NUTRIENT SEEPAGE FROM OPERATING TURKEY BUILDINGS WITH A LITTER SYSTEM

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Abstract. Core soil samples were collected from nine operating turkey buildings with different ages located in areas of different soil types in Minnesota. These samples were analyzed for pH, phosphorus, organic matter, ammonium nitrogen, and nitrate nitrogen to investigate the potential of groundwater pollution by turkey operations. According to the data, for clay loam soil, the chance of leaching of phosphorus to groundwater is slight if the water table is 153 cm below the ground surface. Saturation of ammonium nitrogen in the topsoil can be reached in 20 yr of continuous operation. Therefore, it may be suggested that the topsoil layer in turkey buildings be replaced every 20 yr for areas of high groundwater (within 91 cm or so), and every 40 yr for areas with low groundwater (greater than 153 cm in depth). Also for clay loam soil, the nitrate nitrogen may be able to move down in soil about 91 cm deep in ten years. For barns older than ten years, it is observed that the nitrate nitrogen concentrations are significantly higher inside than outside of barns throughout the entire sampling depth. As a preventive option for turkey producers for nitrate nitrogen in particular, replacing the topsoil layer every ten years may be helpful to obviate the potential pollution of groundwater resource by nitrate leaching. Similar measures may also be applied to loam soil. Due to limited data, the performance of silt and sandy loam soils in preventing nutrient leaching cannot be determined and should receive further research.

Keywords: different soils, groundwater pollution, nutrient seepage, turkey buildings

1. Introduction

In recent years, a growing concern has been voiced by concerned citizens and environmental groups over nutrient contamination of groundwater supply from poultry production systems (Haberstroh, 1997). High nitrogen concentrations have been reported in groundwater in Delaware, which could be caused by poultry productions (Ritter and Chirnside, 1984; Denver, 1991). A correlation between high nitrate levels in drinking water wells in proximity to broiler houses was revealed (Ritter, 1991; Ritter *et al.*, 1994). Andres (1991) estimated that potential nitrate fluxes from sub-basins in the Indian River watershed were greater from poultry

TABLE I
General information on the turkey barns sampled

Barns	Age (yr)	# Birds/m^2/ stocking period	Soil texture
1	9	2.354	Loam
2	10	3.425	Clay loam
3	45	3.783	Clay loam
4	20	4.000	Clay loam
5	30	2.148	Loam
6	40–50	2.604	Silt loam
7	40–50	2.721	Sandy loam
8	30	2.276	Loam
9	30	2.276	Loam

farming than from non-poultry areas. Lomax *et al*. (1995) sampled 30 broiler houses in Delaware and found that the average soil nitrogen content beneath the barn floors was significantly higher than the background (250 mg kg^{-1} soil vs. 8 mg kg^{-1} soil). Haberstroh (1997) reported high concentrations of nitrogen in the soil under turkey buildings in North Dakota. These studies have prompted the need to examine more poultry production facilities in order to obtain additional information to better understand the seepage process. The objective of this study is to investigate the nutrient levels in soils underneath turkey building floors, based on a survey of nine turkey production sites in southern Minnesota. Data provided in this paper indicate that there may exist some potential pollution problems associated with the turkey litter systems. Suggestions on preventive measures are also discussed based on the findings from this project and further research needs are proposed.

2. Materials and Methods

2.1. Site Selection

Nine turkey barns were selected and sampled in this project. These farms were located in areas of different soil types, and the farm information is presented in Table I.

A truck mounted, hydraulic powered soil sampling probe was used to collect six soil core samples along the centerline of each building at equal distances since water pipes as well as other utility lines were identified in the one-third area on both sides along the length of the buildings (Figure 1). For each core sample,

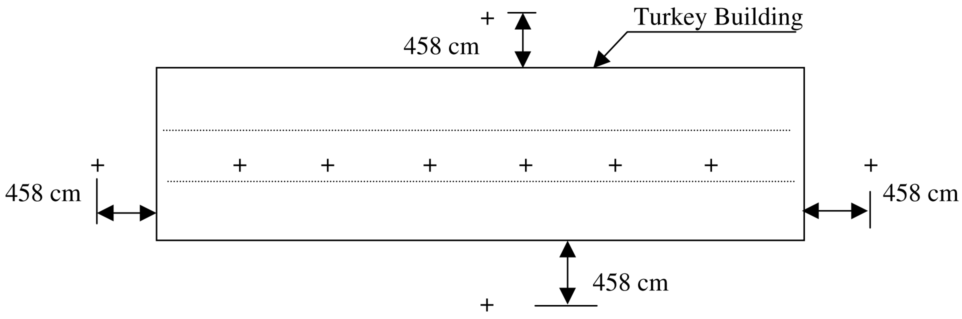

Figure 1. Soil sampling locations designated by a symbol '+' inside and outside of a site.

five individual soil samples in 30.54 cm increments were generated to provide a clear picture reflecting the downward nutrient profile in the soil. The four '+' signs outside the sampling site indicated the possible locations for control samples and a maximum of four could be made based on the accessibility to these locations. The off-site sampling points were, if possible, always 458 cm away from the site edge and in the middle of site length. Soil sampling was conducted when the barn was empty, a short break before restocking with young birds after the mature birds were removed to the market. All the barn floors were constructed of native soil with the surface compaction being the only treatment. The soil sampling work was done between April 1999 and August 2000.

2.2. Sample analysis

Soil samples were air-dried, ground, and analyzed for ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), Olsen-phosphate, percent organic content, and pH, using the standard methods (SSSA and ASA, 1996). In addition to the above analysis, for each site, one core sample collected from the center of the site was also analyzed for soil texture using the method presented by Gee and Bauder (1986) and the results are also presented in Table I. The soil type classification was determined based on the procedures recommended by the United States Department of Agriculture (USDA, 1982).

The mean values and standard deviations for samples at each depth interval were calculated based on the number of samples at this particular depth. The same method was also applied to the background samples. A statistical paired-t test was used to compare sample means at the same depth between different locations at a significance level of $\alpha = 0.05$.

TABLE II

The average pH and standard deviation for all turkey barn sites*

Sampling depth (cm)	Inside	Outside	Inside	Outside	Inside	Outside		Inside	Outside
	Clay loam soil								
	Barn #2		Barn #3		Barn #4				
	(n = 6)	(n = 3)	(n = 6)	(n = 3)	(n = 6)	(n = 3)			
30.54	$7.32\pm0.08^{a,x}$	$8.04\pm0.43^{a,y}$	$6.92\pm0.20^{a,x}$	$7.60\pm0.10^{a,y}$	$6.69\pm0.41^{a,x}$	$7.25\pm0.62^{a,x}$			
61.08	$7.58\pm0.01^{b,x}$	$8.27\pm0.02^{a,y}$	$7.09\pm0.36^{a,x}$	$7.69\pm0.17^{a,y}$	$6.19\pm1.27^{a,x}$	$7.28\pm0.86^{a,x}$			
91.62	$7.98\pm0.13^{c,x}$	$8.20\pm0.01^{a,y}$	$6.95\pm0.81^{a,x}$	$8.01\pm0.16^{a,b,y}$	$6.41\pm1.16^{a,x}$	$7.60\pm0.13^{a,x}$			
122.2	$8.14\pm0.12^{c,x}$	$8.17\pm0.12^{a,x}$	$7.03\pm0.63^{a,x}$	$8.09\pm0.06^{b,y}$	$7.15\pm0.23^{a,x}$	$7.20\pm0.82^{a,x}$			
152.7	$8.04\pm0.14^{c,x}$	$8.23\pm0.07^{a,x}$	$6.93\pm0.92^{a,x}$	$8.00\pm0.27^{a,b,x}$	$7.58\pm0.50^{a,x}$	$7.24\pm0.32^{a,x}$			
	Loam soil								
	Barn #1		Barn #5		Barn #8			Barn #9	
	(n = 6)	(n = 3)	(n = 6)	(n = 3)	(n = 6)	(n = 4)		(n = 5)	(n = 3)
30.54	$7.08\pm0.11^{a,x}$	$7.77\pm0.20^{a,y}$	$6.68\pm0.13^{a,x}$	$7.29\pm0.03^{a,y}$	$7.10\pm0.52^{a,x}$	$6.62\pm0.53^{a,x}$		$7.21\pm0.25^{a,b,x}$	$7.48\pm0.85^{a,x}$
61.08	$7.35\pm0.22^{b,x}$	$7.99\pm0.10^{a,b,y}$	$6.10\pm0.45^{a,x}$	$7.54\pm0.17^{b,y}$	$6.62\pm1.02^{a,x}$	$6.45\pm0.25^{a,x}$		$6.31\pm0.86^{a,x}$	$6.96\pm0.26^{a,x}$
91.62	$7.59\pm0.21^{b,x}$	$8.03\pm0.07^{a,b,y}$	$6.06\pm0.96^{a,x}$	$7.67\pm0.13^{b,y}$	$6.53\pm1.06^{a,x}$	$6.47\pm0.39^{a,x}$		$6.73\pm0.52^{a,x}$	$7.36\pm0.95^{a,x}$
122.2	$7.92\pm0.07^{c,x}$	$8.19\pm0.11^{b,y}$	$6.78\pm1.02^{a,x}$	$7.63\pm0.21^{b,x}$	$6.55\pm0.63^{a,x}$	$6.65\pm0.61^{a,x}$		$7.66\pm0.48^{a,b,x}$	$7.78\pm0.69^{a,b,x}$
152.7	$8.08\pm0.17^{c,x}$	$8.07\pm0.03^{a,b,x}$	$7.06\pm1.09^{a,x}$	$7.99\pm1.11^{a,b,x}$	$6.31\pm1.11^{a,x}$	$7.36\pm1.09^{a,x}$		$7.86\pm0.42^{b,x}$	$8.04\pm0.73^{b,x}$
	Silt loam soil				Sand loam soil				
	Barn #6				Barn #7				
	(n = 4)	(n = 2,1)			(n = 4)	(n = 3,1)			
30.54	$6.89\pm0.13^{a,x}$	$6.64\pm0.72^{a,x}$			$5.91\pm0.29^{a,x}$	$6.40\pm0.90^{a,x}$			
61.08	6.61 ± 0.17^{a}	7.57			$5.07\pm0.76^{a,x}$	$7.12\pm0.33^{a,y}$			
91.62	–	7.35				$6.53\pm1.08^{a,b}$	8.04		
122.2	–	7.47				$7.53\pm1.19^{b,}$	–		
152.7	–	7.42				–	–		

* For comparisons between inside and outside samples at each farm, letters a, b, and c indicate statistical difference at a significance level of $\alpha = 0.05$ between rows, while letters x and y indicate difference between columns for each farm.

3. Results and Discussions

3.1. pH MEASUREMENTS

Table II presents the pH information for all the barns sampled. For the two barns built on clay loam soils (#2 and #3), the soil pH inside the barns was significantly lower than that of the controls (samples from outside of barns) up to 122 cm below the ground surface, indicating that turkey litter may decrease the pH of this type of soil over time. The pH values along the sampling depth for the youngest barn (10 yr old) in this group support this observation because only the top three soil layers have pH values that are lower than the control samples and there is no statistical difference in pH for the other fractions. However, the age effect seems to diminish over time, as there is no statistical difference in pH between the inside and the outside samples in the bottom-sampling layer for the barn of 45 yr old. In other words, the pH only affects one soil layer in 35 yr as compared to three soil layers in the first ten years. Under the same soil type, the increase in acidity was also observed in barn #4 although, in that case, the decline in pH was not statistically significant ($p > 0.05$). The decrease of pH in the soil profile apparently signals the downward migration of manure so it can be inferred that the deep-bedded turkey litter may have the potential to impact soil pH located 122 cm below the ground surface if the turkey barn is in continuous operation for 45 yr or longer. For the 20 yr barn (#4 in Table II), although, due to large variations, there is no statistical difference between pH in the samples from inside and outside, the increase in soil acidity for samples collected in the top three layers within the barn might indicate the impact similar to those observed for the data from the 10- and 45 yr old barns on the clay loam soil (Table II).

For barns built on loam soils (#1, #5, #8, and #9 in Table II), the first three soil layers (30–92 cm) showed a significant decrease in soil pH, that is similar to that observed in barns built on the clay loam soil (barns #2 and #3). Comparing the pH in the soils of barns #8 and #9, there was no significant difference between the inside and outside of the barns for the different layers. Similar to the clay loam soil, a comparison of pH changes in the loam soil type does not appear to follow a pattern that can be clearly defined based on length of existence of the barn. If only the samples in the barns are examined without comparisons between the inside and the outside, it is interesting to note that there is virtually no statistical difference in pH for samples collected from different depths for the three 30 yr barns. This may imply that the manure nutrients must have already penetrated the 153 cm sampling depth in less than 30 yr. This postulate appears to be supported by the data from the 9 yr barn, in which a clearly ascending pH profile is observed along the sampling depth.

For the barn built on silt loam soil (#6), it is difficult to determine the downward leaching of nutrients in the soil since only limited data are obtained. However, a comparison of the soil pH inside and outside the barn within the top 30 cm indicates no difference between the two locations. For the barn built on sandy loam soil (#7), again the data collected are limited but the observed trend suggests an increase in soil acidity in the top three layers within the barn. However, it appears that the impact of litter on pH in the sand loam soil is small despite the barn having been in operation for 40–50 yr. This observation could suggest that sandy loam soil might have a better performance than clay loam soil in retarding the downward travel of nutrient. Since only one site of sandy loam soil is investigated in this project, more research is necessary to verify the finding from this study.

3.2. PHOSPHORUS

The soil phosphorus (Olsen-P) data for all barns are presented in Table III. Large variations have created difficulties in interpreting the data. For clay loam soils, the phosphorus level is obviously raised in the topsoil layer for the 10 yr barn (#2) with no statistical difference between inside and outside samples for the rest of sampling depths. For the 20 yr barn (#4), due to large variations in the outside samples, statistically significant differences between inside and outside for all samples and depths cannot be determined. However, if only the inside samples are examined, the topsoil layer shows a significantly higher phosphorus level than the rest of the sampling layers among which the mean values do not differ much from each other and may be considered as in the same magnitude. This observation implies that for clay loam soils, the accumulation of phosphorus only occurs in the topsoil layer. However, if the data for the 45 yr barn built on clay loam soils are examined, it can be seen that the phosphorus mean levels are raised in the upper two soil layers, which appears to suggest that a downward movement of phosphorus in the soil could take place as barns age. A strange situation was observed that the phosphorus in the control tends to be higher than those samples collected from inside for the 20- and 45 yr barns, which is difficult to explain. One possibility could be that the locations of the control samples were either farmland receiving heavy manure disposal or were turkey production sites at one time in the past. No confirmation of this hypothesis is available, however.

For barns built on loam soils, a scenario similar to that in clay loam soils is observed, i.e., the highest levels of phosphorus generally occurred in the topsoil (30.54 cm). Statistically, due to large variations in the data, there is no difference in phosphorus concentration in samples collected from 61 to 153 cm for all sites on loam soils regardless of site ages, except site #5. However, examining the mean values of the measurements does reveal the fact that topsoil layers contain much higher concentrations of phosphorus than the others, indicating a buildup of phosphorus in the topsoil layer. The tiered distribution of phosphorus concentration along the sampling depth for site #5 can be considered as evidence for this hypothesis. Therefore, it may be inferred that phosphorus is not apt to move downward and may primarily stay in the soil adjacent to the fresh manure. Based on the analysis for the above two soil textures, it may be concluded that phosphorus

TABLE III

The average Olsen-P and standard deviations for all turkey barn sites*

Sampling depth (cm)	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
	Clay loam soil							
	Barn #2		Barn #3		Barn #4			
	(n = 6)	(n = 3)	(n = 6)	(n = 3)	(n = 6)	(n = 3)		
30.54	19.6±7.0^{a,x}	6.6±1.7^{a,y}	45.4±17.7^{a,x}	77.4±37.9^{a,x}	68.7±0.4^{a,x}	77.4±46.4^{a,x}		
61.08	7.2±3.4^{b,x}	5.7±2.9^{a,x}	49.4±26.9^{a,x}	67.1±22.9^{a,x}	29.0±1.3^{b,x}	49.9±20.2^{a,x}		
91.62	7.7±3.2^{b,x}	6.1±1.9^{a,x}	21.7±9.3^{a,x}	29.2±25.5^{a,b,x}	25.3±1.2^{c,x}	29.6±7.7^{a,x}		
122.2	8.9±5.2^{a,b,x}	8.3±2.6^{a,x}	19.7±9.7^{a,x}	24.3±26.2^{a,b,x}	27.4±0.2^{d,x}	24.0±11.4^{a,x}		
152.7	8.1±3.5^{a,b,x}	6.7±1.0^{a,x}	25.3±18.4^{a,x}	21.6±12.4^{b,x}	32.4±0.5^{e,x}	22.8±14.0^{a,x}		
	Loam soil							
	Barn #1		Barn #5		Barn #8		Barn #9	
	(n = 6)	(n = 3)	(n = 6)	(n = 3)	(n = 6)	(n = 4)	(n = 5)	(n = 3)
30.54	36.0±31.0^{a,x}	11.1±1.9^{a,x}	159.7±42.2^{a,x}	149.1±67.8^{a,x}	155.1±162.2^{a,x}	112.4±9.6^{a,x}	104.3±89.6^{a,x}	35.3±31.3^{a,x}
61.08	4.9±1.1^{a,x}	7.1±1.4^{b,x}	40.4±7.4^{b,x}	58.2±25.5^{a,b,x}	35.5±31.2^{a,x}	67.5±25.8^{b,x}	13.0±9.6^{a,x}	23.6±30.4^{a,x}
91.62	4.9±1.3^{a,x}	7.4±1.0^{b,y}	30.3±15.0^{b,c,x}	27.3±14.3^{b,x}	45.0±26.2^{a,x}	22.6±8.3^{c,x}	18.5±13.6^{a,x}	15.3±14.6^{a,x}
122.2	5.9±1.6^{a,x}	6.7±2.9^{b,x}	15.3±4.4^{c,x}	35.8±4.8^{b,y}	42.7±30.3^{a,x}	18.4±9.8^{c,xx}	11.5±7.7^{a,x}	20.4±23.9^{a,x}
152.7	4.9±1.1^{a,x}	6.2±1.7^{b,x}	14.7±5.5^{c,x}	60.6±35.6^{a,b,y}	35.3±31.4^{a,x}	16.2±3.0^{c,x}	10.7±11.5^{a,x}	17.3±20.6^{a,x}
	Silt loam soil				Sand loam soil			
	Barn #6				Barn #7			
	(n = 4)	(n = 2,1)			(n = 4)	(n = 3)		
30.54	275.5±68.5^{a,x}	167.5±6.9^{a,y}			37.5±15.6^{a,x}	83.2±95.2^{a,x}		
61.08	77.8±80.9^{b}	144.8			19.0±9.5^{a,x}	25.8±19.3^{a,x}		
91.62	–	101.2			11.0±5.8^{a}	–		
122.2	–	82.7			13.7±6.3^{a}	–		
152.7	–	78.6			–	–		

* For comparisons between inside and outside samples at each farm, letters, a through e, indicate statistical difference at a significance level of α = 0.05 between rows, while letters x and y indicate difference between columns for each farm.

pollution of groundwater due to seepage may be very limited because of the fairly slow movement of phosphorus in the soil. Again, data from the barns built on silt and sandy loam soils are insufficient to generate legitimate conclusions. The reason why the control samples have higher concentrations of phosphorus than the inside-barn samples could be the same as described previously.

3.3. Organic matter

Table IV shows the percentages of organic matter in soil samples from all sites. Due to large variations, it is difficult to determine the effect of turkey operations on soil organic matter content for barns at all ages. It appears that the organic matter content is higher in the topsoil than in the deeper soil; however, similar situation is observed for the control samples as well. It is interesting to note that the average organic matter content in all the topsoil samples collected from the outside is higher than that of the samples collected inside the barns. A speculation may be made herein based on the current information that turkey litter may accelerate soil organic matter degradation, leading to its lower content in the soil as observed. This postulate cannot be verified in this study, however.

3.4. Ammonium nitrogen

Table V presents the distribution of ammonium nitrogen (NH_4-N) for all sites sampled. For all sites, the level of NH_4-N was significantly increased in the topsoil inside the barn compared to outside irrespective of the soil texture and age of the barn. However, the increase in NH_4-N concentration in subsequent layers greatly varied depending on the soil texture. It can be seen that, for loam soils, the level of ammonium nitrogen only statistically increased in the first 2 to 3 soil layers without regard to the age of barns (9 and 30 yr). Put together, these results imply that the downward movement of NH_4-N in the soil covered with turkey litter is limited to the topsoil only. In other words, the potential pollution of groundwater by NH_4-N leaching from commercial turkey operations may not be significant for barns in continuous operation for 30 yr if the groundwater table is below 91 cm. However, it has to be pointed out that although there is no statistical difference between the inside and outside samples for every comparison due to large variations, the average levels of NH_4-N for samples collected inside the barns are generally higher than those from outside in all depths, suggesting that soil layers below 91 cm deep could still be potentially affected. Therefore, extra caution has to be exercised when examining the possibility of polluting groundwater by turkey production sites.

For clay loam soils, the age effect somewhat appears obvious. For the 10 yr barn, only in the topsoil is the ammonium nitrogen level significantly higher than that of control. However, with the aging of the facilities, ammonium nitrogen tends to move downwards. This is reflected in data for the 20- and 45 yr barns, in which a NH_4-N level significantly higher than the control samples is observed down to 61 and 122 cm, respectively.

TABLE IV

The average percentage and standard deviation of organic matter for all sites (%)*

Sampling depth (cm)	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
	Clay loam soil							
	Barn #2		Barn #3		Barn #4			
	(n = 6)	(n = 3)	(n = 6)	(n = 3)	(n = 6)	(n = 3)		
30.54	$0.90\pm0.3^{a,x}$	$1.91\pm2.1^{a,x}$	$1.01\pm0.3^{a,x}$	$2.35\pm0.7^{a,y}$	$0.91\pm0.3^{a,x}$	$3.10\pm2.3^{a,x}$		
61.08	$0.83\pm0.3^{a,x}$	$0.63\pm0.3^{a,x}$	$0.97\pm0.4^{a,x}$	$0.64\pm0.2^{b,x}$	$0.64\pm0.3^{a,x}$	$0.97\pm0.4^{a,x}$		
91.62	$0.66\pm0.3^{a,x}$	$0.40\pm0.1^{a,x}$	$1.04\pm0.9^{a,x}$	$0.38\pm0.1^{b,,c,x}$	$0.58\pm0.3^{a,x}$	$0.85\pm0.5^{a,x}$		
122.2	$0.72\pm0.8^{a,x}$	$0.39\pm0.1^{a,x}$	$0.86\pm0.5^{a,x}$	$0.38\pm0.0^{c,x}$	$0.62\pm0.2^{a,x}$	$0.77\pm0.4^{a,x}$		
152.7	$0.46\pm0.1^{a,x}$	$0.49\pm0.1^{a,x}$	$1.00\pm0.8^{a,x}$	$0.33\pm0.1^{c,x}$	$0.68\pm0.3^{a,x}$	$1.52\pm1.8^{a,x}$		
	Loam soil							
	Barn #1		Barn #5		Barn #8		Barn #9	
	(n = 6)	(n = 3)	(n = 6)	(n = 3)	(n = 6)	(n = 4)	(n = 5)	(n = 3)
30.54	$1.07\pm0.3^{a,x}$	$2.31\pm2.1^{a,x}$	$3.82\pm0.6^{a,x}$	$4.17\pm0.2^{a,x}$	$1.31\pm1.1^{a,x}$	$4.76\pm1.1^{a,x}$	$1.82\pm1.2^{a,x}$	$3.31\pm2.7^{a,x}$
61.08	$0.74\pm0.3^{a,b,x}$	$0.86\pm0.4^{a,x}$	$2.30\pm0.3^{b,x}$	$1.78\pm0.4^{b,x}$	$1.54\pm1.1^{a,x}$	$3.15\pm1.0^{a,b,x}$	$1.07\pm0.7^{a,x}$	$2.61\pm3.4^{a,x}$
91.62	$0.87\pm0.4^{a,b,x}$	$0.48\pm0.2^{a,b,x}$	$1.93\pm1.0^{b,c,x}$	$0.83\pm0.3^{c,x}$	$1.99\pm1.2^{a,x}$	$1.47\pm0.8^{b,c,x}$	$1.54\pm1.6^{a,x}$	$1.83\pm2.6^{a,x}$
122.2	$0.58\pm0.2^{a,b,x}$	$0.62\pm0.1^{a,x}$	$1.28\pm1.0^{b,c,x}$	$0.94\pm0.9^{b,c,x}$	$2.02\pm1.6^{a,x}$	$0.70\pm0.3^{c,x}$	$0.88\pm1.5^{a,x}$	$1.71\pm2.5^{a,x}$
152.7	$0.57\pm0.1^{b,x}$	$0.41\pm0.0^{b,y}$	$0.72\pm0.6^{c,x}$	$2.50\pm3.3^{a,b,c,x}$	$1.84\pm1.9^{a,x}$	$0.28\pm0.2^{c,x}$	$0.38\pm0.6^{a,x}$	$1.51\pm2.4^{a,x}$
	Silt loam soil				Sand loam soil			
	Barn #6				Barn #7			
	(n = 4)	(n = 2,1)			(n = 4)	(n = 3)		
30.54	$3.10\pm1.0^{a,x}$	$4.10\pm0.1^{a,x}$			$2.20\pm0.8^{a,x}$	$3.23\pm2.0^{a,x}$		
61.08	$0.88\pm0.1^{b,x}$	3.1			$1.87\pm2.1^{a,x}$	$0.92\pm0.7^{a,x}$		
91.62	–	2.0			0.96 ± 0.9^{a}	–		
122.2	–	0.8			0.88 ± 0.8^{a}	–		
152.7	–	0.5			–	–		

* For comparisons between inside and outside samples at each farm, letters a, b, and c indicate statistical difference at a significance level of $\alpha = 0.05$ between rows, while letters x and y indicate difference between columns for each farm.

TABLE V

The averages and standard deviation of ammonium nitrogen for all sites (ppm)*

Sampling depth (cm)	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
	Clay loam soil							
	Barn #2		Barn #3		Barn #4			
	(n = 6)	(n = 3)	(n = 6)	(n = 3)	(n = 6)	(n = 3)		
30.54	$1201\pm286^{a,x}$	$30.5\pm6.07^{a,y}$	$2179\pm416^{a,x}$	$47.9\pm2.71^{a,y}$	$2178\pm630^{a,x}$	$34.1\pm5.75^{a,y}$		
61.08	$56\pm33^{b,x}$	$61.0\pm40.9^{a,b,x}$	$1057\pm288^{b,x}$	$82.9\pm27.9^{b,y}$	$529\pm522^{b,x}$	$35.8\pm13.3^{a,x}$		
91.62	$41\pm23^{b,x}$	$38.6\pm4.96^{a,b,x}$	$480\pm227^{c,x}$	$51.7\pm2.74^{a,y}$	$86\pm69^{b,x}$	$37.5\pm12.1^{a,x}$		
122.2	$38\pm14^{b,x}$	$78.7\pm60.8^{a,b,x}$	$241\pm171^{c,x}$	$42.5\pm14.0^{a,b,y}$	$48\pm22^{b,x}$	$44.3\pm12.6^{a,x}$		
152.7	$36\pm31^{b,x}$	$45.3\pm6.31^{b,x}$	$143\pm123^{c,x}$	$50.8\pm29.3^{a,b,x}$	$61\pm38^{b,x}$	$79.2\pm48.9^{a,x}$		
	Loam soil							
	Barn #1		Barn #5		Barn #8		Barn #9	
	(n = 6)	(n = 3)	(n = 6)	(n = 3)	(n = 6)	(n = 4)	(n = 5)	(n = 3)
30.54	$2223\pm267^{a,x}$	$30.0\pm5.98^{a,y}$	$1569\pm591^{a,x}$	$60.0\pm7.21^{a,y}$	$810\pm592^{a,x}$	$90.8\pm30.2^{a,y}$	$887\pm618^{a,x}$	$56.2\pm34.3^{a,y}$
61.08	$223\pm120^{b,x}$	$32.1\pm5.98^{a,y}$	$678\pm628^{a,b,x}$	$51.8\pm6.31^{a,x}$	$487\pm258^{a,x}$	$58.8\pm10.1^{a,y}$	$602\pm263^{a,x}$	$51.9\pm25.1^{a,y}$
91.62	$48\pm10^{c,x}$	$26.3\pm12.6^{a,b,x}$	$106\pm55^{b,x}$	$39.6\pm0.00^{b,y}$	$165\pm135^{a,x}$	$117\pm131^{a,b,x}$	$141\pm107^{b,x}$	$60.5\pm18.1^{a,x}$
122.2	$52\pm32^{c,x}$	$28.8\pm10.2^{a,b,x}$	$81\pm36^{b,x}$	$68.9\pm41.4^{a,b,c,x}$	$157\pm115^{a,x}$	$49.8\pm20.9^{a,b,x}$	$92\pm120^{b,x}$	$173\pm215^{a,x}$
152.7	$36\pm25^{c,x}$	$21.6\pm2.39^{b,x}$	$105\pm55^{b,x}$	$100.8\pm9.01^{c,x}$	$135\pm116^{a,x}$	$37.5\pm4.83^{b,x}$	$76\pm86^{b,x}$	$171\pm228^{a,x}$
	Silt loam soil				Sand loam soil			
	Barn #6				Barn #7			
	(n = 4)	(n = 1)			(n = 4)	(n = 3)		
30.54	648 ± 175^{a}	76.6			$1177\pm561^{a,x}$	$125\pm120^{a,y}$		
61.08	495 ± 158^{a}	132.7			$327\pm228^{b,x}$	$54.3\pm24.3^{a,y}$		
91.62	–	135.3			58.7 ± 27.2^{c}	–		
122.2	–	40.9			$77.1\pm62.9^{b,c}$	–		
152.7	–	39.7			–	–		

* For comparisons between inside and outside samples at each farm, letters a, b, and c indicate statistical difference at a significance level of $\alpha = 0.05$ between rows, while letters x and y indicate difference between columns for each farm.

It is interesting to note that the NH_4-N concentration is almost doubled in the topsoil when the barn is in operation from year 10 to year 20 but remains unchanged thereafter up to year 45. Although data are very limited, this may imply that the saturation concentration of clay loam soil for NH_4-N is around 2200 ppm and it will take about 20 yr of continuous operation to reach saturation. When saturation is reached, the holding capacity of NH_4-N by the soil can be considered maximized and exhausted so downward leaching of NH_4-N is expected to accelerate. To avoid this, it is suggested that the topsoil layer in turkey buildings should be replaced every 20 yr for areas where groundwater table is high (within 91 cm or so), and every 40 yr for areas where groundwater table is low (more than 153 cm below ground surface). This phenomenon is not observed for loam soil type.

The silt loam soil may have a poor capacity of holding nutrients because there are no differences in NH_4-N concentration between the first- and second-soil layers. However, the data from the silt loam soil barn are limited and have to be interpreted with this fact in mind. For the sandy loam soil, the concentration of NH_4-N is significantly high in the two topmost layers suggesting that penetration of this nutrient appears to have reached only these layers. Since the barn with a sandy loam soil has been in operation for 40–50 yr, it seems that the capability of preventing NH_4-N from moving down by sandy loam soil is as good as, if not better than, that of clay loam and loam soils. More data are needed to verify this observation.

3.5. Nitrate nitrogen

The nitrate nitrogen (NO_3-N) data for all the turkey sites sampled is presented in Table VI. Except for barns #6 and #7 where insufficient data were accumulated, all the other soils displayed a significant increase in NO_3-N inside the barn compared to outside in at least two soil layers (Table VI). For the clay loam soil, the barn of ten years of age has shown a NO_3-N penetration of about 61 cm deep in the soil. For barns older than ten years, the NO_3-N concentrations are significantly higher inside than outside throughout the entire sampling depth, a clear indication of penetration. Therefore, for areas of high groundwater (less than 153 cm from ground surface), it is recommended to replace the topsoil layer every ten years to obviate the potential pollution of water resource by NO_3-N. For areas of low groundwater, the frequency of replacing the topsoil layer may be reduced and should be considered on a case-by-case basis. The means of NO_3-N in the top two soil layers in the 45 yr barn are lower than their counterpart in the 20 yr barn, which could not be explained and could result from the unequal denitrification rates at the two sites. However, due to large variations in sample analysis, there is no statistical difference for such comparisons.

Similar scenarios are also observed for loam soil type in the sense that the nine-year barn indicates higher NO_3-N concentrations than the control in the first three soil layers, while for all the 30 yr barns, the levels of NO_3-N are higher than the

TABLE VI

The averages and standard deviations of nitrate nitrogen for all sites (ppm)*

Sampling depth (cm)	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
	Clay loam soil							
	Barn #2		Barn #3		Barn #4			
	(n = 6)	(n = 3)	(n = 6)	(n = 3)	(n = 6)	(n = 3)		
30.54	$1524 \pm 423^{a,x}$	$2.50 \pm 0.2^{a,y}$	$2432 \pm 1319^{a,x}$	$7.67 \pm 1.9^{a,y}$	$3880 \pm 842^{a,x}$	$3.32 \pm 0.8^{a,y}$		
61.08	$226 \pm 70.1^{b,x}$	$3.44 \pm 1.6^{a,y}$	$1686 \pm 806^{a,x}$	$6.09 \pm 2.2^{a,y}$	$2005 \pm 600^{b,x}$	$2.30 \pm 0.5^{a,y}$		
91.62	$12.66 \pm 7.7^{c,x}$	$3.28 \pm 2.5^{a,x}$	$830 \pm 477^{a,b,x}$	$7.80 \pm 2.5^{a,y}$	$717 \pm 278^{c,x}$	$3.01 \pm 1.7^{a,y}$		
122.2	$4.39 \pm 0.4^{c,x}$	$2.39 \pm 1.4^{a,y}$	$308 \pm 221^{b,x}$	$5.17 \pm 1.0^{a,y}$	$209 \pm 83.1^{d,x}$	$11.6 \pm 11.9^{a,y}$		
152.7	$6.46 \pm 5.0^{c,x}$	$2.39 \pm 0.9^{a,x}$	$93.7 \pm 105^{b,x}$	$6.44 \pm 2.3^{a,y}$	$53.1 \pm 35.9^{e,x}$	$2.93 \pm 1.6^{a,y}$		
	Loam soil							
	Barn #1		Barn #5		Barn #8		Barn #9	
	(n = 6)	(n = 3)	(n = 6)	(n = 3)	(n = 6)	(n = 4)	(n = 5)	(n = 3)
30.54	$2198 \pm 482^{a,x}$	$9.63 \pm 4.6^{a,y}$	$1801 \pm 155^{a,x}$	$12.4 \pm 0.1^{a,y}$	$334 \pm 284^{a,x}$	$18.6 \pm 5.0^{a,y}$	$703 \pm 491^{a,x}$	$25.5 \pm 31.1^{a,y}$
61.08	$694 \pm 189^{b,x}$	$4.82 \pm 0.6^{a,b,y}$	$1862 \pm 300^{a,x}$	$4.86 \pm 2.4^{b,y}$	$368 \pm 197^{a,x}$	$16.4 \pm 4.7^{a,y}$	$277 \pm 283^{a,b,x}$	$18.1 \pm 18.7^{a,x}$
91.62	$79 \pm 19.8^{c,x}$	$4.88 \pm 0.6^{a,b,y}$	$871 \pm 202^{b,x}$	$7.37 \pm 3.9^{b,y}$	$166 \pm 37.1^{ma,x}$	$19.6 \pm 15.7^{a,y}$	$76.9 \pm 68.5^{b,x}$	$12.1 \pm 6.9^{a,x}$
122.2	$8.75 \pm 4.3^{d,x}$	$5.53 \pm 0.9^{a,x}$	$219 \pm 142^{c,x}$	$11.4 \pm 9.3^{a,b,y}$	$149 \pm 162^{a,x}$	$15.8 \pm 14.4^{a,x}$	$28.1 \pm 17.7^{b,x}$	$7.46 \pm 3.0^{a,x}$
152.7	$7.68 \pm 2.1^{d,x}$	$4.28 \pm 0.4^{b,y}$	$88.5 \pm 59.3^{c,x}$	$11.3 \pm 12.5^{a,b,y}$	$99 \pm 146^{a,x}$	$12.8 \pm 7.2^{a,x}$	$33.9 \pm 19.8^{b,x}$	$7.51 \pm 2.1^{a,y}$
	Silt loam soil				Sand loam soil			
	Barn #6				Barn #7			
	(n = 4)	(n = 2,1)			(n = 4)	(n = 3,1)		
30.54	914 ± 550^{a}	5.7			2370 ± 605^{a}	13.3		
61.08	605 ± 375^{a}	2.7			571 ± 439^{b}	32.4		
91.62	–	2.2			107 ± 19.8^{b}	13.3		
122.2	–	2.4			101 ± 97.5^{b}	–		
152.7	–	6.0			–	–		

* For comparisons between inside and outside samples at each farm, letters, a through e, indicate statistical difference at a significance level of $\alpha = 0.05$ between rows, while letters x and y indicate difference between columns for each farm.

control in most depths, indicating a downward movement of this nutrient in soil over time. It appears that, to avoid potential pollution of groundwater by NO_3-N, measures that are similar to those recommended for the clay loam soil above may be employed to reduce or defer the downward movement of NO_3-N. Again, this has to be considered case by case in combination with various management plans.

For silt loam soil, the seepage has apparently gone through the sampling depth, i.e., 61 cm below the ground surface, after the sites being in operation for 40–50 yr. The sandy loam soil indicates a better holding capacity of NO_3-N than silt loam soil because the NO_3-N concentration in topsoil is significantly higher ($p < 0.05$) than the concentration of this nutrient in all the other sampling depths. This argument may be supported by comparisons made along the sampling depth for the two soil types. It can be seen that there is no statistical difference in NO_3-N concentration between the top two layers for silt loam soil but there is for sandy loam soil.

4. Conclusions

According to the pH analysis, for barns built on clay loam soils, the deep-bedded turkey litter have the potential to reduce soil pH and, thus, may impact soil characteristics and groundwater quality located 122 cm below the surface if the barns are in continuous operation for 45 yr or longer. For barns built on loam soil, it may be inferred that the manure effect on soil mineral N up to 153 cm sampling depth may occur in less than 30 yr. For turkey barns built on either a sand or a silt loam soil, the current data are insufficient to make legitimate conclusions on the rate of downward leaching of nutrients in the soil.

Based on the phosphorus analysis, it may be inferred that the manure phosphorus tends to stay in the topsoil for both loam and clay loam soils. Therefore, the phosphorus pollution of ground water resource due purely to seepage may not be severe. In addition, the data indicate that clay loam soil is able to keep phosphorus from moving down by at least ten to twenty years, implying that the downward movement of phosphorus into clay loam soil could be a relatively slow process. This means that the chance of phosphorus leaching to the groundwater through clay loam soil is unlikely if the water table is 153 cm below the ground surface. Again, data from the barns built on silt loam and sandy loam soils are insufficient to generate legitimate conclusions.

The influence of turkey litter on soil organic matter content may not be significant based on the data collected from this study.

According to the data, the downward movement of ammonium nitrogen in loam soil covered with turkey litter is limited to the topsoil only. Thus, the potential pollution of groundwater by ammonium nitrogen leaching may not be a problem for barns in continuous operation of 30 yr. Although the ammonium-N data were quite variable resulting in no statistical differences in most instances, the average concentrations are higher inside than outside, suggesting the need for extra caution when determining the possibility of ammonium-N polluting groundwater. For the clay loam soil, it seems that the saturation of ammonium nitrogen in the topsoil is reached in 20 yr of continuous operation. Therefore, it may be suggested that the topsoil layer in turkey buildings be replaced every 20 yr for areas of high groundwater (within 91 cm or so), and every 40 yr for areas with low groundwater (greater than 153 cm). Obviously, this suggestion may not be practical for most turkey operations. However, if the concern of groundwater pollution becomes an issue that threatens the growth of turkey industry, the measures recommended in this paper may offer an option to the growers. Silt loam soils may not be suitable for turkey litter sites because of the poor retaining capacity of nutrients, while sandy loam soil needs further research.

For the clay loam soil, the nitrate nitrogen can leach about 61 cm deep in ten years. For barns older than ten years, it is observed that the nitrate nitrogen concentrations are significantly higher inside than outside of barns throughout the 153 cm sampling depth. Therefore, it is recommended to replace the topsoil layer, in instances where the barn is located on a clay loam soil, every ten years to obviate the potential pollution of groundwater resource by nitrate leaching. Similar measures may also be needed in cases where the barn exists on a loam soil. Further research on barns located on silt loam and sandy loam soils is warranted before definite conclusions can be drawn.

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