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B764: Nitrogen Transformation and Movement in a Marine Sediment Soil Following Treatment with Varying Rates of Poultry Manure

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NITROGEN TRANSFORMATION AND MOVEMENT IN A MARINE SEDIMENT SOIL FOLLOWING TREATMENT WITH VARYING RATES OF POULTRY MANURE

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INTRODUCTION

Nitrate in water can be hazardous to human health and also cause excess algal growth (5, 7, 14, 17). Recent research has revealed agriculture to be a potential contributor to these problems (2, 6, 9, 12). Nitrate (NO_3-) present in the soil, in amounts in excess of plant needs, may be leached through the soil profile to the groundwater and eventually to lakes and streams. At the same time, efficient and economical disposal of animal manures has become a tremendous problem for agriculturalists. Many techniques for the disposal of these manures have been developed (10, 15). One that is often used because of economy is direct disposal on the land. Recent results have indicated that transformation of nitrogen from the organic to the inorganic form may require a long period of time (1, 6). In addition, movement of nitrate through the soil to the groundwater may also require an extended amount of time (12, 18). As a result, the detrimental effects of animal waste disposal may not appear in the water until long after application.

This investigation was undertaken under laboratory conditions to determine the transformation and movement of nitrogen through a poorly drained marine sediment soil following application of varying rates of poultry manure.

METHODS AND MATERIALS

Twenty soil columns were constructed in the greenhouse by packing polyvinychloride pipe with soil materials from a poorly drained Scantic silt loam. The columns were 25cm ID by 122cm in length.

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The soil was added by horizon in 5cm increments and packed to the bulk density commonly found in that soil in the field (Table 1). An enclosed free water table was constructed below the soil column (Figure 1). Suction lysimeters were installed in each of the three soil horizons

Table 1. The desirable depth and bulk density for soil horizons prior to application of 5 nitrogen treatments.

Horizon	Horizon depth (cm)	Total depth (cm)	Bulk density (g/cc)
A_p	30	0-30	1.04
B_2	60	30-90	1.45
C	30	90-120	1.60

and a sampling point was made in the free water table (18). Tensiometers were inserted 6 inches into the soil surface to monitor moisture content. Soil and water in the surface horizon were maintained near field capacity to approximate the moisture content which normally occurs in this soil under field conditions.

Fresh poultry manure was mixed into the A horizon to a 6-inch depth at rates of 0, 200, 400, 800 and 1600 pounds of nitrogen per acre (lb/A). The soil was seeded to common timothy which was grown for three months under a controlled photoperiod of fourteen hours daylight and in the initial 3-month period two harvests were made. In subsequent periods, only one harvest was possible because of less natural light in winter months. The same process was carried out two more times at 3-month intervals, thereby extending the experiment over a 9-month period. The timothy forage was harvested for yield and chemical analysis.

Soil solution samples were taken bi-weekly during each of the three application periods. The samples were refrigerated at 4C until analyses were performed. Analyses were normally completed within 24 hours of sampling. Samples were analyzed for NH_4–N and NO_2+NO_3–N on the Technicon Auto Analyzer according to the procedure described by Hannawalt and Steckel (8).

At the completion of the study, each horizon of the soil was analyzed for NH_4–N and NO_2+NO_3–N on the Technicon Auto Analyzer. Total nitrogen, organic matter and pH were determined for each horizon using the Kjeldahl, Walkley-Black and Peech methods, respectively. The timothy forage and poultry manure were analyzed for total nitrogen by the Kjeldahl method. Poultry manure was acidified

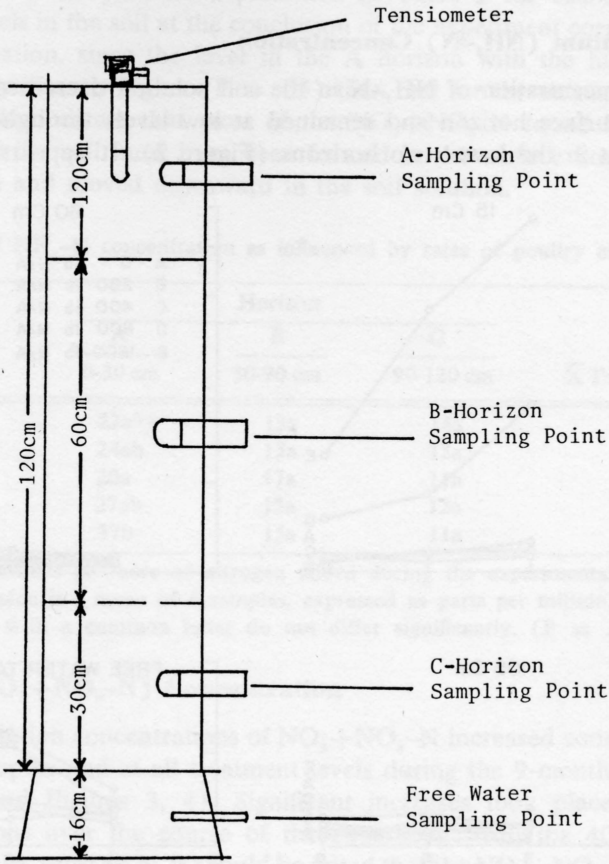

Figure 1. Soil column with details of sampling points, tensiometer placement and soil horizon depth.

with 5 percent H_2SO_4 upon sampling to reduce loss of nitrogen during the drying process. The total N content of the free water table was also determined.

Microbiological measurements were performed at the conclusion of the 9-month period for *Nitrosomonas, Nitrobacter* and the denitrifiers as described by Alexander and Clark (3) for the nitrifiers, and Alexander (4) for the denitrifiers.

The analysis of variance method and Duncan's new multiple range test were carried out as described by Steel and Torrie (16), with P = .05.

RESULTS AND DISCUSSION

Ammonium (NH_4–N) Concentration

Concentration of NH_4–N in the soil solution decreased over time in the surface horizon and remained at low levels throughout the experiment in the lower two horizons (Figure 2). It appears that some

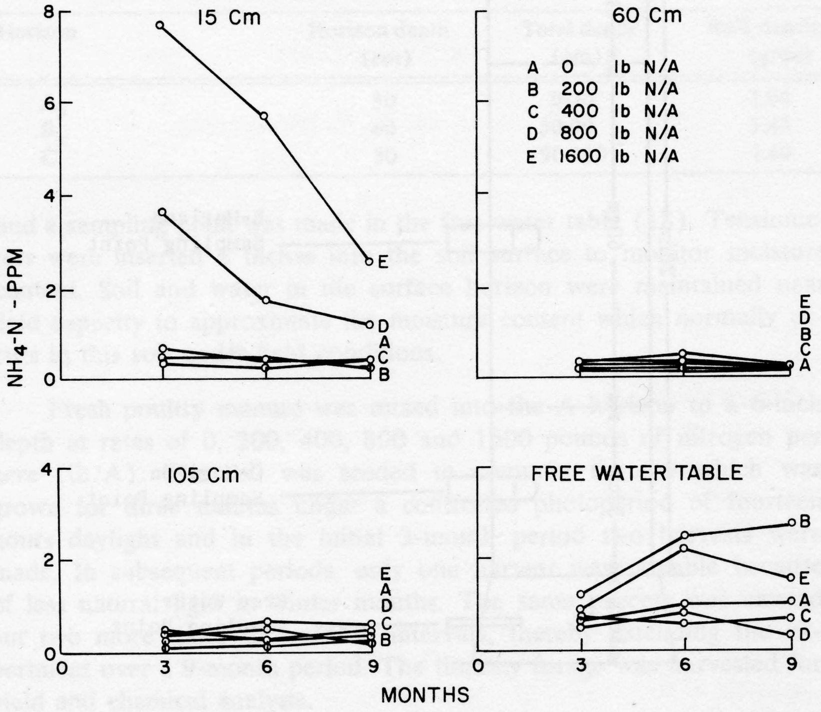

Figure 2. Soil solution NH_4–N concentration during 3-month periods following application of poultry manure at 4 soil depths.

NH_4–N may have moved downward through the soil column over time because the concentrations in the free water table were slightly elevated at the 9-month sampling for the 200 and 1600 lb/A treatments. The significance of these results is questionable however, since no increase occurred for the two intermediate N treatments.

The decrease of solution NH_4–N in the surface horizon and the relatively low levels in the lower horizons throughout the 9-month period can be explained by the fact that many of the NH_4 cations would have been removed from solution by the cation exchange complex of the soil, and also this particular form of N would have been transformed to NO_3–N. Data presented in Table 2 for exchangeable NH_4–N levels in the soil at the conclusion of the experiment corroborate this explanation, since the level in the A horizon with the highest N rate was significantly higher ($P = .05$) than that for the untreated soil. These results indicate that most of the NO_2+NO_3–N found in lower horizons of the soil must have been formed in the surface horizon by nitrification and moved downward in the soil solution.

Table 2. Soil NH_4–N concentration as influenced by rates of poultry manure.

	Horizon			
	A	B	C	
Treatments[1]	0-30 cm	30-90 cm	90-120 cm	$\overline{X}$ Treatments
0	22a[2 3]	13a	14a	16a
200	24ab	15a	12a	17a
400	20a	17a	11a	16a
800	27ab	13a	12a	17a
1600	37b	15a	11a	21b

[1] Total pounds per acre of nitrogen added during the experimental period.
[2] Each value is a mean of 4 samples, expressed as parts per million.
[3] Values with a common letter do not differ significantly. ($P = .05$)

Nitrate (NO_2+NO_3–N) Concentration

Soil solution concentrations of NO_2+NO_3–N increased consistently at all soil depths and at all treatment levels during the 9-month period (Table 3 and Figures 3, 4). Significant increases took place in all three horizons over the course of the experiment with the 400, 800 and 1600 lb/A rates on N. It should be noted that the NO_2+NO_3–N content of the free water table under the soil columns was raised significantly following two applications of N at the 400 and 1600 lb/A rates. However, the lack of a significant effect with the 800 pound treatment suggests that only the 1600 pound rate should be considered as having a major effect on water quality. At least it is clear that three applications of the 200 lb/A N rate did not significantly affect water quality in comparison to the untreated soil.

Analysis for soil NO_2+NO_3–N content at the completion of the study (Table 4) indicate a trend similar to that found for solution NO_2+NO_3–N, although the levels in the lower depths of the soil were much lower than those found in the solution. In the surface horizon the NO_2+NO_3–N levels in the soil treated with 400 and 800 lbs/A of N were significantly higher than those treated with zero and 200 lb rates, and the 1600 lb rate was significantly higher than the intermediate

Table 3. The soil solution NO_2+NO_3–N concentration by depth and time as influenced by 5 rates of nitrogen applied 3 times over a 9-month period.[1]

Horizon	Season	0	200	400	800	1600
		N Treatments (lbs/A.)				
A	1	21a	103a	139a	166a	182a
0-30 cm	2	34a	110ab	200b	242b	248b
	3	46a	133b	228b	276c	325c
B	1	29a	34a	42a	38a	65a
30-90 cm	2	39a	46a	67a	112b	174b
	3	44a	57a	102b	148c	226c
C	1	16a	17a	28a	29a	32a
90-120 cm	2	32a	41a	68b	80b	113b
	3	29a	41a	80b	114c	198c
C	1	5a	3a	7a	5a	9a
Free	2	12a	10a	37b	15a	45b
Water	3	12a	13a	39b	23a	71b
Table						

[1] Concentration values are reported as an average of 4 samples taken 6 times during a 3-month period, expressed as parts per million.

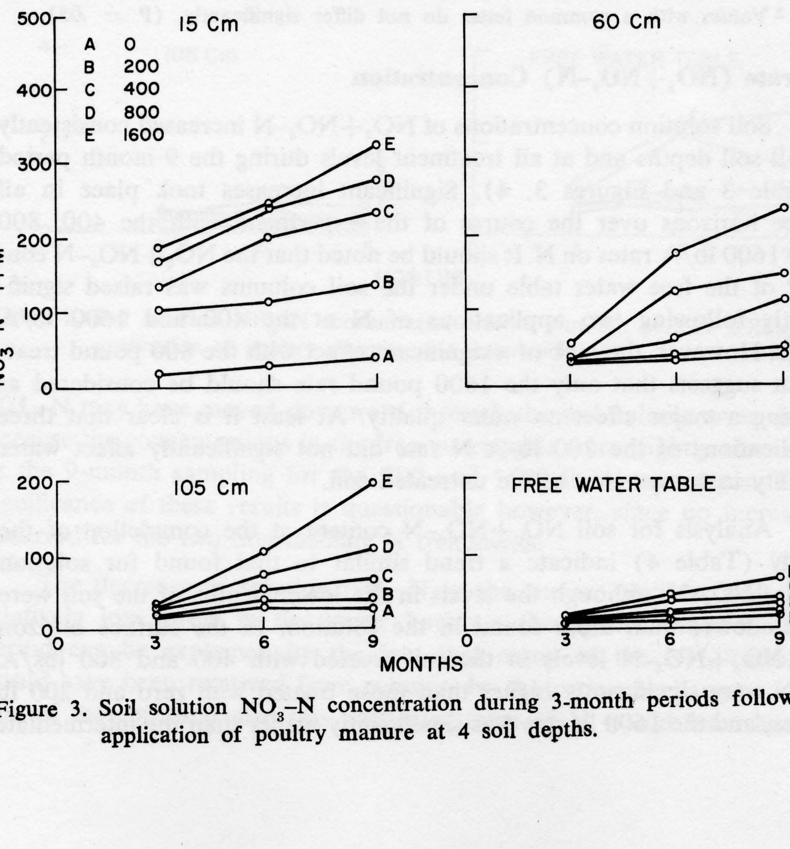

Figure 3. Soil solution NO_3–N concentration during 3-month periods following application of poultry manure at 4 soil depths.

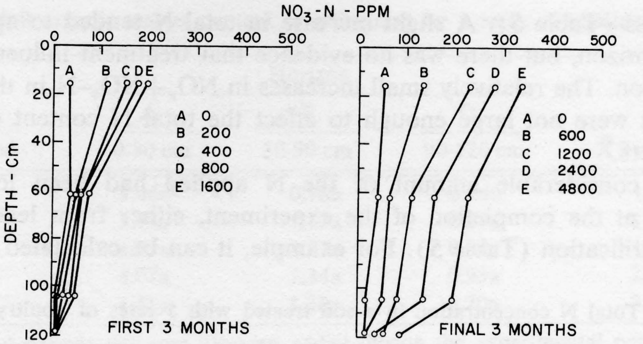

Figure 4. Soil solution NO_3–N concentration by depth averaged for the first and third 3-month period after application of poultry manure.

Table 4. Soil NO_2+NO_3–N concentration as influenced by five rates of poultry manure.

	Horizon			
	A	B	C	
Treatments[1]	0-30 cm	30-90 cm	90-120 cm	$\bar{X}$ Treatments
0	15a[2]	10a	3a	9a
200	43a	9a	5a	19ab
400	106b	9a	5b	40bc
800	146b	16b	6b	56c
1600	220c	26c	10c	85d

[1] Total pounds per acre nitrogen added during the experimental period.
[2] Each value is a mean of 4 samples, expressed as parts per million.

rates. These increases indicated that N transformation occurred primarily in the surface horizon where the manure was applied and the NO_2+NO_3–N moved downward through the profile in that form. As noted earlier this agrees with the observation that little NH_4–N moved from the surface horizon (Figure 2).

The NO_2+NO_3–N levels in the lower soil horizons were significantly increased by total N applications of 2400 and 4800 lbs/A, and in the C horizon also by the 1200 pound rate.

Total Nitrogen

Analysis of the soil for total N at the completion of the study revealed that a consistent positive relationship existed in the surface horizon with increasing rate of N application. In fact, the 0.3 percent total N in the surface of the soil treated with 4800 lbs/A of N was significantly higher than it was in the soil which received 1200 lbs. of

N, or less (Table 5). A slight increase in total N tended to appear in the B horizon, but there was no evidence that treatment influenced the C horizon. The relatively small increases in NO_2+NO_3–N in the lower horizons were not large enough to affect the total N content of those soil layers.

A considerable amount of the N applied had been lost from the soil at the completion of the experiment, either from leaching or by denitrification (Table 5). For example, it can be calculated that the

Table 5. Total N concentration in a soil treated with 5 rates of poultry manure.

	Horizon			
	A	B	C	
Treatments[1]	0-30 cm	30-90 cm	90-120 cm	$\overline{X}$ Treatments
0	0.23a[2]	0.08a	0.05a	0.12a
200	0.24a	0.09a	0.05a	0.13a
400	0.25a	0.08a	0.04a	0.13a
800	0.26ab	0.10a	0.05a	0.14b
1600	0.30b	0.10a	0.04a	0.15b

[1] Total pounds per acre nitrogen added during the experimental period.
[2] Each value is a mean of 4 samples, expressed as percent nitrogen.

untreated surface soil contained 4600 lbs. of N/A as compared to 6000 lbs/A for the soil which received the 1600 lb. rate. This indicates the soil N level had been raised only 1400 lb/A and that apparently, 3400 lb/A had been mineralized and lost from the surface soil.

Soil Organic Matter

Organic matter content of the soil tended to increase as application level increased in both the surface and middle horizons (Table 6). Although significance was not established among treatments within any of the horizons, the overall trend is similar to that found for total nitrogen.

Soil Acidity

A significant decrease in pH occurred in the surface horizon between the control and all treated plots (Table 7). A similar effect, although not significant, was also observed under the two highest treatments in the B and C horizons, indicating that breakdown of the manure occurred, and that organic matter components moved through the soil in appreciable amounts at the two highest rates. Nitrification normally results in a reduction in pH of the medium where it occurs because hydrogen ions are released in the process.

Table 6. Soil organic matter content as influenced by 5 rates of poultry manure.

	Horizon			
	A	B	C	
Treatments[1]	0-30 cm	30-90 cm	90-120 cm	$\overline{X}$ Treatments
0	3.46a[2]	0.78a	0.74a	1.66a
200	3.74a	1.13a	0.97a	1.94a
400	4.03a	0.87a	0.34a	1.75a
800	4.07a	1.34a	0.93a	2.11b
1600	4.41a	1.38a	0.70a	2.16b

[1] Total pounds per acre nitrogen added during the experimental period.
[2] Each value is a mean of 4 samples, expressed as percent organic matter.

Table 7. Soil pH as influenced by 5 rates of poultry manure.

	Horizon			
	A	B	C	
Treatments[1]	0-30 cm	30-90 cm	90-120 cm	$\overline{X}$ Treatments
0	5.40a[2]	5.85a	6.30ab	5.85d
200	5.03b	5.85a	6.50b	5.79cd
400	5.10b	5.90a	6.50b	5.83bc
800	4.95b	5.50a	6.07ab	5.53a
1600	5.03b	5.75a	5.98a	5.58ab

[1] Total pounds per acre nitrogen added during the experimental period.
[2] Each value is a mean of 4 samples.

Population of Microbes

Marked numerical increases in microbial populations were observed in response to increasing rate of manuring. The increase in populations of *Nitrosomonas* (Table 8), suggested that a greater amount of NH_4^+ was converted to NO_2^- as treatment level was increased. This partially explains the decrease in solution NH_4^+ (Figure 2) as *Nitrosomonas* population increased over time. Largest populations were found in the surface horizon where the environment would be expected to have been more aerobic, and therefore, more conducive for their growth, while much lower populations were observed in the subsurface horizons.

Population of *Nitrobacter* tended to increase with treatment level up to the rate of 1200 lb/A of N (Table 8). Although soil pH was similar among treated plots in the surface horizon where population levels were greatest, toxic products of the breakdown process may have tended to limit the population buildup. In all cases, populations

Table 8. Populations of microbes in a soil treated with 5 rates of poultry manure.

Treatments[1]	Nitrosomonas	Nitrobacter	Denitrifiers
0	0.8a[2]	2a	12a
200	22.8a	423a	121a
400	48.6a	727a	135a
800	49.6a	341a	91a
1600	237.2a	315a	66a

[1] Total pounds per acre nitrogen added during the experimental period.

[2] Each value is a mean of three horizons, expressed as $10^5/10$ grams of soil.

of *Nitrobacter* were greater than those of *Nitrosomonas* at the completion of the experiment, indicating conversion of most NO_2^- to NO_3^-. As with *Nitrosomonas,* population numbers of *Nitrobacter* were greatest where the soil environment was most aerobic.

Populations of denitrifiers followed a pattern similar to that of *Nitrobacter,* as a buildup in numbers occurred from the control to treatment of 1200 lb/A of N and declined at the higher rates (Table 8). Populations reached a maximum in the middle horizon, indicating that it was the zone of growth with the best combination of reducing conditions and available energy source. Lack of an energy source in the lowest horizon, which undoubtedly was the most reduced zone, is indicated by the lack of change in organic matter or total nitrogen between treatment levels. In addition, NO_3^- which was needed as a hydrogen acceptor in the reducing environment, was higher in the middle horizon than in the lowest horizon.

Plant Uptake of Nitrogen

Nitrogen content, dry weight and nitrogen uptake for the timothy grass are shown in Appendix Tables 1-4 for each of the four harvests. The N content of the 0, 200 and 400 lb/A treatments increased over

Table 9. Total nitrogen balance sheet as influenced by 5 rates of poultry manure after 3 periods of application.

Treatment (lbs/A of N)	Original + added N	Measured N[1]	Recovery of added N (%)
0	117.34[2]	117.34	100.0
200	122.26	117.06	0[3]
400	127.12	119.23	19.3
800	136.84	136.41	97.8
1600	156.34	142.26	63.9

[1] Includes nitrogen recovered in timothy harvests, soil at completion of experimental period and free water table at completion of experimental period.

[2] Each value is a mean of 4 samples and is expressed as grams of nitrogen per soil column.

[3] This value was actually negative since less N was recovered than was originally present in the soil.

Table 10. Percent N, dry weight and nitrogen uptake by timothy at harvest 1 as influenced by 5 rates of nitrogen.[1]

Treatments (lbs/A.)	Percent N	Dry Weight (gms)	N Uptake (gms)
0	3.1a	3.4ab	0.107a
200	3.6b	10.1c	0.352b
400	3.7b	6.4bc	0.240ab
800	3.9b	4.2ab	0.160a
1600	3.9b	1.1a	0.087a

[1] Each value is a mean of 4 samples.

Table 11. Percent N, dry weight and nitrogen uptake by timothy at harvest 2 as influenced by 5 rates of nitrogen.[1]

Treatments (lbs/A.)	Percent N	Dry Weight (gms)	N Uptake (gms)
0	3.0a	2.7a	0.078a
200	3.2a	12.4b	0.390b
400	3.6ab	9.4b	0.350b
800	4.0b	5.7a	0.229ab
1600	4.0b	3.4a	0.138a

[1] Each value is a mean of 4 samples.

Table 12. Percent N, dry weight and nitrogen uptake by timothy at harvest 3 as influenced by 5 rates of nitrogen.[1]

Treatments (lbs/A.)	Percent N	Dry Weight (gms)	N Uptake (gms)
0	4.5a	1.9ab	0.085ab
200	4.6a	5.5c	0.247b
400	5.0a	4.8bc	0.237b
800	3.9a	1.0a	0.049a
1600	1.4a	0.3a	.0042a

[1] Each value is a mean of 4 samples.

Table 13. Percent N, dry weight and nitrogen uptake by timothy at harvest 4 as influenced by 5 rates of nitrogen.[1]

Treatments (lbs/A.)	Percent N	Dry Weight (gms)	N Uptake (gms)
0	4.8b	1.7b	0.081ab
200	5.0bc	2.6b	0.129b
400	5.2c	2.0b	0.101b
800	0.0a	0.0a	0.0a
1600	0.0a	0.0a	0.0a

[1] Each value is a mean of 4 samples.

time in the plant tissue. During the first two harvest periods, nitrogen content in the 800 and 1600 lb/A treatments was greater than that found in the lower treatments. Nitrogen content at the two higher treatments later decreased, eventually resulting in no nitrogen uptake as seed germination ceased. The greatest response, over time, of timothy to nitrogen application, occurred at treatments of 200 and 400 lb/A. Dry weight, nitrogen content and total plant uptake were greater at these two treatment levels than the control and two highest treatments. It should be pointed out, however, that stage of maturity at time of harvest varied from one harvest to the next. The first two growth periods, and subsequent harvest, occurred under conditions of warm air temperature and long day length. The final two growth periods occurred under decreasing temperature and light conditions in the fall and winter months. This affected nitrogen percentage as younger more succulent tissue harvested during the last two periods contained a greater percentage of nitrogen than the timothy harvested at early bloom stage during the first two harvests.

A considerable decrease in percentage of germination and subsequent seedling growth occurred under the two highest treatment levels. This effect was most evident during the final two seedings. Isolated seedlings did develop normally; however, most seeds failed to germinate. A reason for this occurrence may have been the toxic effects of NH_3 as it volatilized from the manure, as noted by Lorenz, et al. (11) using onions. Another explanation is the osmotic effects of salts in the manure on the seeds, resulting in desiccation of the germinating seeds. This effect was reported by Olson and Drier (13) on germinating wheat seeds. Although manure was applied to the six-inch depth of the soil, organic matter from the manure was observed at the soil surface. This effect was observed only at the two higher treatments which also were the only ones to exhibit germination failures.

Nitrogen Recovery

Compilation of all incoming and outgoing sources of N in this study revealed an extreme amount of variability (Table 9), with values ranging from a negative value (less than zero) for the 200 lb/A treatment to 98 percent for the soil which received 800 lb/A. Calculations were based on the amount of N recovered in excess of the level present in the untreated soil (117.34 g/column), expressed as a percentage of the amount of N added during the experimental period. These data can be considered only as approximations. Mineralization of N from the initial organic fraction of the soil was assumed to be the same at all treatment levels. The differential addition of manure with a C/N ratio more conducive to microbial activity may have altered the rate of mineralization, particularly at the higher rates.

The recovery data indicate a considerable amount of N may have been lost from the system by volatilization (denitrification) during the 9-month period. For example, recovery of applied N from the two lower N rates (600 and 1200 lb/A) was extremely low, suggesting that most of the N volatilized under these conditions. The higher recovery values noted for the two highest N treatments may have resulted from an overloading of the soil system within a short period of time and consequently the mineralization process was not completed on as great a percentage of the manure as occurred with lower treatment levels. This conclusion is borne out by the data in Table 3 where it can be seen that the NO_2+NO_3–N level in the soil solution of the 200 lb/A treatment was 133 ppm at the conclusion of 9 months, whereas it was 325 ppm for the 1600 lb/A treatment. If mineralization of N had been equivalent for both rates, the concentration of NO_2+NO_3–N should have been 1064 ppm.

Even though a considerable amount of N appears to have been volitilized it is important to note that a significant quantity of NO_2+NO_3–N moved downward through the soil and accumulated in the free water table beneath the soil column under the columns receiving rates of 400, 800 and 1600 lb/A of N per application.

SUMMARY

A Scantic soil in laboratory columns was treated with five levels of nitrogen in the form of poultry manure three different times over a 9-month period. The resulting leachate and soil were analyzed for selected chemical and microbiological properties.

NO_2+NO_3–N leached through the soil column and levels of NO_2+NO_3–N increased in the free water table, reaching levels of 39, 23 and 71 ppm for the free water under soil treated with a total of 1200, 2400 and 4800 lb/A of N, respectively. A significant increase occurred between treatments within each horizon as treatment level increased, whereas a significant decrease within treatment occurred as depth increased. A decreasing trend in soil solution NH_4–N concentration over time was observed at the two highest treatments in the A horizon, apparently as a result of nitrification. Concentrations in the B and C horizons remained low during the experimental period. Soil NH_4–N tended to decrease as depth increased and showed no relationship to treatment level.

Total nitrogen exhibited a significant increase between the high and low treatments within the A horizon, but not the B or C horizons. A similar effect occurred for organic matter with both the A and B horizon organic matter levels increasing quite consistently as treatment increased. A decreasing trend in soil pH took place in the A horizon under all treatments but the control with extremes of 4.95 for the next to highest N treatment versus 5.4 for the untreated soil. This effect also occurred under the two higher treatments at the B and C horizons.

Soil microorganisms (*Nitrosomonas, Nitrobacter* and the denitrifiers) tended to increase under all treated plots as compared to the control. Population levels for the two nitrifiers were greatest in the A horizon. The denitrifiers were most numerous in the B horizon.

An evaluation of all incoming and outgoing sources of nitrogen accounted for a varying amount of the added N, ranging from essentially zero for the lower N rates to more than two-thirds for the two highest rates. It appears a substantial amount of the added N was not mineralized during the 9-month period for the two highest rates. Denitrification appears to have been a significant factor, although the percentage was inversely related to rate.

CONCLUSIONS

Based on these data collected under laboratory and greenhouse conditions it appears that manure should not be applied annually to poorly drained marine sediment soils under Maine climatic conditions at rates of N which exceed approximately 200 lb/A if groundwater quality is to be protected. At higher N rates, NO_3–N moves downward through the soil during the wet portion of the year as a result of nitrification in the surface layer and denitrification does not proceed at a rate adequate to prevent NO_3–N from reaching the water table.

When manure is applied annually to poorly drained marine sediment soils in Maine at N rates which do not exceed 200 lb/A, denitrification and plant uptake account for nearly all of the N which is mineralized.

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