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Influence of Sewage Sludge Application on Soil Nitrate Distribution in a Clay Soil

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ABSTRACT : Nitrate contamination in the aquatic systems is the primary indicator of poor agricultural management. The influence of sewage sludge application rates (0, 10, 25, 50 and 100 dry Mg/ha) on distribution of nitrate originating from the sewage sludge in soil profiles was investigated. Soil profile monitoring of nitrate was carried out with a Lakeland clay soil in 1997. Irrespectively of the sewage sludge application rates up to 50 dry Mg/ha, the concentration of NO_3-N at the 120 cm depth was below 10 mg/kg and the difference due to the amount of sewage sludge application was negligible at this depth. There was virtually no NO_3-N below 120 cm depth and this was confirmed by a deep sampling up to 300 cm depth. Most of the nitrate remained in the surface 60 cm of the soil. Below 120 cm depth, nitrate concentration was very low because of the denitrification even at high sewage sludge rate of 100 dry Mg/ha. The NO_3-N concentrations in the soil fluctuated over the growing season due to plant uptake and denitrification. The risk of groundwater contamination by nitrate from sewage sludge application up to high rate of 100 dry Mg/ha was very low in a wheat grown clay soil with high water table (< 3 m).

Key words: clay soil, groundwater contamination, nitrate leaching, sewage sludge.

INTRODUCTION

A major problem facing municipalities is the disposal of sludge produced in sewage treatment plants[1]. There are certain environmental concerns associated with the use of sewage sludge for agricultural purposes. It is a possible source of high N levels that may promote NO_3^- leaching and consequently contaminate underlying groundwater[2]. Groundwater supplies are of particular concern since we do not have very effective techniques to rehabilitate contaminated groundwater aquifers. The Environmental Protection Agency of USA has set a maximum contamination level of 10 mg/L NO_3-N or 45 mg/L of NO_3^- to be safe for drinking water. Nitrate in drinking water is a potential health hazard to humans and has been linked with methemoglobinemia ('blue baby' syndrome) in infants and cancer in adults[3].

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Nitrate contamination of aquifers is becoming a serious environmental problem worldwide, notably because of increasing use of inorganic fertilizers and disposal of organic material on or beneath the land surface[4]. Nitrate in the groundwater of several agricultural areas in southern Ontario, Canada, exceeds 10 mg/L NO_3-N[5]. Concerns have also been expressed in Canada because 85% of the water consumed by livestock comes from groundwater[6]. Henry and Meneley[7] in a review of fertilizer and groundwater nitrate in Western Canada concluded that nonpoint contamination of aquifers from N fertilizer is unlikely but recent studies clearly indicate that the problem of shallow unconfined aquifer contamination by excess manure and fertilizer application is spreading[8].

The potential impact of sludge applications on groundwater quality can be monitored through either NO_3^- analysis of soil cores or soil solution samples[9]. It is necessary to minimize the residual NO_3^- in the agricultural field, particularly in the soils receiving organic N source because the soil N content was 2~3 times higher than that of synthetic fertilizer applied soils. Nitrate leaching from agricultural soils has been widely studied[10]. But attention has been focused mainly on sandy soils because clay soils are usually not considered to have a high nitrate leaching potential. The objective of this study was to investigation the influence of sewage sludge application on soil nitrate distribution in a clay soil.

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° 20′), 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[11]. This soil is developed on moderately to extremely calcareous, dominantly fine sediments and is imperfectly drained, resulting in a high water table (< 3 m)[12]. 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 sewage sludge was obtained from the City of Winnipeg's North End Water Pollution Center. Table 1 presents the chemical characteristics of the soil and sewage sludge used.

Experiment site was treated with sewage sludge in May 1996. Sludge was applied at 10, 25, 50 and 100 dry Mg/ha, which corresponded to 185, 463, 925 and 1850 kg N/ha as total Kjeldahl N, and wheat was grown annually. There were three replicates of each treatment plus control (no sludge) with randomized complete block design. The plot size was 1.8 m × 3.6 m.

Soil profile samples were taken to depths of 300 cm. Spring and fall soil samples were taken on May 26 and November 3 in 1997, respectively. 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[13] 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)[14]. Moisture content was determined by the gravimetric method and the results were tabulated based on an air-dry soil basis.

Table 1. Properties of Lakeland clay soil (0~20 cm depth) and sewage sludge used in this study

Property	Soil	Sewage sludge[a]
pH	8.2	6.2
Organic C (g/kg)	35.6	228
Total-N (g/kg)	3.8	18.5
NH_4-N (mg/kg)	2.0	7.0
NO_3-N (mg/kg)	8.0	1455

[a] Anaerobically digested sewage sludge collected from the drying beds.

RESULTS AND DISCUSSION

The concentration distributions of NO_3-N in soil profiles up to 300 cm depth were shown in Fig. 1. The concentration of NO_3-N in the spring (Fig. 1a) was very low and there seemed to be no difference between the no-sludge treatment and sludge treatments up to 50 Mg/ha. With the addition of 100 Mg/ha, however, an appreciable amount of NO_3-N was found down to the 100 cm depth. Below this depth there was very little NO_3-N. Either there was no leaching of NO_3-N at the site or all the NO_3-N leached below a depth of 150 cm was disappeared. It seemed very likely that the NO_3-N leached below the deeper depth was all denitrified since a typical smooth diffusion front of NO_3-N at the deeper depth was not observed below 150 cm depth for the 100 Mg/ha treatment, which indicated that NO_3-N was 'consumed' at deeper than 150 cm depth. Application of 100 Mg/ha of sewage sludge was a high application rate and the presence of a high NO_3-N concentration at the surface definitely showed this. As stated by Lerch et al.[15], these higher NO_3-N concentrations associated especially with 100 Mg/ha of sewage sludge indicate a potential for leaching of NO_3-N below the root zone. Barbarick et al.[16] alluded that the larger sludge application rate overcame immobilization demands experienced with the smaller sludge rate and released excess N that was then susceptible to loss from the root zone. However, NO_3-N concentration at the deep depth was very low.

The concentration of NO_3-N in the fall soil samples (Fig. 1b) was highest (though only around 10 mg/kg) at the surface and gradually decreased with depth. There was no difference in the distribution pattern due to the application rate of sewage sludge. For sewage sludge treatments up to 50 Mg/ha, the pattern of distribution was virtually identical to that observed in the spring

(Fig. 1a), except that of 100 Mg/ha which showed the presence of very high NO_3-N in the surface zone in spring.

Comparison of the data presented in Fig. 1 shows that most of the NO_3-N is present above 120 cm (Table 2). Such a pattern of distribution indicates that the NO_3-N is rather unstable below that depth, probably due to denitrification. Denitrification has a seasonal pattern in temperate climates[17]. Hanson et al.[18] found that pulses of denitrification activity occur in the spring and fall, when soil moisture levels are at their highest and plant uptake of water and NO_3^- is minimal. The absence of an effect of sewage sludge rate and the gradual decrease in the NO_3-N concentration distribution with soil depth indicated that NO_3-N transport to a greater depth is very unlikely under the present soil and environmental conditions. Thus, it is more likely that the NO_3-N present in the spring would be utilized partly by wheat with the remaining portion very likely denitrified when transported to a deeper depth either by diffusion or advection.

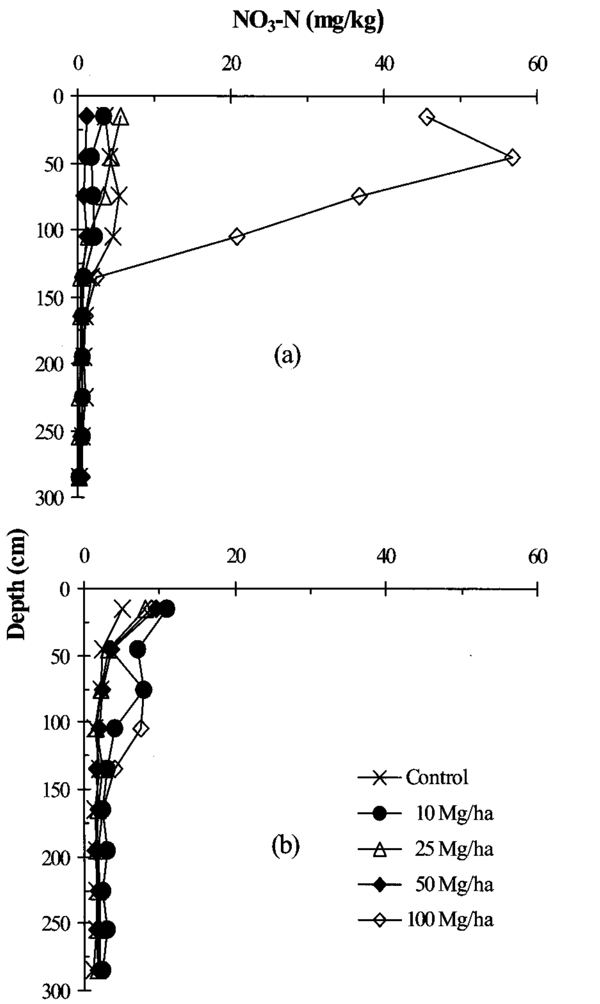

Fig. 1. Nitrate-N distribution in the soil profile as affected by various amount of sewage sludge application in 1996 (a) in the spring and (b) in the fall, 1997. Each point is the mean of three replicates.

On a sewage sludge application site, efforts must be made to control the leaching losses of N compounds. There is no simple relation between N application and leaching loss. Land-use practices influence the amount of N reaching groundwater. Many factors such as land use, crop rotation, cultivation, climate, soil type, soil drainage, fertilizer timing and application rate influence N leaching loss[19]. With leaching, the basic approach is to have a viable crop to retain the N. However, if N loading by sludge exceeds the amount of N that can be assimilated by plants at the site, excess N may be mineralized and may leach into groundwater through the soil. Soon et al.[20] concluded that minimal NO_3^- pollution of groundwater would occur if the amount of N applied in sludge was consistent with the N requirement of the crop grown. The sewage sludge application rate depended on plant N requirement. Determining this rate is critical in preventing NO_3^- leaching into groundwater.

CONCLUSIONS

Irrespectively of the sewage sludge application rates, there was virtually no nitrate below 120 cm depth. Such a decrease in the nitrate was attributed to the active denitrification at that zone. Leaching of nitrate to the groundwater did not occur when sewage sludge were added at rates up to 100 dry Mg/ha. Thus, the present maximum limit of 56 dry Mg/ha, which is issued by

Table 2. Amounts of nitrate-N in the soil profile in 1997 as affected by sludge application rate

Depth	Rate of sludge application (Mg/ha)				
	0	10	25	50	100
cm			kg N/ha		
			Spring		
0 ~ 120	44a	37a	59a	47a	658b
120 ~ 300	12a	10a	6a	8a	15a
			Fall		
0 ~ 120	52a	76a	68a	80a	142b
120 ~ 300	36a	46a	50a	44a	58a

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

Manitoba province, is probably safe with respect to groundwater infiltration of nitrate and therefore, the current lifetime loading limit could be increased, provided soils similar to those used in this study are utilized for sewage sludge application. More research should be conducted over a long period of time account for the N variability of the sewage sludge and varia- tions in weather for the establishment of an agronomic rate of sewage sludge application for preventing ground- water contamination by nitrate.

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