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Effects of liquid hog manure on soil available nitrogen status, nitrogen leaching losses and wheat yield on a sandy loam soil of Western Canada

1 CEU IN SOIL AND WATER MANAGEMENT

In many agricultural production systems, nitrogen (N) is often the most common limiting nutrient for crop growth and inputs of N from external sources are frequently used to meet crop N requirement and maintain optimum yields. While a number of N fertilizer sources are available (e.g. chemical, manure, compost), synthetic fertilizer N remains the most widely used for crop production in conventional agriculture. Farmers have used manure and fertilizers for many years to promote soil health and enhance crop yields. However, increasing concerns over environmental sustainability and rising synthetic fertilizer costs are leading both researchers and producers to consider increasing the use of organic N fertilizers (e.g. green manure, compost, industrial organic residues) over synthetic N fertilizers and developing management strategies (e.g. right amount, improved timing and placement) to improve farm sustainability while at the same time achieving profitability.

The use of organic residues (including manure) has been extensively studied under many environmental conditions and agronomic cropping systems to evaluate their effectiveness for enhancing crop production and reducing agricultural N losses to groundwater and the atmosphere (Kramer et al. 2006). Efficient use of manure may reduce nitrate (NO_3^-) leaching losses and costs associated with the use of N fertilizers (Van Wieringen et al. 2005; Kramer et al. 2006). When applied at equivalent total N rate, manure generally provides greater crop yields than synthetic N fertilizers due to the presence of additional nutrients and organic matter in the manure (Mooleki et al. 2002; Buckley et al. 2011).

It is estimated that Canadian farms produce between 12 and 15 million hogs annually, 40% of which comes from the western part of the country (Statistics Canada 2011). Manitoba represents Canada's third largest hog-producing province with a yearly production of about two-and-a-half million hogs. Larson (1991) estimates that a hog can produce as much as two tonnes of manure each year, suggesting that about five million tonnes of manure may be available on a yearly basis from the hog population of Manitoba. According to Manitoba Conservation (2006), pig manure is applied to approximately 120,000 ha, corresponding to 2.5% of the crop land area in Manitoba. Based on the quantity of nutrients present in pig manure and the land area used for liquid manure application in Manitoba, it is estimated that about 120 kg N ha^{-1} is added to manured land annually.

Whereas numerous studies have been conducted on the effect of application of cattle and poultry manure on crop lands, only few studies

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have attempted the integrated measurements of the impact of rates of LHM (liquid hog manure) on crop performance and N uptake (N_{up}), soil nutrient composition and groundwater quality. There is little knowledge regarding the efficient management of LHM on the Canadian Prairies, particularly on the permeable sandy soils over a sensitive unconfined aquifer such as the Assiniboine Delta Aquifer.

This study was designed with the following objectives: 1) to assess the effects of land application of LHM on wheat yield and biomass production on a coarse sandy soil; 2) to evaluate the effect of liquid hog manure on plant tissue N and soil available N status; and 3) to quantify N leaching losses associated with increasing amount of hog manure application rate. Such knowledge is needed in order to design liquid hog manure-N management practices that optimize crop yield while minimizing losses and associated environmental problems.

MATERIALS AND METHODS

FIELD DESIGN AND CULTURAL PRACTICES

The experiment was conducted during three consecutive years (2002, 2003 and 2004) in a farmer-cooperator field, located about 10 km northwest of Carberry, in the rural Municipality of North Cypress in southwestern Manitoba, Canada (49° 53' 59" N, 99° 20' 59" W and 383.5 a.s.l.). The region has a sub-humid prairie climate, characterized by an average annual precipitation of 456 mm, approximately 70% of which falls as rain during the period of April throughout October and the remaining 30% as snow during the winter months. The soil type is moderately well-drained Fairland loamy fine sand (Orthic Black Chernozem, Ehrlich et al. 1957). Three consecutive years prior to the start of this experiment the site was cropped to buckwheat (*Fagopyrum esculentum*), barley and canola in rotation.

The field experiment was set up as a randomized complete block design with four blocks in a relatively flat field in an area measuring 65 m × 55 m (0.36 ha) in size. Blocks were separated by 5 m buffer zones. Six agronomic treatments were used for this experiment for a total of 24 experimental plots, each of which measured 100 m^2 (10 m × 10 m) in size. Three liquid hog manure (LHM) nitrogen treatments (N rates) were applied to supply approximately 64, 128 and 192 kg N ha-1 of total nitrogen and designated as LHM_{64} (low), LHM_{128} (medium) and LHM_{192} (high), respectively.

Prior to seeding, plots were tilled (15 May 2002, 17 May 2003 and 6 May 2004) to about 10-cm soil depth and LHM was applied at the low, intermediate and high rates to the treatment plots, once a year, using an Aerway manure application system. The applicator was attached to a 3800 L tanker equipped with a positive displacement pump and a bypass to continually mix the manure. The pump was calibrated to deliver 64 kg ha^{-1} of manure N in a single pass. Therefore, LHM_{64}, LHM_{128} and LHM_{19}2 plots received one, two and three passes of the manure applicator, respectively. Plots were seeded with hard red spring wheat (*Triticum aestivum* L. 'AC Barrie') on 28 May in 2002, 20 May in 2003 and 28 May in 2004 at a seeding rate of 120 kg ha-1. Plots received in-crop weed control using MCPA, mecoprop, and dicamba (TargetTM) tank mixed with clodinafop-propargyl (HorizonTM) plus an adjuvant (ScoreTM) at 275 g a.i. ha^{-1}, 62.5 g a.i. ha^{-1}, 62.5 g a.i. ha^{-1}, 55 g a.i. ha^{-1} and 1 L ha^{-1}, respectively (recommended rate).

LYSIMETER DESIGN AND INSTALLATION

One undisturbed soil core lysimeter made up of schedule 80 PVC pipe (3.3 cm-thick, 54.2 cm-internal diameter and 106.7 cm-deep) was installed within each plot in the spring of 2002 to collect soil water leachate Each undisturbed soil core lysimeter was installed in the middle section of each plot, 2 m inside the south border using a drop hammer (7.6 x 7.6 x 2.5 cm piece of steel) mounted on a trailer with a collapsible tower attached onto the rear deck and a large winch on the front of the deck.

DATA COLLECTION AND ANALYSIS

Baseline soil samples were collected on 30 April, 2002 prior to the initiation of the experiment. The baseline soil sampling was performed on one-half of the field plots (three within each block). Following lysimeter installation in 2002, soil samples were taken four times on 25 June, 23 July, 23 September and 25 October. The selected soil sampling periods were, one in the spring (post-seeding), one in the summer (mid-season) and one in the fall (post-harvest).

All soil samplings were performed by randomly taking two soil cores within the plot, at the soil depth intervals of 0-10, 10-20, 20-30, 30-60, 60-90, 90-120 cm. The extracts were analyzed colorimetrically (Maynard and Kalra, 1993) using a Technicon auto-analyzer II (Pulse Instrumentation Ltd, Saskatoon, Sask. Canada).

Leachate collection from the lysimeters was initiated approximately a month after lysimeter installation. Thereafter, timing of sampling was determined based on rainfall events. Wheat was harvested manually at maturity each year (6 September 2002, 19 August 2003 and 18 September 2004) from four randomly placed quadrants (1 m^2) in each plot to determine grain yield and straw biomass.

RESULTS AND DISCUSSION

WHEAT GRAIN YIELD AND STRAW BIOMASS

Grain yield of wheat was measurably affected by both treatment and year (Table 1). The effect of the interaction between treatment and year was statistically significant due to the differences in grain yield among treatments which occurred in 2004 (data not shown) but not in 2002 and 2003. In both 2002 and 2003, grain yield ranged between 1.1 (un-amended plots) and 1.3 Mg ha^{-1} (high manure-N plots) and was indistinguishable among LHM treatments (data not shown). In contrast, 2004 grain yield ranged from 2.5 (un-amended plots) to 3.9 Mg ha^{-1} (high manure N rate). Indeed, grain yield was 22, 32 and 52% greater in plots that received the low, medium and high manure-N rates, respectively, relative to the un-amended plots. The yield range observed in years 2002 and 2003 was smaller than what had been reported (2.6 Mg ha^{-1})

TABLE I

Effects of year and rate and their interaction on yield (Mg ha^{-1}), N content (%), N uptake (Mg N ha^{-1}), N use efficiency (%) and cumulative N use efficiency (%) of wheat

Effect	Yield		N content		N uptake			NUE[a]	CNUE[b]
	Grain	Straw	Grain	Straw	Grain	Straw	Plant		
P level									
Year	<0.0001	<0.0001	0.122	0.684	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Rate	0.014	0.010	0.044	0.093	0.001	0.005	<0.0001	0.385	0.001
Year*Rate	0.027	0.028	0.865	0.356	0.004	0.067	0.001	0.600	0.050

[a] *Nitrogen Use Efficiency;* [b] *Cumulative Nitrogen Use Efficiency*

in the region for spring wheat grown under normal N fertilization level (72.5 kg ha^{-1}) and adequate soil moisture conditions (Gauer et al. 1992; Carew et al. 2009).

Like many agronomic crops, precipitation during the growing season is expected to have an impact on wheat yield (Hussain and Mudasser 2007; Hurd 1994). Compared to the long-term average precipitation, years 2002 and 2003 coincided with drier growing seasons (i.e. 23 and 17% less rainfall, respectively; (data not shown), which likely explains the poor performance of the crop in all treatment plots. The better performance of wheat in 2004 than in the previous two years was likely due to more favorable rainfall in 2004, which was 16% greater than the long-term average (data not shown). Increased precipitation and enhanced soil moisture supply have been found to increase wheat yield in Western Canada (Gauer et al. 1992; Smith et al 2003, Mohr et al. 2007; Carew et al. 2009). The observed grain yield increase with increasing manure-N rate obtained in 2004 was expected as wheat has been widely shown to respond positively to higher soil N availability (Gauer et al. 1992; Raun and Johnson, 1999; Karamanos et al., 2003; Carew et al. 2009).

Similar to grain yield, wheat straw yield was significantly affected by year, rate and their interaction (Table 1). The rate × year interaction was due to significant differences in straw yield among treatments in year 2004 but not in years 2002 and 2003 (data not shown). Straw yield was the highest (5.1 kg ha^{-1}) at the high manure N rate. Application of the intermediate manure N rate also resulted in similar straw yield as the high manure N rate followed by the low rate and the un-amended treatment plots. The yield advantage observed in the manure amended plots over the un-amended treatment may be due to the addition to the soil of the inorganic N and other plant essential nutrients (e.g. Ca, P, K, Mg, Na, and S) contained in the manure in these plots (data not shown). The disparity in straw yield among the years (2002, 2003 and 2004) was likely due to the differences in precipitation of these years (data not shown). Vasconcelos et al (1997), who evaluated the effect of increasing applications of hog manure on soil nutrient status, nitrate leaching and wheat growth, reported a comparable benefit in wheat dry matter production and attributed that to enhanced soil moisture and available N.

PLANT N UPTAKE

The main effects of year and N rate were significant for N_{up} of both grain and straw of wheat. There was a significant year × treatment interaction for grain N_{up} whereas the interaction effect of these two factors was not significant for straw N_{up} (Table 1). Similar to grain and straw yields, year × treatment interaction for grain N_{up} was due to the difference in N_{up} between treatments, which occurred in 2004 but not in 2002 and 2003. Application of LHM at high rate resulted in significantly greater N_{up} of wheat grain than the low N rate as well as the un-amended control treatment plots in 2004. The intermediate N rate also significantly increased grain N_{up} relative to the control. Overall, total N_{up} of wheat crop was significantly (P<0.0001) affected by treatment main effects; with the plant N_{up} substantially increasing with increasing amount of applied LHM. Likewise, the main effect of year was significant (P<0.0001) and there was also a significant year × rate interaction effect (P=0.001, respectively; Table 1). The year × rate interaction was due to the fact that in 2002 and 2003, the crop N_{up} was unaffected by manure application.

Nitrogen Use Efficient (NUE) of the crop significantly differed (P<0.0001) among year, but the main effect of N rate and year × rate interaction were not significant (P>0.05).

SOIL AVAILABLE N

There were significant year × season × rate × depth interactions (P<0.0001) for both soil NO_3^--N and total available N whereas the 4-way interaction was not significant for soil NH_4+-N (Table 2). In all three experimental years, the application of LHM significantly increased soil NO_3^--N concentration in the spring, particularly in the top 30 cm of the soil profile, relative to the control (Figs. 1A1, 1B1 and 1C1). Following treatment application, NO_3^--N concentration was significantly increased relative to the un-amended plots (4 - 5 mg N kg-1) near the soil surface (0-10 cm) at the low (20 - 25 mg N kg^{-1}), intermediate (30 - 48 mg N kg^{-1}) and high (50-68.5 mg N kg^{-1}) manure N rates. The NO_3^--N concentrations of the un-amended plots remained close to the initial (baseline) soil NO_3^--N levels (data not shown). Below the 30 cm depth, NO_3^--N concentrations were indistinguishable between the manure N amended plots and the control treatment. By mid-season and fall 2002 (Figs. 1A2 and 1A3), crop uptake and most likely downward movement decreased NO_3^--N

TABLE 2

Effects of year, season, rate, depth and their interactions on soil NO_3^--N (mg N kg^{-1}), NH4+-N (mg N kg^{-1}) and total available N (mg N kg^{-1})

Effect	NO_3^--N	NH_4+-N	Total available N_a
P level			
Year	0.3295	<0.0001	<0.0001
Season	0.2681	<0.0001	<0.0001
Year × Season	0.0163	<0.0001	<0.0001
Rate	<0.0001	0.2670	<0.0001
Year × Rate	<0.0001	0.0035	<0.0001
Season × Rate	0.1942	0.2746	0.1553
Year × Season × Rate	<0.0001	0.0048	<0.001
Depth	<0.0001	0.0021	<0.0001
Year × Depth	<0.0001	<0.0001	<0.0001
Season × Depth	<0.0001	<0.0001	<0.0001
Year × Season × Depth	<0.0001	<0.0001	<0.0001
Year × Season × Depth	0.8165	0.0037	0.1163
Year × Rate × Depth	<0.0001	0.0130	0.0024
Season × Rate × Depth	0.0151	0.5413	0.0107
Year × Season × Rate × Depth	<0.0001	0.7826	<0.0001

[a] *Total available N, sum of soil NO_3^--N, NH_4+-N concentrations.*

level within the top 0-30 cm of the soil profile. Below 30 cm soil depth, NO_3^--N concentration increased relative to the spring season levels in the intermediate and high manure N rate plots, suggesting downward movement of NO_3^--N.

NITROGEN LEACHING LOADS

As reported by Bakhsh et al. (2005), excessive application of manure in general, and hog manure in particular, may result in significant leaching of NO_3^-. In addition to the amount of applied N, other factors such as soil type and crop species as well as amount of precipitation may also influence leaching losses of NO_3^-. In this study, no leachate and trace of leachate was collected from the lysimeters in 2002 and 2003, respectively, due to below normal precipitation in these years. In 2004 when precipitation was above normal, percolated water (leachate) was obtained from almost all lysimeters and water (data not shown).

In 2004, there was a significant (P<0.0001) main effect of season for leached water (data not shown). However, the main effect of treatment and season × treatment interaction effect were not significant (P = 0.988 and 0.999, respectively). The amount of water collected from the lysimeters was indistinguishable between treatments in spring, summer and fall (Fig. 2A).

CONCLUSION

This study examined soil available N status, N leaching losses, and wheat yield, N uptake as well as N use efficiency on a sandy soil as affected by four rates of N amendment applied as LHM. Manure treatment had little effect on crop performance and N leaching in both 2002 and 2003 likely due to below normal precipitation. In contrast, in 2004 under conditions of above normal precipitation, LHM increased grain yield and N uptake by about 40% when N rates were increased to 196 kg ha^{-1}. Increasing the rate of manure N application increased soil NO_3^--N concentration and residual N as expected, with the highest increase recorded in the high manure N rate plots. In 2002 and 2003 when precipitation was below normal, no N leaching (or only trace of leachate) was recorded from the treatment plots. In 2004 when precipitation was above normal, N losses due to leaching were high in all treatments plots; however, N leaching was much greater in the spring and when manure N rate exceeded the intermediate manure N rate. The over-application of liquid hog manure may not be recommended on coarse soils due to elevated risk of nutrient loss (mainly nitrate) and subsequent contamination of groundwater. Above the intermediate rate, one should consider perennial crops and slow release fertilizers or compost to build nutrient retention capacity of these soils, especially when important aquifers are at risk of nutrient contamination.

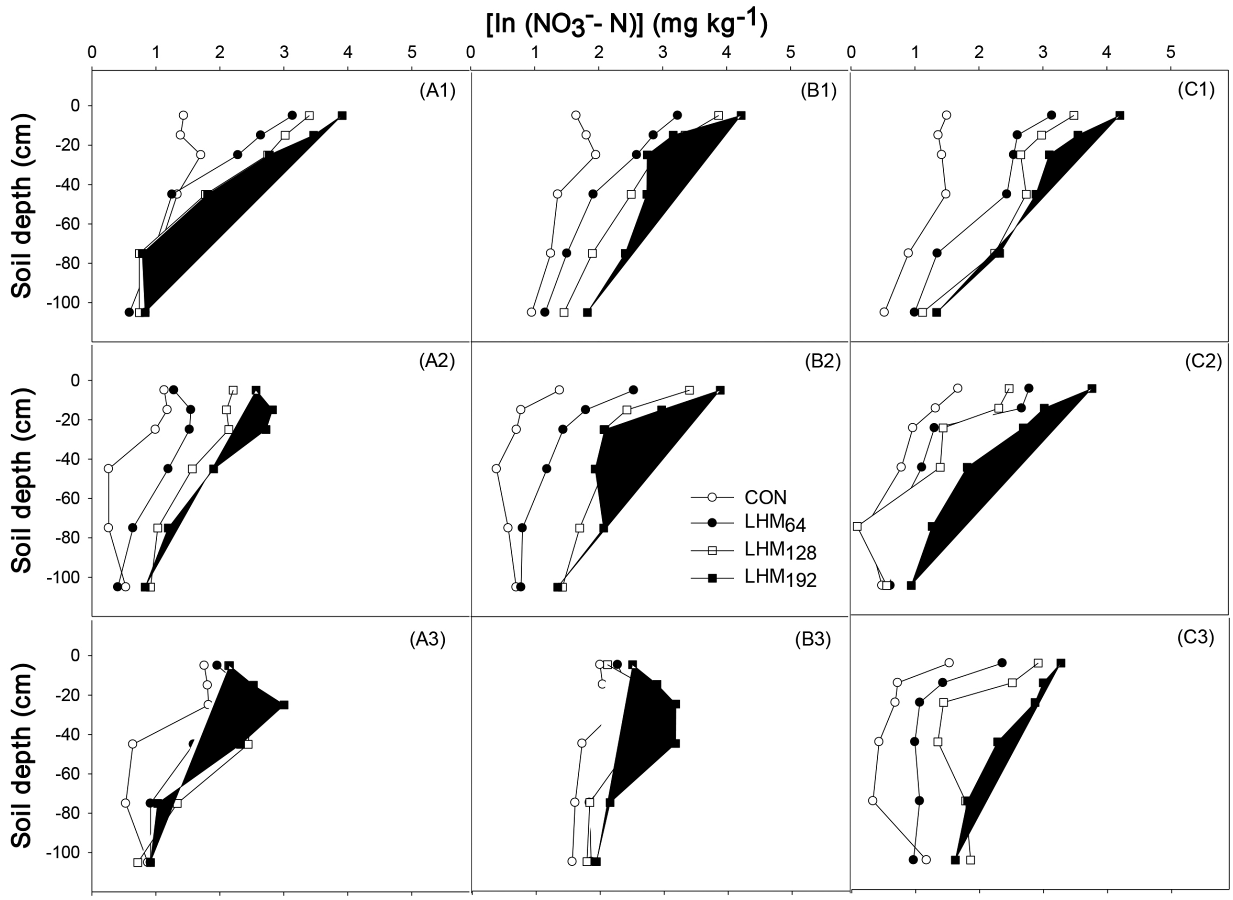

FIGURE 1. (ABOVE)

Soil nitrate concentrations measured at six (0-10, 10-20, 20-30, 30-60, 60-90 and 90-120 cm) soil depths as affected by manure N rates at Carberry, Manitoba, Canada. Nitrate concentrations are given for spring (post-seeding), mid-summer and fall (post-harvest) for 2002 (A1, A2, and A3, respectively), 2003 (B1, B2, and B3, respectively) and 2004 (C1, C2, and C3, respectively). CON, LHM_{64}, LHM_{128} and LHM_{192} are un-amended plots and liquid hog manure application rates of 64, 128 and 192 kg N ha^{-1}, respectively.

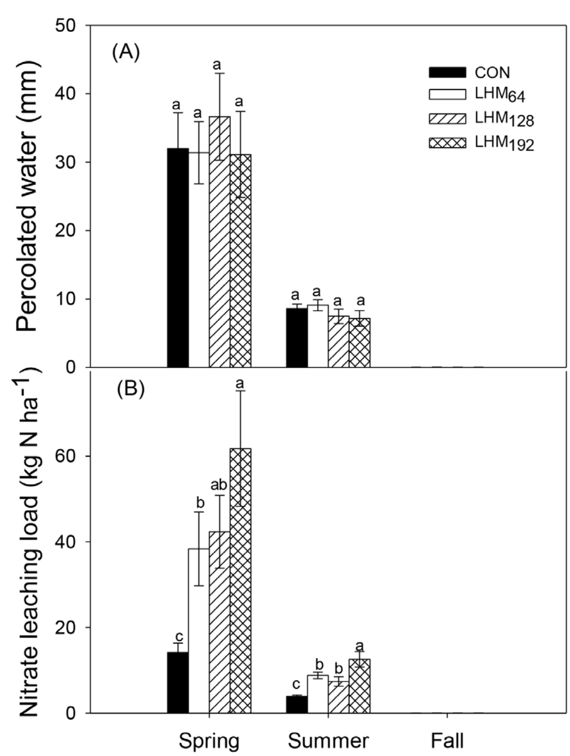

FIGURE 2. (RIGHT)

(A) Quantity of leached rain water and (B) leached nitrate below the root system (120 cm) during the growing season of 2004 as affected by different rates of N from liquid hog manure application at Carberry, Manitoba, Canada. CON, LHM_{64}, LHM_{128} and LHM_{192} are un-amended plots and liquid hog manure application rates of 64, 128 and 192 kg N ha^{-1}, respectively.