crop). a, b - see Fig. 1.

CONCLUSIONS

Hog manure in addition to IF increased total N, NH_4-N, and NO_3-N in runoff and drainage water more for corn than for forage. Fall application greatly increased NH_4-N in runoff and drainage, especially for corn, the effect being year dependent. Split applications sometimes reduced NH_4-N in water. Higher runoff P often resulted from fall HM applications. Much greater relative yield increase resulted for forage than for corn when HM was applied. There was more NO_3-N increase in the surface soil layers under corn. Hog manure resulted in a non-significant Mehlich III soil-P increase.

Table IV. Statistical analyses of indexes for yield and uptake variables. F values and significance.

		Variable		
		Yield	Uptake	
Source of variation	df		Total N	Total P
Crop (C)	1	286.45**	262.01**	387.14*
Treatment (T)	3	1.70	**3.02+**	**6.25***
CxT	3	0.13	0.24	1.07
Error (between)	8	0.0745	0.0894	0.0661
Year (Y)	3	1.47	1.12	9.59**
YxC	3	**2.62+†**	**2.94***	**2.87*L**
YxT	9	0.49	0.28	1.32
YxCxT	9	0.76	0.90	1.24
Error (depth)	24	0.0006	0.0372	0.0313

df = degrees of freedom
+,*,** Significant at P = 0.10, 0.05, and 0.01 levels, respectively
L = Significant with log transform
† Bolded F values indicate that all information for the variable is contained in this effect.

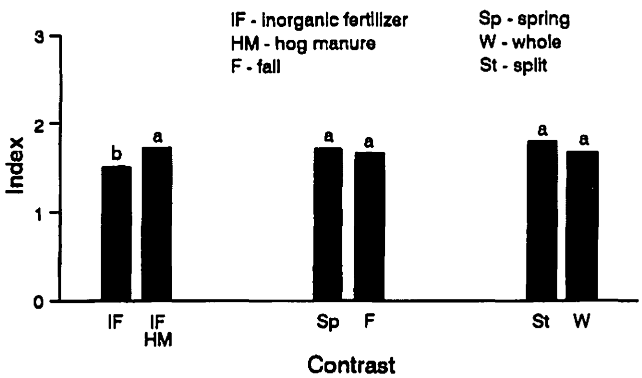

Fig. 14. Treatment contrast for N uptake index (treatment values divided by IF value for each crop). a, b - see Fig. 1.

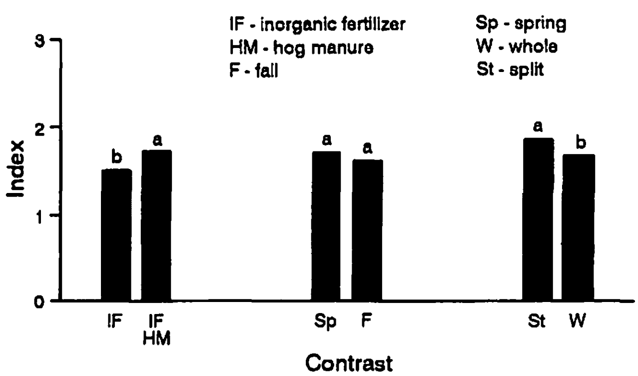

Fig. 15. Treatment contrast for P uptake index (treatment values divided by IF value for each crop). a, b - see Fig. 1.

Thus, these results indicate that applying hog manure to corn and forage, when crop requirements were already met, did indeed increase nutrient losses to runoff and drainage. Consequently, crop requirements should be respected in order to reduce nutrient loss and prevent excessive buildup in the soil. Spring rather than fall applications should be recommended, because the former resulted in less nutrient loss, especially as NH_4-N. Splitting applications of large amounts sometimes was advantageous to reduce nutrient losses. However, especially for the nitrogen forms, there was often less nutrient loss from forage than from corn for the same degree of overfertilization (three times).

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