NITRATE NITROGEN IN THE SOIL PROFILE AND DRAINAGE WATER AS INFLUENCED BY MANURE AND MINERAL FERTILIZER APPLICATION IN A BARLEY–CARROT PRODUCTION SYSTEM

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Abstract. Nitrate-N (NO_3^--N) is a ubiquitous pollutant in both surface and groundwater in many agro-ecosystems. This has elicited a concerted effort to identify management strategies that mitigate NO_3^-–N pollution, without compromising crop yield. This study was conducted on a field site located at the Bio-Environmental Engineering Centre (BEEC) in Truro, NS, Canada during 1999 and 2000. The site has been used since 1997 to investigate the relative effect of inorganic versus organic fertilizer (liquid hog manure; LHM) applied at rates (70 kg N ha^{-1}) on NO_3^--N leaching from a carrot rotation system. NO_3^--N concentrations were monitored in both the soil profile and in tile drainage effluents from eight treatment plots. The LHM treatment elicited significantly ($P < 0.01$) higher soil NO_3^--N concentrations than inorganic fertilizer (IF) in June and October during 1999, but not 2000. The sampling date and soil depth were significant in most cases. Annual flow weighted averages (FWA) of NO_3^--N in drainage water were generally greater for plots receiving LHM (15.4 and 10.5 mg L^{-1} for 1999 and 2000, respectively), when compared to IF (8.9 and 6.0 mg L^{-1} for 1999 and 2000, respectively), but the difference was significant ($P < 0.05$) only in 1999. Maximum NO_3^--N concentrations in drainage water were similar for both treatments, while the LHM treatment had a significantly higher percentage of samples that were $>$10 mg L^{-1}. The total NO_3^--N load was greater for the LHM treatment when compared to the IF treatment in 1999. Barley and carrot yields were unaffected by treatment applications.

Keywords: inorganic, leaching, manure, nitrate, yield

1. Introduction

Disposal of animal manure is a significant concern for the environmental management of concentrated livestock operations. Manure is often applied to agricultural land and usually supplemented by mineral fertilizers to meet crop nutrient requirements (Versteeg, 2001). In addition to supplying nutrients, manure positively affects many soil properties including organic matter, microbial processes and water holding capacity. Despite benefits for crop growth, manure nutrients can be a potential

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threat to the quality of both surface and groundwater if not properly managed. Problems associated with land application of manure typically result from limited land-base availability (Rodd *et al.*, 1996) and the variable nutrient content of manure (Motavalli *et al.*, 1989; Loecke *et al.*, 2004). Hog operations in Nova Scotia have the lowest crop land in Canada to accommodate the manure produced (Rodd *et al.*, 1996).

Continuous long-term manure applications may result in the accumulation of selected nutrients in the soil profile (e.g. phosphorus) than subsequent crops can utilize, while other nutrients such as nitrate-nitrogen (NO_3^--N)] are highly mobile and may rapidly leach to groundwater (Kumar *et al.*, 1998). Furthermore, in tile drained systems, NO_3^--N can be intercepted by tile systems, and be discharged to surface water bodies. As a result, widespread NO_3^--N losses have been documented in many intensively managed agro-ecosystems of North America (Gordon *et al.*, 2000; Randall *et al.*, 2001; Elmi *et al.*, 2004). On the other hand, tile drainage systems are important to sustainable crop production on many soils in humid regions such as Nova Scotia.

Losses of NO_3^--N from agricultural soils to surface and groundwater have gained increasing attention during the past few decades, given their detrimental effects on rivers, lakes, and coastal water ecosystems and on drinking water quality. High NO_3^--N levels in surface water resulting from intensive agricultural production can promote excessive algal growth in streams and lakes, thereby impairing water quality (Spalding and Exner, 1993). Along with phosphorus (P), nitrogen (N) is often a limiting factor in aquatic ecosystems. Consequently, its introduction into these systems may enhance eutrophication.

A major challenge that agricultural industry is faced with is how to protect surface water and groundwater quality while meeting the needs of farmers to maintain economically viable production systems. To achieve and maintain water quality guidelines, farmers are facing restrictions on land-use practices, including the use of manure and fertilizer. In response to growing concerns and new regulations, producers have been increasingly adopting farming practices and technologies aimed at reducing risks related to manure management systems. There is a need for better information on the relative merits of manure and mineral management systems that minimize impacts on the environment. Comparison of manure and mineral fertilizer on crop performance is also relevant to the development of best management practices for utilizing manure nutrients.

The relative effects of manure and mineral fertilizers on NO_3^--N losses, and the subsequent entry of NO_3^--N to subsurface drainage systems and crop yield are reported in this paper. Objectives of this investigation therefore include evaluating impacts of fertilizer type [inorganic fertilizer (IF) vs. liquid hog manure (LHM)] on (i) NO_3^--N accumulation in the soil profile; (ii) leaching losses of NO_3^--N into tile drain systems and (iii) on crop yield.

2. Materials and Methods

2.1. FIELD MANAGEMENT AND EXPERIMENTAL DESIGN

Field experiments were conducted through 1999 and 2000 at a field site located at the Bio-Environmental Engineering Center (BEEC) of the Nova Scotia Agricultural College (NSAC) in Truro, Nova Scotia. The site was established in 1993 to study the influence of fertilizer type (IF vs. LHM) on NO_3^--N concentrations in the soil profile and drainage water. The 2.9 ha site consists of eight subsurface drainage plots (48 m × 24 m). Subsurface drains (100 mm diameter) were established at 0.80 m depth with a 12-m spacing. Drains from each plot enter a heated outflow building, where they are connected to a tipping bucket. Each tipping bucket is wired to a Campbell Scientific CR10 data-logger (Campbell Scientific Corp., Logan, Utah) for continuous monitoring. Buffer plots isolate the treatment plots hydrologically. Buffers between plots had no fertilizer applied in either year.

The cropping sequence for the study was barley (*Hordeum vulgare*) in 1999 and carrots (*Daucus carota* L.) in 2000. Tillage was performed in the fall each year immediately after harvesting the crops. A moldboard plow was the primary tillage. During the 2 years preceding the study, the experimental site was cropped with carrots. A complete list of field operations is summarized in Table I. Each year, four of the plots received IF (17-17-17 in 1999 and 12-24-22 in 2000) at a rate of 70 kg N ha^{-1}, while the remaining plots received LHM applied at the same rate (70 kg N ha^{-1}). Treatments were laid out as a randomized complete block design with four replication. Fertility treatments were assigned randomly within each block. This site has a history of manure applications and rates used in this study are typical of those currently applied to carrots in the region.

Liquid-hog manure was obtained from NSAC research farm. Prior to application, manure was well agitated and samples collected in triplicate and analyzed for

TABLE I

Field operations and management activities at the study site in 1999 and in 2000

1999	2000	Activities
May 11	May 11	Primary tillage (plowing to 0.20-m depth)
May 4	May 16	Pre-planting soil sampling
May 17	May 18/19	Application of manure and mineral fertilizer (17-17-17 in 1999 and 12-24-22 in 2000)
May 17	May 22	Planting (barley in 1999 and carrots in 2000)
June 3	June 31	Soil sampling after manure and fertilizer application
August 24	October 2	Yield samples collected
October 14	September 13	Post-harvesting soil sampling

nutrient content within 24 h. On an average, the liquid-hog manure had 2.11 kg N t^{-1} in 1999 and 3.08 kg N t^{-1} in 2000. Manure and fertilizer rates were chosen to provide a similar quantity of plant-available N, based on the assumption that plant availability of manure N is 50% of total N (Sims, 1987; Langman *et al.*, 1991; Cooperband *et al.*, 2002). These results were used to adjust N application rates of manure [66 T ha^{-1} (70-40-43) for 1999 and 45 T ha^{-1} (70-14-23) for 2000]. Differences in manure nutrient levels between the two years are presumably the result of various factors, including manure storage, handling, and age of the manure. The manure was surface applied to the plots using a vacuum-tank liquid manure spreader and was incorporated the same day by plowing to a depth of approximately 20 cm. No supplemental chemical fertilizer was applied to plots receiving manure.

The soil is predominantly of the Pugwash soils group (Orthic Melanic Brunisol), which is well-to-moderately drained with a friable, fine sandy loam-textured Ap horizon underlain by a friable 0.15- to 0.20-m thick, fine sandy loam-textured Bm horizon (Webb and Langille, 1996).

Meteorological measurements at the site were recorded hourly using automated weather station and a Campbell Scientific CR10 datalogger (Edmonton, AB). Winter precipitation (snow + rain) and long-term (1971–2000) precipitation and temperature averages were also obtained from an Environment Canada Climate Station, located within 3 km of the experimental site. The precipitation data collected at the site were used when available, while the data from the Environment Canada climate station were generally used during winter months.

2.2. SAMPLING STRATEGY

Soil samples (three samples from each plot) were collected annually prior to manure and fertilizer applications in early May (spring sample), June (summer sample) and late September or early October (fall sample) each year to determine residual soil NO_3^--N. Samples were collected over three depth increments (0–0.2 m, 0.2–0.4 m, and 0.4–0.8 m) using a hand-held auger. All soil samples were frozen for 1 to 3 weeks prior to analysis. Samples were then thoroughly mixed and moist subsamples of 10 g were shaken with 100 mL (1:10 soil/extractant ratio) of 1 M KCl for 60 min. The soil suspensions were filtered through Whatman # 5 filter paper. Nitrate-N was quantified using a Lachat flow injection autoanalyzer (Lachat Quickchem, Milwaukee, WI), using the method of Keeney and Nelson (1982).

Tipping buckets located at the outlet of each subsurface drain recorded the drainage water discharge. Sampling was performed according to a flow-weighted average (FWA) strategy, in that the frequency of water sampling was set according to accumulated drainage volume. This strategy was adopted to ensure that samples were collected throughout the entire flow event. Water samples were collected manually in 50 mL Fisher Scientific Falcon Blue bottles and were frozen immediately until they could be analyzed (within 1 to 2 weeks) for NO_3^--N at the Charlottetown

Agriculture and Agri-food Canada (AAFC) Research Station, using a Technicon TRAACS 800 Model No. 782-86T autoanalyzer.

Loading of NO_3^--N is a function not only of NO_3^--N concentration in the drainage water, but also a function of transport volumes. The annual FWA and the total flow from each drain were used to calculate the NO_3^--N mass (kg N ha^{-1}) load. The annual mass load from each system was determined by multiplying the annual FWA of each drain by the total flow for the entire year for that drain, and dividing it by the area of the plot that corresponds to that particular drain.

2.3. YIELD MEASUREMENTS

Due to the types of crops planted, different methods were used to obtain the yield and plant samples. Barley grain yield was determined by hand harvesting individual ears from a subplot consisting of three 2.5-m stretchs in the three middle rows of each plot. The barley from each sampling area was placed through a seed cleaner and then oven dried for 72 h at 70 °C. The mass (kg) from each plot was recorded. The area sampled was determined by multiplying the seeding width (0.18 m) by the length of the strips sampled (2.5 m). The field was moldboard-plowed to a 0.2-m depth in the first week of November, incorporating all barley residue into the soil.

In 2000, a dicer carrot variety was grown. To determine the yield for each plot, five 3-m strips were measured across each plot at 8-m increments. The carrots were manually harvested from each strip and weighed. The tops were removed and harvested from each 3-m strip and weighed.

2.4. STATISTICAL METHODS

An analysis of variance (ANOVA) was performed to assess if there was a significant difference between the IF and LHM treatments with respect to the average annual drainage water, FWA NO_3^--N concentrations in the soil profile, NO_3^--N load and crop yield. Before the analysis of any data was performed the assumptions of normality, constant variance and independence were checked (Montgomery, 2001). When the assumption of normality was not met, an appropriate transformation was performed. The statistical analysis for soil NO_3^--N was done on the cubic-transformed data, while a log-transformation fitted the drainage flow and FWA NO_3^--N concentrations. In both cases results were back transformed to the original scale. Once the data were tested, a Tukey's test was used on the factors found to be significant to determine significant differences. A repeated measures analysis of variance was used to test the main effects of treatment, soil depth, sampling date and year. All statistical analyses was performed using SAS (SAS Institute, 2000). Except where stated, difference were declared significant at the 5% probability level.

TABLE II

Monthly precipitation and mean monthly air temperature during the 1999 and 2000 growing and non-growing seasons, and the 30-year normals (1971–2000) for the region

	Precipitation (mm)			Air temperature (°C)		
Month	1999	2000	1971–2000*	1999	2000	1971–2000
May	43.9	84.6	93.7	13.1	5.5	9.8
June	47.9	58.1	85.1	17.1	8.9	14.7
July	47.4	75.8	89.8	20.1	14.6	18.4
August	120.3	68.5	85.4	18.6	18.1	17.8
September	160.3	96.4	101.3	18.4	14.6	13.4
October	90	133.9	104.6	15.7	17.9	13.6
May–October	509.8	517.3	559.9	15.73	13.9	13.63
November–April	604.7	607.7	617.2	0.37	−0.38	−2.0

*Canadian climate normals (Environment Canada, 1971–2000).

3. Results and Discussion

3.1. METEOROLOGICAL DATA

The total precipitation and average temperatures for 1999 and 2000, along with the 30-year normals (1971–2000) are presented in Table II. On average, both growing seasons (May–October) were drier than normal. In 1999, May through July was dry, with May being the driest (43.9 mm, <50% of the normal month). Conversely, August and September were wet (120.3 and 160.3 mm, respectively). Rainfall in these months accounted for nearly 55% of the growing season rainfall. With the exception of October, rainfall during the 2000 growing season was below normal (Table II). It is worth noting that most of the rainfall in both years occurred towards the end of growing season. Mean temperatures during the growing season were 15.73 °C for 1999 and 13.9 °C for 2000. Precipitation in the non-growing season (November–April) was close to normal in both years. Non-growing season average temperatures were much warmer than normal; 0.4 °C for 1999 and -0.4 °C for 2000, compared to −2.0 °C for the years 1971 to 2000.

3.2. SOIL NO_3^--N CONCENTRATIONS IN THE SOIL PROFILE

Soil NO_3^--N concentrations in 1999 and 2000 are presented in Figure 1. A summary of their statistical analysis is shown in Table III. In 1999, although soil NO_3^--N content was significantly ($P < 0.0001$) affected by treatments, the effect was most pronounced on the June 3 sampling date with the manure amendment, which

TABLE III

Summary of the analysis of variance statistical for soil samples in 1999 and 2000. Means comparison of interaction effects whose *P*-values are shown in boldface will be discussed in subsequent sections

Source of variations	*P*-values for 1999	*P*-values for 2000
Treatment	0.0001	0.7916
Depth	0.0001	**0.0001**
Treatment ∗ depth	0.5661	0.3754
Date	0.0001	0.6112
Treatment ∗ date	**0.0423**	0.3573
Date ∗ depth	**0.0002**	0.1847
Treatment ∗ date ∗ depth	0.2725	0.3426

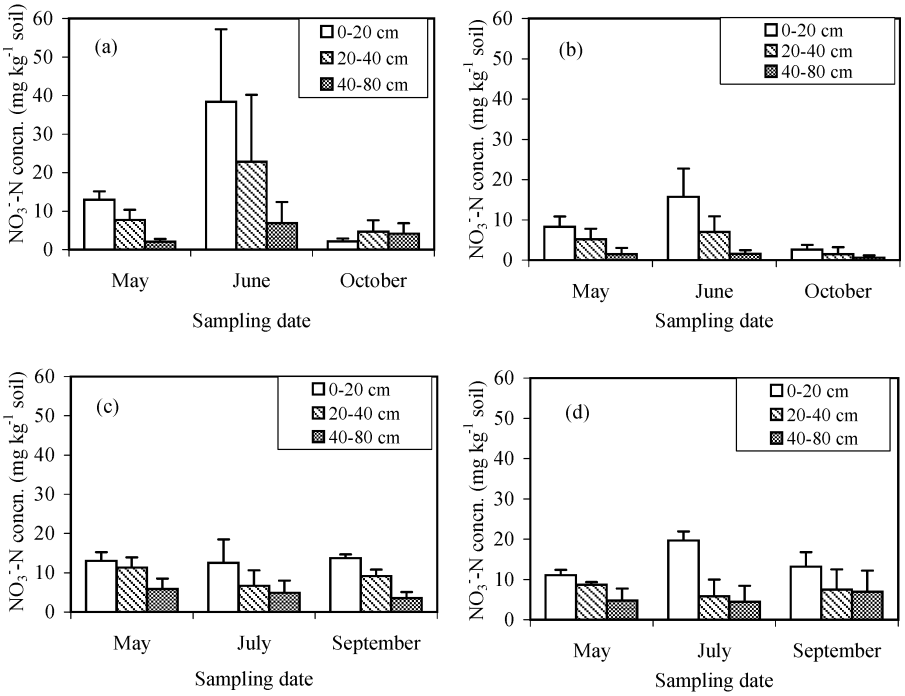

Figure 1. Average soil NO_3^--N concentrations (mg kg^{-1}) under (a) organic (liquid-hog manure), (b) inorganic fertilizer for 1999 and (c) liquid-hog manure and (d) inorganic fertilizer for 2000. Vertical bars represent standard error of the mean.

resulted in a slightly significant ($P < 0.0423$) date*treatment interaction (Table III). Soil NO_3^--N concentrations in June were significantly greater under LHM than the IF, with no significant difference ($P > 0.05$) between the two treatments in May and October 1999 (Table IV), which resulted in date ∗ treatment interaction (Table III).

TABLE IV

Mean NO_3^--N concentrations (mg kg^{-1} soil) of treatment $*$ sampling date interaction effects in 1999 growing season. Means preceded by the same upper-case letter (within rows), and means followed by the same lower-case letters (within columns) are not significantly different (Tukey–Kramer adj $P > 0.05$)

Sampling dates	Liquid-hog manure	Inorganic fertilizer
May	A 4.59 b	A 3.70 a
June	A 16.51 a	B 5.81 a
October	A 3.26 b	A 1.28 b

There was also a significant ($P < 0.0002$) date $*$ depth interaction, suggesting that soil NO_3^--N concentrations varied differently in the soil profile over time. In 1999, the NO_3^--N concentrations in the top soil layer (0–0.20 m) were greater than those in the other two depths under both fertility treatments (Figure 1a and b), except in October 1999 under LHM (Figure 1a). The average NO_3^--N concentrations in this month were all low when compared with the other sampling dates, and ranged from 1.17 to 9.4 mg kg^{-1}. In June, the concentrations of NO_3^--N under LHM treatment were the highest at the two uppermost soil depths (Figure 1a). With LHM and IF being applied on May 17, 1999, the high concentrations found in the soil samples on June 3 were expected.

In 2000, soil NO_3^--N concentrations were not affected by fertility, and sampling depth was the only factor found to be significant (Table III). The NO_3^--N concentrations from both treatments remained high after harvest, ranging from 8.30 to 13.04 mg kg^{-1} (Figure 1c and d). We suspect that the high residual soil NO_3^--N at the end of the growing season was related primarily to environmental conditions, rather than being a direct treatment effect. As shown in Table II, early parts of the 1999 growing season (May–July) were warmer than normal, which may have encouraged increased mineralization of manure-N. In addition, these same months (May–July) were dry. Dry conditions following fertilizer amendments may not have encouraged optimal plant uptake and other forms of N losses such as denitrification. Consequently, some manure-N applied in 1999 apparently carried over and accumulated in the soil profile. These findings suggest that greater quantities of NO_3^--N accumulate in the soil profile under dry conditions, increasing the risk of NO_3^--N pollution in subsequent seasons, regardless of treatments applied and management practice.

Our results, in general, show that the application of manure resulted in soil NO_3^--N levels similar to that of mineral fertilizer. There are two important implications for this observation: at modest application rates, it is possible to apply manure on a long-term basis without excessive soil NO_3^--N accumulation and, thereby, without subsequent danger of degrading groundwater and surface water quality. Secondly, the assumption of 50% manure-N availability in the first year of application was valid, or at least was not substantially in excess of plant needs. Previous studies have shown manure-N mineralization rate over the first growing season ranging from 30 to 70%. For example, Allison (1966) estimated that under optimal field conditions the mineralization of organic N is typically between 50 and 70%, and is often much lower. A study on fresh solid swine manures, Loecke *et al.* (2004) estimated one-third of the total N to be plant available in the first year after application, while Beauchamp (1998) indicated that incorporated hog manure can have up to 80% of the N available as fertilizer.

Similar to our results, Jokela (1992) showed that the quantity of soil NO_3^--N (to 1.5 m depth) in the fall following manure application was similar or less than that of inorganic fertilizer. Other studies (e.g., Miller and MacKenzie, 1978; Roth and Fox, 1990) however, have found higher levels of NO_3^--N in soil following harvest from plots receiving beef or hog manure, than from inorganic fertilizer. Roth and Fox (1990) found that residual soil NO_3^--N (to 1.2-m depth) at harvest for grain corn was greater in manured soils (135 kg ha^{-1}) than in non-manured soils (115 kg ha^{-1}).

We recognize that matching crop needs to manure-N availability is extremely difficult given the large number of influencing factors and the complexity of their interactions. These factors include weather, manure type and handling process, spatial and temporal variability of manure mineralization, and field history.

3.3. DRAINAGE OUTFLOW AND NO_3^--N CONCENTRATIONS IN DRAINAGE WATER

The total monthly drainage discharge, FWA of NO_3^--N concentrations, and NO_3^--N mass load during 1999 and 2000 are presented in Figures 2 and 3. On annual basis, drainage (mm) for 1999 was two times higher that in 2000 for both fertility treatments (Table V). This is due to the significant precipitation before planting (March) and at the end of the growing season (August and September), when crop uptake was either non-existent or minimal (Table III). Consequently, NO_3^--N losses were greatest from August ttrough December (Figure 2b and c). In contrast to these observations, Phillips *et al.* (1981) found similar NO_3^--N in tile drainage effluents from silage corn receiving 897 kg N ha^{-1} from liquid dairy manure than NO_3^--N from 134 kg N ha^{-1} applied as inorganic fertilizer. Kimball *et al.* (1972) however, reported greater leaching of NO_3^--N from IF than from LHM. Over a 6-year period with two levels (0 and 224 kg N ha^{-1}) of N rates, they observed more NO_3^--N was lost by leaching from ammonium nitrate (34-0-0) compared with dairy manure. In general, the immediate availability of N in manure to crops is lower compared to inorganic fertilizer because of the slow release of organically bound N (Jokela, 1992). This would allow more time for mineralization and denitrification from a manure source. As well, the timing of precipitation events following fertilizer application could result in large amounts of inorganic fertilizer being leached from the soil.

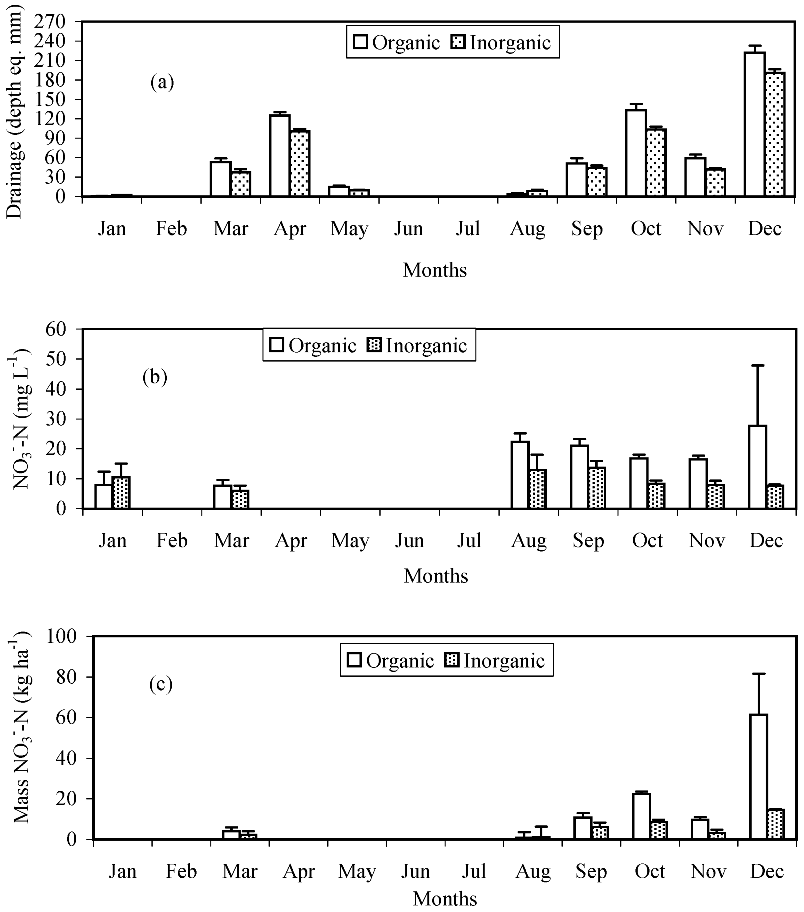

Figure 2. Average monthly (a) drainage outflow (mm), (b) NO_3^--N concentrations (mg L^{-1}) and (c) NO_3^--N mass loss (kg ha^{-1}) during 1999.

In 2000, the amount and timing of precipitation were less variable (Table II). Large quantities of drainage were recorded only in March and April, with little measured thereafter (Figure 3a). This has resulted in high NO_3^--N concentrations but negligible mass loadings (Figure 3b and c). Concentrations of NO_3^--N in the drainage water were at their highest in July (Figure 3b).

The amount of NO_3^--N lost through the drainage system is greatly influenced by drainage outflow volume and the soil NO_3^--N concentrations (Randall *et al.*, 2003). It was important in this study to determine if annual subsurface flow was related to the treatments. Based on annual averages, manure had a significant effect on subsurface drain flow and FWA of NO_3^--N concentrations in 1999, but not 2000 (Table V). This is consistent with soil NO_3^--N observations where there was no treatment effect in 2000 (Table III). As noted earlier, manure amendment improves

TABLE V

Total drainage (m^3), FWA NO_3^--N concentrations (mg L^{-1}), NO_3^--N loads (kg ha^{-1}), for the liquid-hog manure and inorganic fertility treatments. Barley and carrot crops were grown in 1999 and 2000, respectively

	1999			2000		
Treatments	Drainage flow (m^3)	NO_3^--N (mg L^{-1})	NO_3^--N (kg ha^{-1})	Drainage flow (m^3)	NO_3^--N (mg L^{-1})	NO_3^--N (kg ha^{-1})
Liquid-hog manure	191.0 a (22)*	15.4 a (1.11)	16.6 a (1.06)	93.0 (13)	10.5 (0.7)	5.8 (1.2)
Inorganic fertilizer	156.0 b (7)	8.9 b (0.22)	8.0 b (0.18)	76.0 (8)	6.01 (0.34)	2.61 (0.24)

*Different letters within columns indicate significant ($P < 0.05$) differences. Values in parentheses represent standard error of the mean.

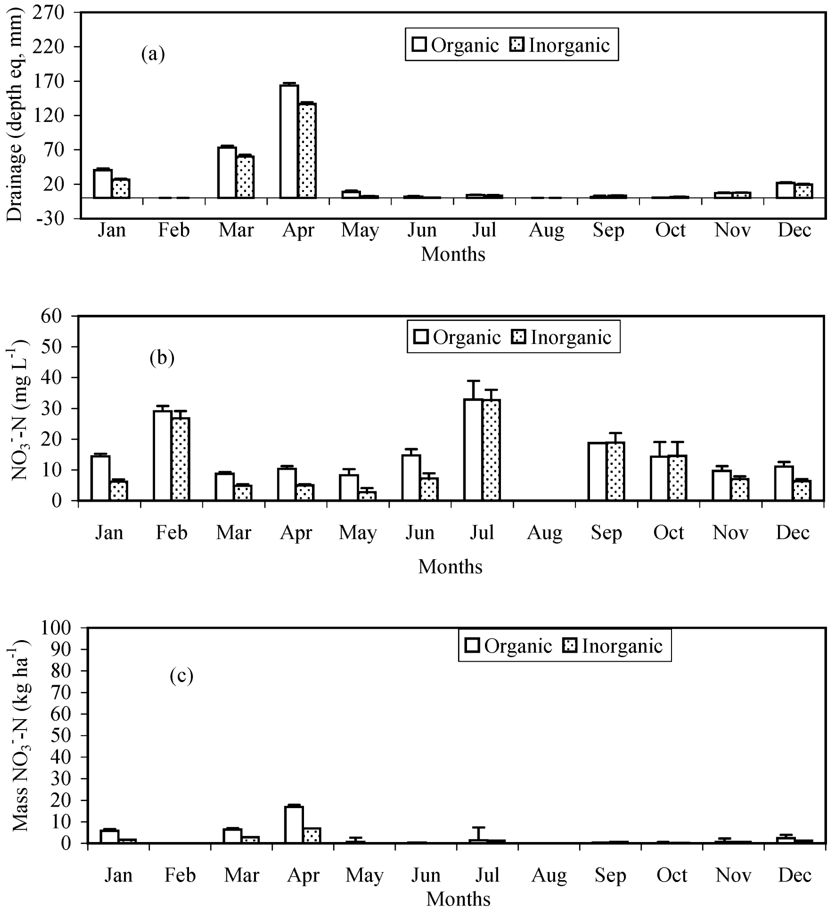

Figure 3. Average monthly (a) drainage outflow (mm), (b) NO_3^--N concentrations (mg L^{-1}) and (c) NO_3^--N mass loss (kg ha^{-1}) during 2000.

physical, chemical and biological properties of soils. Therefore, it is possible that water losses through surface runoff might have been reduced under manured plots, resulting in greater water percolation through the soil profile and, consequently, greater drainage effluents.

The annual FWA of NO_3^--N concentrations and NO_3^--N mass loads were greater for both the LHM and IF treatments in 2000 than in 1999. In 1999, NO_3^--N annual loads ranged from 2.61 to 16.61 kg ha^{-1}, with the load being greater for the LHM. In 2000, the NO_3^--N loss was negligible (Figure 3c). Milburn and Richards (1994) found an annual NO_3^--N loss of 30 kg ha^{-1} and an annual FWA of 5 mg L^{-1} following an application as high as 90 kg ha^{-1} of N from a combination of manure and fertilizer on a corn crop. In a previous study from this site, Gordon *et al.* (2005) found that the average NO_3^--N load was 16.9 kg ha^{-1} and 15.7 kg ha^{-1} for hog manure and inorganic treatments, respectively. These losses are greater than we observed in 1999 and 2000. The differences between the two years of study is presumably a result of differing climatic conditions and cropping systems. It is likely that wetter conditions during 1999 and 2000 growing seasons, May–October (509.8 mm and 517.3 mm, respectively) than during 1997 and 1998 growing seasons (320.6 mm and 333.7 mm, respectively) might have promoted other N pathways losses such as denitrification. These differing findings emphasize the need to quantify all major N pathways simultaneously. Such an approach is important because the different pathways of N losses to the environment are inter-dependent.

It is important to identify when the NO_3^--N concentrations in drainage effluents are likely to reach maximum levels to ensure that management strategies are implemented to lower the risks associated with high NO_3^--N levels. Descriptive statistical results indicated that NO_3^--N concentrations were >10 mg L^{-1} in 16 and 8% of the samples collected from IF treatment and 65 and 56% for the LHM treatment during 1999 and 2000, respectively. While the frequency of samples exceeding 10 mg L^{-1} was less in IF treatment, it is worth noting that during the experiment the IF treatment did result in NO_3^--N concentrations up to 36 mg L^{-1}. It must be noted however, that although water quality concerns are often expressed in terms of drinking water quality guidelines of 10 mg NO_3^--N L^{-1}, water quality deterioration caused by eutrophication may occur at considerably lower of NO_3^--N concentrations than drinking water standards (Burkholder *et al.*, 1992).

3.4. CROP YIELD

Barley yield did not differ significantly ($P > 0.1$) between the LHM (6.20 t ha^{-1}) and IF (5.43 t ha^{-1}) treatments. These yields are slightly higher compared to typical barley yields of 3.70 to 4.94 t ha^{-1} for the area. Likewise, no significant difference ($P > 0.9$) was found in carrot yields in 2000 (21.96 t ha^{-1} for the LHM and 22.13 t ha^{-1} for the IF). In contrast to these findings, Lorimor *et al.* (1998) found that manured plots out yielded commercially fertilized plots in a 2-year corn study. In an earlier experiment at this site, Gordon *et al.* (2005) reported similar yields for carrots (16.9 t ha^{-1} for organic and 17.5 t ha^{-1} for inorganic, and 19.1 t ha^{-1} for organic and 20.7 t ha^{-1} for inorganic treatments in 1997 and 1998, respectively). The slight increase in both barley and carrot yields may be a suggestion that plant uptake from the hog manure plots was higher compared to the inorganic plots. If this is correct, it is likely to be due to manure-N becoming available at the later stages of crop growth through mineralization.

4. Conclusions

There is a growing need to develop nutrient management strategies that minimize negative environmental impacts while also ensuring sustainable crop production. This study reports on the impacts of the manure and mineral fertilizer applications on leachate water quality, soil-profile N concentrations and crop yields. During the two seasons in which this experiment was conducted, greater NO_3^--N concentrations in the soil profile and in drainage water were observed with manure in 1999, but not in 2000. From agronomic point of view, we conclude that producers can substitute manure for commercial fertilizers without yield reductions.

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