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Residual Effects of Sewage Sludge Applied to a Clay Soil on Soil Nitrate Distribution with Three Different Field Management Practices

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Agricultural application of sewage sludge is becoming popular as a means of nutrient recycling in many areas of the world (Jacobs, 1981). Guidelines on application of sewage sludge should take account of many factors, such as sludge type, time, and method of application (Shepherd, 1996). Because of a growing need to apply municipal sewage sludge on agricultural lands, there is a developing urgency to have criteria for disposal practices that will preserve the productivity of these lands and prevent entry of potentially toxic elements (Chaney et al., 1987). Agricultural management has a large impact on nitrate leaching and the use of various catch crops reduce nitrate leaching (Finke, 1993; Higgins, 1984;). Nitrate leaching from agricultural soils has been focused mainly on sandy soils because clay soils are usually not considered to have a high nitrate leaching potential (Stout et al., 2000; Verdegem and Baert, 1984). The objective of this study, therefore, was to investigate the residual effect of sewage sludge three years after application of high amounts of sewage sludge on the soil nitrate distributions as affected by field management practices whether such an application to a clay soil would have any impact on the possible soil and groundwater contamination due to nitrate originating from the sewage sludge.

MATERIALS AND METHODS

The experiment site was located at the City of Winnipeg's sewage sludge experimental farm, Oak Hammock Marsh (latitude 50° 7', longitude 97°0'), Manitoba, Canada. The soil at the research site is a dominant soil type in Manitoba, and classified as Lakeland series, a Gleyed Rego Black Chernozem by Canadian System of Soil Classification and as Vertisols by US Soil Taxonomy (Brierley et al., 1996). This soil is developed on moderately to extremely calcareous, dominantly fine sediments and is imperfectly drained, resulting in a high water table (< 3 m) (Land Resource Unit, 1998). The soil at the experiment site was a calcareous clay soil, with the top soil (0 - 20 cm) containing 19% sand, 34% silt, and 47% clay. The pH of soil was 8.2 and the contents of Organic C, Total-N, NH_4-N, and NO_3-N were 35.6 g kg^{-1}, 3.8 g kg^{-1}, 2.0 mg kg^{-1}, and 8.0 mg kg^{-1}, respectively. The sewage sludge was obtained from the City of Winnipeg's North End Water Pollution Center. The sewage sludge was anaerobically digested sludge from the mechanical dewatering facility. The pH of sludge was 6.8 and the contents of Organic C, Total-N, NH_4-N, and NO_3-N were 230 g kg^{-1}, 32.1 g kg^{-1}, 7060 mg kg^{-1}, and 10.0 mg kg^{-1}, respectively.

Experiment site was treated with sewage sludge in May 1995. The rates of sewage sludge treatments were 10, 25, and 50 Mg ha^{-1} (dry weight basis), which corresponded to 321, 803, and 1605 kg N ha^{-1} as total Kjeldahl N, and these application rates were about 4 - 20 times higher than 60 - 100 kg N ha^{-1} of the general N demand for wheat. There were three different field management practices treatments imposed on the sewage sludge amended soils. The first management treatment (Fallow treatment) was to leave the treated site fallow for the first year after sewage sludge application and then to grow spring wheat (Triticum aestivum L. cv. Katepwa) annually from the 2nd year on, to see the behaviour of NO_3-N derived from the decomposition of the sludge. The second management treatment (Wheat treatment) was to crop wheat annually to observe the residual effect of the sludge as an N source on the 3rd year after application. The third management treatment (Wheat plus N fertilizer treatment) was to add 70 kg N per hectare of commercial fertilizer as urea in addition to the sludge application to determine the effectiveness of the sludge with added commercial fertilizer. The cropping systems and application of additional urea to the third management treatment were identical to that of previous years. All plots were given a basal application of 40 kg P_2O_5 per hectare each year. There were three replicates of each treatment plus control (no sludge) with randomized complete block design. The plot size was 1.8 m x 3.6 m.

In 1997, the 3rd year after the application of sewage sludge, soil samples were taken to depths of 120 cm. Spring and fall soil samples were taken on May 19 and November 3. Soil samples were taken from five randomly selected locations in each plot and composited into one sample and were stored in a cooler and brought to the laboratory for analysis. Soil samples were extracted with 2 M KCl at a soil:solution ratio of 1:5 (Bremner, 1965) and the filtered extracts were analyzed for NO_3-N by a colorimetric method using a flow injection system FIAstar 5020 Analyzer (FOSS TECATOR, Sweden) (Smith and Scott, 1991). Moisture content was determined by the gravimetric method and the results were tabulated based on an air-dry soil basis. The experiment data were analyzed using Generalized Linear Models procedures (SAS Institute, 1989).

RESULTS AND DISCUSSION

The concentration distributions of NO_3-N in soil profiles in the spring of 1997 under three different field management practices treatments (fallow, wheat, and wheat plus N fertilizer) with various rates of sewage sludge application are presented in Figure 1. The distribution of NO_3-N in the fallow treatment showed the control, which received no sewage sludge, had about 20 mg NO_3-N kg^{-1} at the surface and that the concentration decreased almost linearly with depth. The concentration was nearly zero at 120 cm depth. With the application of sewage sludge, the NO_3-N content in the surface increased somewhat over the control treatment, indicating that the residual effect of sewage sludge applied in 1995 was still evident at the surface. The NO_3-N content increased with depth on all sewage sludge treated soil and showed the maximum content at around 50 cm depth. The maximum concentration of NO_3-N was related to the amount of sewage sludge applied, though not directly proportional. The soil in the fallow treatment was sampled to a depth of 300 cm and NO_3-N was measured (Table 1). Table 1 showed that the concentration of NO_3-N in the deep depth was less than 1 mg kg^{-1}.

Table 1. Contents and amounts of nitrate-N in the soil profile (0 – 300 cm) for fallow treatment in the spring, 1997.

Depth (cm)	Rate of sludge applied (Mg ha^{-1}) 0	10	25	50
	------------ mg kg^{-1} ------------			
120 - 150	ND[a]	0.8	0.8	0.4
150 - 180	ND	0.3	0.9	0.3
180 - 210	ND	0.3	0.9	0.2
210 - 240	ND	0.3	0.7	0.4
240 - 270	ND	0.3	0.4	0.2
270 - 300	ND	0.2	0.8	0.4
	Total amounts (kg N ha^{-1})			
0 - 120	171	453	489	664
120 - 300	0	9	21	10

[a]ND denotes not detectable.

Growing wheat for the last 2 years (as opposed to 1 year of wheat for fallow treatment) prior to the soil sampling in 1997 modified the distribution patterns of NO_3-N. Generally more NO_3-N is confined to the surface zone as compared to the fallow treatment. When 50 Mg ha^{-1} of sewage sludge was applied the position of maximum concentration of NO_3-N was found at around 50 cm depth. The pattern of distribution of NO_3-N of the 50 Mg ha^{-1} with the wheat treatment was similar to that of fallow treatment with 50 Mg ha^{-1} with the exception that the 2 years of wheat growth had lowered the concentration of NO_3-N in the soil profile. The application of 70 kg ha^{-1} N as urea in addition to the application of sewage sludge for the wheat treatment has modified the NO_3-N distribution in the soil profile. The patterns of NO_3-N distribution were similar to those without additional urea when the rates of sewage sludge application were less than 50 Mg ha^{-1}. When 50 Mg ha^{-1} of sewage sludge was applied, there was more NO_3-N in the soil profile and the additional 70 kg ha^{-1} of N has definitely increased the residual NO_3-N in the soil profile especially at the upper zone of the soil profile.

The concentration distributions of NO_3-N in soil profiles in the fall of 1997 are shown in Figure 2. The NO_3-N contents were more or less uniformly distributed

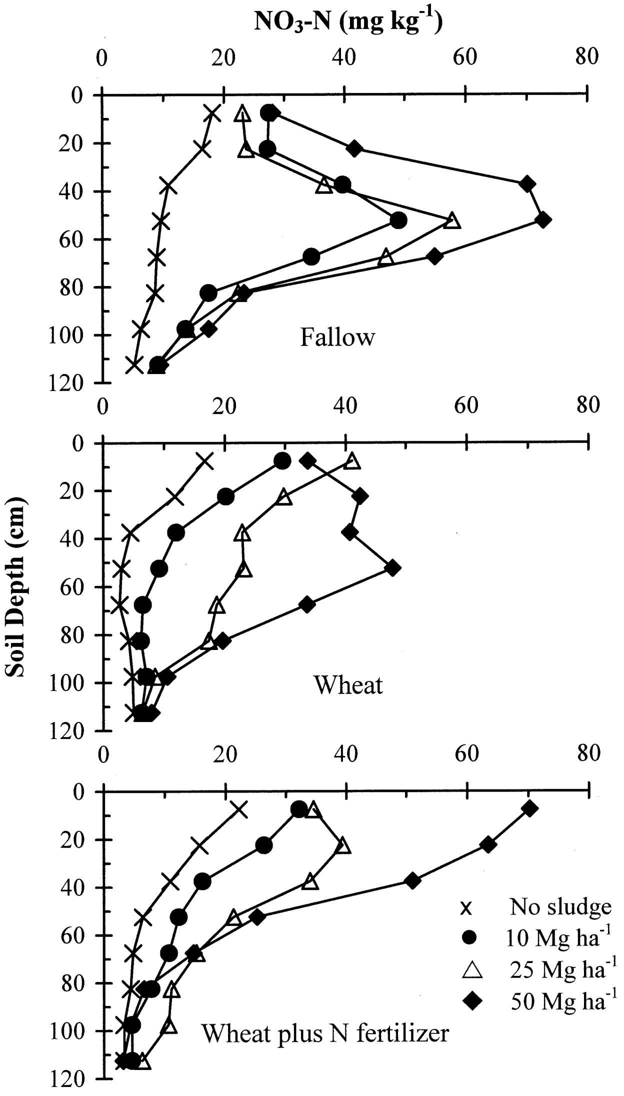

Figure 1. Nitrate-N distribution in the soil profile in the spring of 1997 as affected by different field management practices anc various amount of sewage sludge application in 1995.
Each point is the mean of three replicates.

throughout the soil profile up to 100 cm irrespectively of the field management practices. On the whole, the concentration of NO_3-N in the soil profile was related to the amount of sewage sludge applied in 1995 (Table 2).

Table 2. Statistical analysis on the average of nitrate-N content in soil profile between 0 – 120 cm depth in 1997 as affected by field management practices and sludge application rate in 1995.

Management	Mean (kg ha^{-1})	Sludge Rate (Mg ha^{-1})	Mean (kg ha^{-1})
	Spring		
Fallow	26.6a[a]	0	8.6a
Wheat	17.3b	10	17.9b
Wheat + N Fertilizer	18.7b	25	23.8c
		50	33.0d
	Fall		
Fallow	17.7a[a]	0	9.7a
Wheat	16.0a	10	14.1b
Wheat + N Fertilizer	16.8a	25	19.2c
		50	24.4d

[a]Values in the same column followed by different letters are significantly different (Duncan's multiple range test, p=0.05).

An attempt was made to calculate the average observable rate of the movement of the sewage sludge derived NO_3-N. It would be approximately 25 cm yr^{-1} since the position of the maximum NO_3-N concentration was located at 50 cm depth 2 years after the application of the sewage sludge. Such a calculation is based on the position of the maximum NO_3-N concentration in the soil profile. The observation seems to indicate that the nitrate was denitrified at the deeper depth. The shape of the NO_3-N distribution curves indicated that they are not symmetric, the loss of NO_3-N occurred at a depth deeper than 50 cm since the rate of decrease in the NO_3-N at the deeper depth was much steeper. Such an asymmetric distribution can be caused by the consumption of NO_3-N at the deeper depth. The presence of a denitrification process at the deeper depth is further supported by the fact that the NO_3-N concentration at the 120 cm depth was nearly independent of the amount of sewage sludge application even though the NO_3-N concentration at the mid-depth was dependent upon the amount of sludge application. Denitrification, the anaerobic process in which microbes convert NO_3^- to N gases, is one of the major processes consuming NO_3^- in soil (Firestone, 1982). Denitrification can be a major pathway on heavy soils or in wet conditions (Hanson et al., 1994). Mills and Zwarich (1982) suggested that denitrification can be an important loss process for sewage sludge, and this would help explain the apparent disappearance of some the applied N.

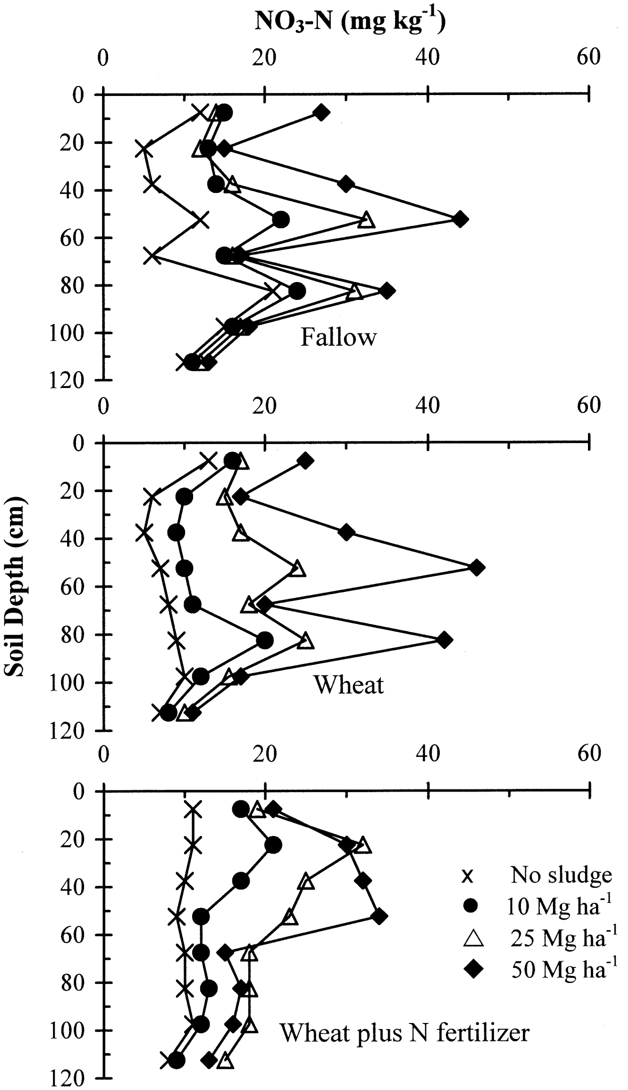

Figure 2. Nitrate-N distribution in the soil profile in the fall of 1997 as affected by different field management practices and various amount of sewage sludge application in 1995. Each point is the mean of three replicates.

For fallow treatment, the total amounts of NO_3-N below 120 cm were extremely low (Table 1). There was virtually no sewage sludge effect upon the NO_3-N concentration at this depth. Therefore, either the NO_3-N derived from applied sewage sludge did not move down to this depth within 2 years or the NO_3-N derived from applied sewage sludge denitrified prior to reaching depths below 120 cm. The application of sewage sludge at the rate of 50 Mg ha^{-1} added NO_3-N in excess of what wheat can consume for 2 years. This excess was evidently enhanced by the addition of more fertilizer. Even though the total amount of NO_3-N on the surface vadose zone may be in excess of that amount required by the wheat, the excess NO_3-N was not detectable at 120 cm depth. This was also true whether wheat was grown or the soil was left as fallow. Thus, even though we did not measure other factors affecting the denitrification process such as redox potential values in soil profile, it could be speculated that NO_3^- is unstable in the deep horizon of the soil profile and its disappearance is probably due to denitrification.

The NO_3-N concentrations in the soil fluctuated over the growing season due to plant uptake and denitrification. Groffman and Tiedje (1989) reported that the annual rates of N loss to denitrification using the intact core technique ranged from less than 1.0 kg N ha^{-1} yr^{-1} in a well-drained sandy soil to nearly 40 kg N ha^{-1} yr^{-1} in a poorly drained clay loam soil. Vegetative uptake and denitrification in warm, wet, and C-rich environment are responsible for the natural removal of NO_3^- in shallow aquifers (Spalding and Exner, 1993). To summarize, this study shows that the sewage sludge loading rate up to 50 Mg ha^{-1} would be safe with respect to groundwater infiltration of nitrate and therefore, the lifetime loading limit could be increased, provided soils similar to those used in this study are utilized for sewage sludge application.

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