Annals of Tropical Research 28(1):14-35

Nitrate concentrations in animal manure dumping sites

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ABSTRACT

Sebial M. C. and L. S. Sonon. 2006. Nitrate concentrations in animal manure dumping sites. *Ann. Trop. Res.* 28(1):14-35

This study aimed to characterize the chemical and physical properties of soil, and measure the nitrate concentrations at varying soil depths in the manure disposal sites of the Leyte State University piggery and beef cattle projects. Soil chemical analysis revealed that organic matter in both the piggery and beef cattle areas were concentrated in the upper 20 cm and gradually decreased with depth. A similar trend was observed for total N where the 0-20 cm depth contained approximately 0.30% N and this level decreased in the deeper soil layers. The soil in the piggery area was slightly acidic (pH 5.30) while that in the cattle area was near neutral (pH 6.50). The entire soil profile in both sites was generally highest in nitrate at the surface and decreased with depth. Nitrate concentrations were relatively higher when there were more animals in the project site. Solution samples from 120 cm lysimeters yielded high levels of nitrate (about 200 mg L^{-1}), an indication that this ion was being moved to greater soil depths.

Keywords: soil nitrate concentrations, animal manures, dump sites

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INTRODUCTION

The use of animal manures as organic fertilizers to crops has long been practiced by farmers. They include chicken dung, cattle, swine, sheep and goat manures. They are considered as complete fertilizers since they contain nitrogen, phosphorus and potassium with some amount of molybdenum (Magdoff, 1978). Uincho (1959) reported that the average composition of farm manure is 0.5% nitrogen, 0.25% phosphoric acid and 0.5% ash. A ton of manure could supply 5 kg nitrogen, 2.5 kg phosphorus and 5 kg potassium. In addition, Tisdale and Nelson (1975) stated that manures increase the cation exchange capacity of soil since they serve as the storage of nutrients. Manure releases its nutrients fastest when the soil provides warm, moist condition favorable for microbial decomposition. Aside from their effect on the chemical properties on soils, manures contribute to the improvement of the soil physical properties like aggregation, porosity, and water holding capacity, which in turn will permit faster movement of air and water to move down into the soil leaving less water to move horizontally on surface erosion. All of these properties are essential to the growth and development of crops (Cooke, 1975).

Manure fertilizers generally originate from livestock industries engaged in commercial scale. In swine operation, the volume of manure production average about 3.8 L per 45 kg animal per day (Pontin and Baxter, 1968). Wet manure contains 5-9% total solids, 83% of which may be volatile. In a dairy cattle (*Bus indicus*) operation, manure production ranges from 33-65 kg with an average of 39 kg per animal per day (Loehr, 1970).

Surface spreading of manures is the most common method of manure disposal. Handling and disposal of manure, however, becomes a problem when its utilization as a fertilizer is not a component of the farming activities and operation. This is particularly true in dumping sites where deposition of animal wastes exceeds the loading capacity of the soil. Manures impart foul odor and may harbor insect pests that cause crop damage if there is heavy application.

Another concern from heavy deposition of manure is the release of nitrogen and other compounds to the environment at rates exceeding the soil's agronomic loading rate. Nitrogen compounds and other soluble chemicals not used by plants or assimilated or decomposed by microorganism may leach below the four-foot soil profile (Giddens *et al.*, 1973) and reach the groundwater. Nitrate-nitrogen is considered a groundwater pollutant because it is mobile in the soil. Such pollution may cause hazard to human and animal lives that depend on the groundwater as source of drinking water. Health hazard is set at 10 mg L^{-1} NO_3- - N (44 mg L^{-1} NO_3-) in drinking water because of the possibility of causing methemoglobinemia because bacteria in their systems can reduce nitrates to much more toxic nitrites (Donahue, 1970). Moreover, high levels of nitrates may increase the risk of eutrophication (Miller and Donahue, 1990).

To minimize pollution of groundwater, it is essential to follow recommended manure application rates. In manure dumping sites however, information on the consequences of applying manure in excess of the soil's safe loading capacity is lacking. This study determined the effect of continuous application of manure on the chemical and physical properties of soils and measured the concentration of nitrates at different depths at various times of manure deposition.

MATERIALS AND METHODS

Site selection

The study was conducted at the pig and cattle waste disposal sites of the Livestock Production Projects of the Department of Animal Science and Veterinary Medicine, LSU, Baybay, Leyte. The waste disposal system of the piggery production project, in operation for approximately 15 years, was an open box type collection pond (lagoon) with porous concrete sidewalls but open at the bottom end for vertical seepage of the liquid waste. Designed originally to contain waste volume commensurate to the size of piggery operation, poor management had virtually rendered the disposal system inadequate as the lagoon became increasingly silted with wastes spilling over to wider surrounding areas after heavy rains. The present study was located near the lagoon and along an inland waterway that drained into nearby stream.

The piggery population consisted of 10 breeders (2 years), 4 gilts (6 mos. old), 5 grower finisher (3-4 mos. old), 3 starter (2 mos. old), and 18 piglets on weanlings (30-35 days old). Feed requirements varied between pig age group. The Leyte State University Piggery history records indicated that the feed utilization efficiency was 40% (personal communication, piggery in-charge). Feed utilization efficiency was defined as the ratio of feeds consumed to the feeds given to animals per unit time.

The cattle project, located 50 meters west of the Piggery Project, consisted of two adjacent barns that housed dairy and beef cattle with total animal population varying between 48 to 60 heads. Manures were deposited 3 meters from the barns on a grassy site measuring 5 meters (length) by 4 meters (width). The area was practically unconfined where manures splashed and dispersed over a wide area during heavy rains.

Preparation of lysimeters

The vacuum lysimeter consisted of a ceramic cup (7 cm length and 0.7 cm inner diameter), and polyvinyl chloride (PVC) pipes of three different lengths (20, 60 and 120 cm). The cup was a porous material composed of 55 % Al_2O_3 , 35 % SiO_2, and small amounts of Fe_2O_3, TiO_2, CaO, MgO and Na_2O, K_2O and SO_3 (Creasy and Dreiss, 1998). The ceramic cups were attached to lengths of PVC pipes with epoxy cement. Following the procedures of Sonon (1992), lysimeters were soaked in 8 M HCl solution and rinsed well with distilled water prior to use.

Installation of lysimeters

Three 1-m^2 quadrants (plots) were established near each manure site (piggery and cattle) and secured from stray animals and intruding pedestrians with a wire fence. Three lysimeters of various lengths (Fig 1) were installed in each plot.

Using a bucket auger, holes were cored to appropriate depths and soils were removed. Lysimeters were then inserted and set firmly into the holes. A sufficient quantity of soil from the bottom of the hole was poured back followed by slight tamping to insure good contact between the porous cup and the

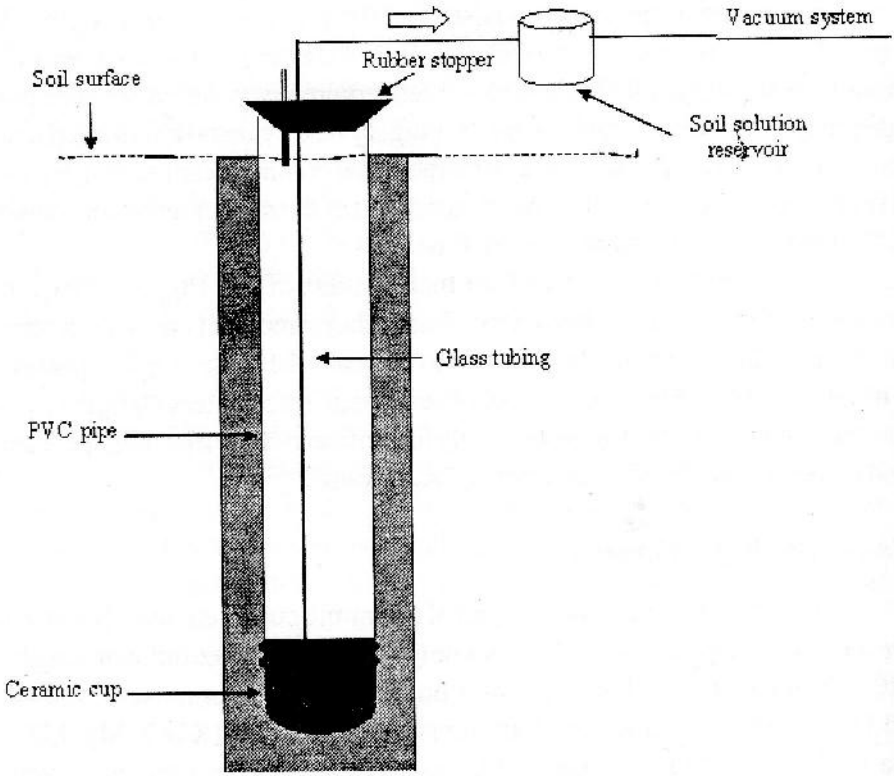

Figure 1. Schematic diagram of lysimeter solution sampler and vacuum system.

surrounding material.

Soil sampling and laboratory analysis

Soil samples were collected from various depths (0-5, 5-10, 10-20, 20-40, 40-60 and 60-120 cm) at the start of the study and followed by a monthly sampling during the ensuing ten-week period. Two 120-cm soil cores were extracted from each plot using a soil auger and cores were subdivided into desired depth intervals. The auger was thoroughly washed with distilled water in-between soil core extraction to minimize cross contamination of soil samples. To avoid formation of preferential flow paths within the plot, the holes were back filled with soil materials from uncontaminated adjacent area.

Soil samples were analyzed for physical and chemical properties at the Soil Chemistry Laboratory of the Department of Agronomy and Soil Science, LSU, Baybay, Leyte. The initial soil samples were analyzed for particle size distribution (Gee and Bauder, 1986), soil pH at 1:1 soil/water mixture, organic matter (OM) content (Nelson and Sommers, 1982), nitrate (NO_3-) and total N concentrations (Bremner and Mulvaney, 1982). The succeeding monthly soil samples were analyzed for OM content, NO_3-, and total N concentrations. Soil NO_3- was extracted by adding 25 mL of 0.10 M KCl to 10-g soils, agitated for 1 hour, and filtered through #42 Whatman filter paper. Soil NO_3- was quantified using a specific ion electrode coupled to a double junction reference electrode (Orion 90-12 attached to a pH millivolt meter).

Soil solution sampling

Water sampling in each lysimeter was done every week and after each heavy rain within a period of four (4) months. Lysimeters at depths <120 cm did not yield enough liquid for analysis. A negative pressure (60 psi) was applied to each sampler after which, the lysimeter was sealed from the atmosphere for 24 hours. Soil solution was siphoned out using a hand operated portable pump (Fig. 1). Each lysimeter was purged of residual solution using distilled water prior to the next sampling period. The solution samples were refrigerated at 4^0C until NO_3- analysis was done.

Nitrate (NO_3^-) analysis of soil solution

A 1-mL aliquot (soil solution) and 25-mL of Ionic Strength Adjustor (ISA) were mixed in a beaker for about 5-minutes using a glass stirring rod. The NO_3^- concentration was read directly in a millivolt meter equipped with specific NO_3^- electrode coupled to a double junction reference electrode as mentioned earlier. Fresh standards were prepared using KNO_3 at concentrations 0.5, 1.0, 2.0, 5.0 and 10.0 mg L^{-1} NO_3- in every sampling period. If concentration did not fall within the range of standards, necessary dilutions were made.

Data analysis and interpretation

Graphical presentation of NO_3^- concentration-depth relationship as a function of time was developed for each study site. Mean NO_3^- concentrations in each depth in every sampling period were calculated and used in establishing trends graphically. The results were related to the management practices of the area, physical and chemical properties of the soil and precipitation data.

Meteorological data

Data on daily rainfall throughout the conduct of the study was taken from the records of the PAG-ASA Agrometeorological Station, LSU, Baybay, Leyte.

RESULTS AND DISCUSSION

I. Soil properties

Particle size distribution

The particle size distribution of soil in the piggery and cattle sites are depicted in Figs. 2A and 2B, respectively. Sand contents in both sites were high (>60%) and classified as loamy sand. Textural discontinuity was noted in the piggery site where clay and silt contents decreased at the 40-cm layer but started to rise at the 120-cm depth. There was an apparent deposition of fine fractions in deeper horizons. The cattle site exhibited a more gradual change in particle distribution but the clay particle fraction tended to increase at the 120-cm depth.

Organic matter

In the piggery site, OM was concentrated at the upper 20 cm and gradually decreased with depth (Table 1). The highest OM content was obtained during the month of August but concentrations decreased sharply in November. It was obvious that the population of animals determined the potential level of OM in soils. The study started with more animals (August) in the project site, but eventually decreased upon disposal of animals when they reached marketable age. During this time, OM at the 0-5 cm depth decreased from 6.58% in August to 2.51% in November. This change was noted throughout the soil profile tested. When young-aged pigs were added to replace the disposed ones in December, OM started to increase again. In the cattle site, OM was also concentrated at the upper 20 cm depth but decreased to levels near zero beneath the 20 cm depth (Table 2). As in the piggery area, OM gradually decreased at upper 20 cm except in December probably due to the decreasing number of animal heads. There were 60 heads of cattle at the start of the monitoring activity and later was reduced to 48 heads after marketing some of them.

Total N (%)

The total N (%) in the soil profile follows the distribution pattern as that of organic matter in both study sites (Tables 3 & 4). Total N (~0.30%) was high at the surface and decreased to near zero at 120 cm depth. Furthermore, result also showed changes of total N with sampling period perhaps due to different amount of manure deposition. At the start of the experiment, there was higher manure deposition and decreased as sampling progressed.

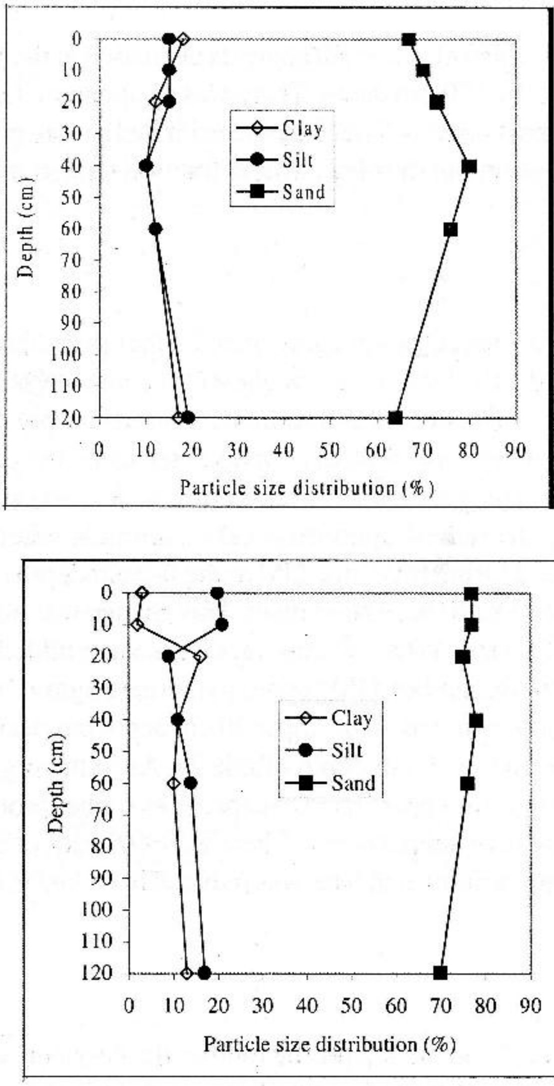

Figure 2. Particle size distribution at different soil depths in piggery (A) and cattle (B) project sites.

Table 1. Organic matter content (%) of the piggery area at varying soil depths from August to December, 1999.

Depths (cm)	Sampling Time, 1999				
	August	September	October	November	December
0-5	6.98	5.99	4.57	2.51	4.73
5-10	5.85	4.59	2.10	1.65	3.79
10-20	5.07	2.80	2.08	2.02	2.25
20-40	2.68	2.05	2.10	1.04	0.54
40-60	1.67	1.33	0.50	0.63	0.67
60-120	1.13	1.53	0.77	0.59	1.01

Table 2. Organic matter content (%) of the beef cattle area at varying soil depths from August to December, 1999.

Depths (cm)	Sampling Time, 1999				
	August	September	October	November	December
0-5	6.33	6.55	3.70	4.50	7.32
5-10	5.25	4.50	2.46	2.76	5.95
10-20	2.94	3.98	1.77	1.24	5.78
20-40	0.84	2.35	0.37	0.47	3.08
40-60	0.50	1.17	0.43	0.25	1.48
60-120	0.83	1.43	0.05	0.65	1.35

Consequently, N content was relatively higher at the start and decreased with time.

Soil pH

The initial and final soil pH of the piggery area ranged from 5.3 to 5.7 and 5.5 to 5.9, respectively (Table 5). It appeared that the area had been acidified from continuous manure deposition because the pH of adjacent non-contaminated areas was near neutral (~pH 7.0). On the other hand, the initial and final soil pH of the cattle area ranged from 6.45 to 6.75 and 6.5 to 6.75, respectively (Table 6). These values are considered to be near neutral.

II. Nitrate Concentration in Soils

A. Piggery area

Nitrate in soil extracts

Result of the study indicated that nitrate concentration was generally highest at the surface and decreased with depth (Fig. 3). During the first sampling, nitrate was concentrated (25.35 mg kg^{-1}) at the surface and decreased to about 5 mg kg^{-1} at the 120 cm depth. This result could also be attributed to higher amount of OM and total N at the surface and decreased with depths. As sampling progressed to the fourth period (4 months since start of the study), nitrate levels in all depths decreased (<5 mg kg^{-1}). This could be due to lower amount of OM and N contents of the soil. On the fifth sampling (December), nitrate concentrations throughout the profile started to increase again (>5 mg kg^{-1}).

The foregoing trend could be attributed to the livestock population in the piggery. At the start of our monitoring activity, there were 60 heads of 3-5 month old pigs raised. With time, this population gradually decreased as pigs were disposed when they attained marketable weight. Consequently, waste deposition would be expected to be high at the start and should have dwindled with time. As the manure decomposed and further nitrification occurred, nitrates were subsequently released. Thus, high nitrate residues were observed at the

Table 3. Total nitrogen content (%) of the piggery area at varying soil depths from August to December, 1999

Depths (cm)	Sampling Time, 1999				
	August	September	October	November	December
0–5	0.32	0.19	0.23	0.12	0.23
5–10	0.24	0.22	0.18	0.10	0.21
10–20	0.20	0.13	0.16	0.07	0.14
20–40	0.18	0.12	0.18	0.07	0.04
40–60	0.11	0.09	0.12	0.07	0.05
60–120	0.03	0.09	0.09	0.05	0.06

Table 4. Total nitrogen content (%) of the beef cattle area at varying soil depths from August to December, 1999.

Depths (cm)	Sampling Time, 1999				
	August	September	October	November	December
0–5	0.29	0.30	0.22	0.19	0.28
5–10	0.26	0.21	0.17	0.18	0.25
10–20	0.12	0.19	0.13	0.11	0.25
20–40	0.14	0.09	0.07	0.06	0.13
40–60	0.08	0.07	0.05	0.04	0.11
60–120	0.08	0.08	0.06	0.05	0.14

Table 5. Soil pH of the piggery area at varying soil depths sampled in August and December, 1999.

Depths (cm)	Soil pH	
	Initial (August, 1999)	Final (December, 1999)
0 - 5	5.30	5.50
5 - 10	5.35	5.55
10 - 20	5.65	5.75
20 - 40	5.70	5.75
40 - 60	5.60	5.80
60 - 120	5.45	5.90

Table 6. Soil pH of the beef cattle area at varying soil depths sampled in August and December, 1999.

Depths (cm)	Soil pH	
	Initial (August, 1999)	Final (December, 1999)
0 - 5	6.50	6.55
5 - 10	6.45	6.55
10 - 20	6.65	6.50
20 - 40	6.70	6.75
40 - 60	6.55	6.65
60 - 120	6.70	6.70

early part of the study and decreased up to the fourth sampling.

At about the time when the fifth soil sampling was performed (later part of November), new batch of pigs were raised to replenish the ones that were sold already (40 heads). Perhaps, it is for this reason that nitrate concentrations from the surface down to the 120 cm depth during the fifth sampling started to increase again. Such observation strongly suggests the ease with which nitrate could migrate in soils.

It is important to mention that this area has been used as dumping site for pig manures for several years already. Expectedly, the soils generally contain higher nitrate residues than any other agricultural soils. Once nitrate is formed, it could easily be carried by water and leached to greater depths. As found by Evans *et al.* (1977) in their three-year study manure treated plots had more nitrate in the soil down to 90 cm in the first year down to 240 cm in the second year and down to 360 cm by the third year. Nitrate from manure decomposition and nitrification moved rapidly through soil and built up at deeper layers each year. So in our present study, it was possible for nitrate to have accumulated at greater depths but a large fraction could have been transformed to other forms, i.e., through denitrification.

Nitrate in lysimeter samples

All the lysimeters except at 120 cm depth did not yield enough volume of solution samples for the analysis. Thus, the following discussion refers only to solution samples from 120 cm depth.

Figure 4 shows the nitrate concentration and the amount of rainfall at different sampling times. The result indicated that NO_3- concentrations at the 120 cm depth markedly fluctuated throughout the duration of the study. On the first week, mean nitrate concentration was measured to be at 94.64 mg L^{-1} and it increased to 120 and then to 186.52 mg L^{-1} during the second and third samplings, respectively. Mean nitrate concentration remained unchanged (188 mg L^{-1}) on the fourth week. From the fifth to seventh week of sampling, nitrate concentrations decreased. Then at later part of monitoring (8th to 10th week), nitrate concentration tended to increase again from 55.29 to 90.91 mg L^{-1}.

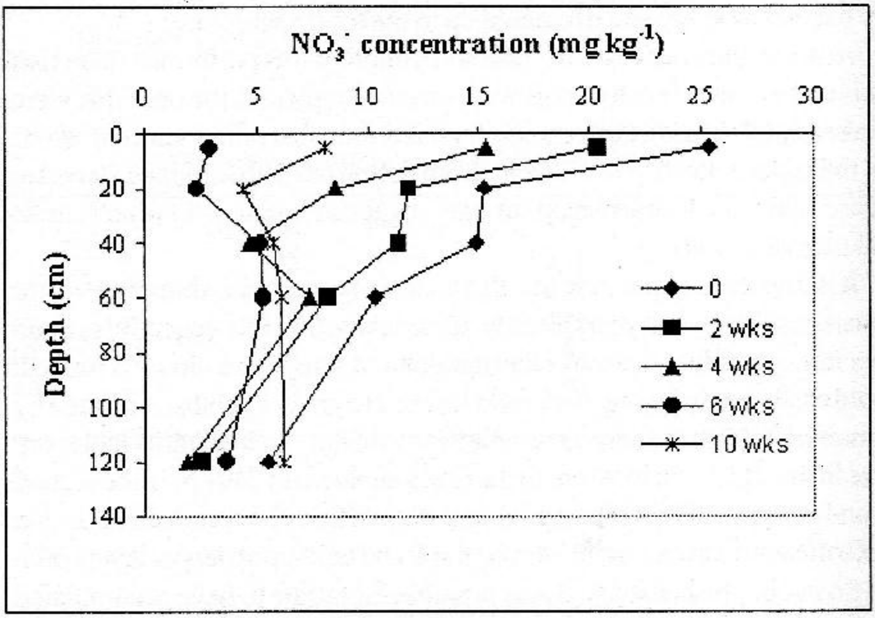

Figure 3. Nitrate concentration (mg kg^{-1}) in the soils of pig manure disposal site as a function of time at different depths. Weeks (wks) refer to time elapsed from the start of monitoring activities. Each point represents the mean of three replicates.

Figure 4 further illustrated the inclination of nitrate to move consequent to the amount of precipitation received. During the entire monitoring period, nitrate concentration peaked (188 mg L^{-1}) when the amount of rainfall received was at 280 mm. The foregoing trends clearly indicated that nitrate moved in response to the amount of manure deposited at the surface and the climatic conditions that prevail during the conduct of the experiment. As explained in the previous section, there were number of pigs at the start of the study and it decreased with time as some animals were sold. At high manure deposition, there existed a high potential for nitrification. Being a negatively charged ion, the interaction of nitrate with the soil materials (such as adsorption) would be minimal and instead it could easily move down to greater depths with moving water. As described by Jury and Nielson (1989), the movement of nitrate ion through the soil is governed by convection or mass flow with the moving solution.

Another factor that could have played a major role in the mobility of nitrate in soil is texture. The soil texture of the piggery area is sandy loam in which sand is >60% and clay is only <20%. The loose texture of the soil in the study site was favorable for a relatively fast water infiltration and percolation which allow water and nitrate to move through the profile easily. High rainfall creates downward hydraulic gradients and considerable leaching would result in the removal of nitrate from the soil.

Although not determined in this study, another avenue of nitrate loss in soils could be denitrification. Denitrification is the biological reduction of nitrate (NO_3^-) to dinitrogen (N_2) if the reaction goes to completion. During heavy rains, the diffusion of gases in and out of the profile could be restricted resulting in the creation of an anoxic environment. So, when nitrate moved to these anaerobic zones and in the presence of denitrifiers, it could be easily denitrified to NO_2, N_2O and N_2 either singly or in combination. Many studies have indicated that there is an increase in denitrifiaction with an increase in soil moisture content (Bremner and Shaw, 1958 and Malhi *et al.* 1990).

B. Beef cattle area

Nitrate in soil extracts

The nitrate concentration at different sampling times and depths are shown

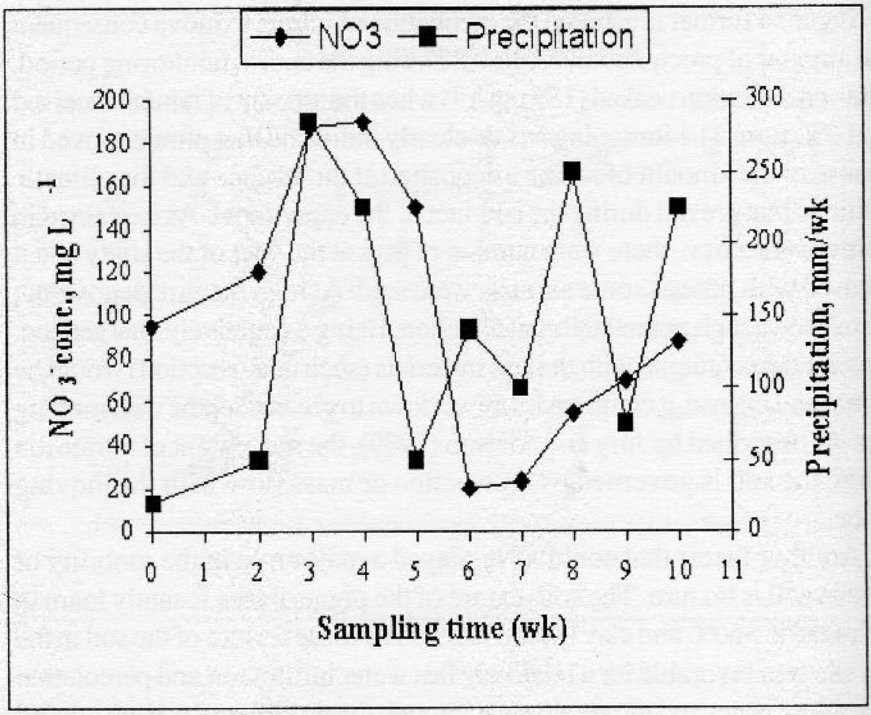

Figure 4. Relationship between nitrate concentration (mg L^{-1}) in 120-cm lysimeters of pig manure disposal site and the amount of rainfall (mm) received.

in Figure 5. As in the piggery area, nitrate concentration was generally highest at the surface and decreased with depth. This trend could be due to high amount of OM, total N and pH which favors nitrification process. During the first and second samplings, nitrate levels at the surface were 58.68 mg kg-1 and 63.39 mg kg^{-1}, respectively. However, in subsequent samplings, nitrate concentrations decreased. This decreasing trend in nitrate with time could be due to the increase in the mount of manure deposited as cattle population during the first 2 months was 60 and later reduced to 48. Since manure was being deposited at the surface, it was expected that it is in this soil layer that would exhibit greater response to variability in manure deposition as well as OM and N contents in the soil. Thus, a significant decrease in nitrate concentration was observed at the 0-10 cm depth during the third month as a result of declining number of animal heads. Moreover, the data also clearly indicated that nitrates were being leached down to lower depths. This is attributed by the fact that the soil has a coarse texture. Below the 0-40 cm sampling depths, nitrate concentration decreased from the first two samplings to the third. However, in the fourth sampling nitrate concentrations in the lower depths (40-120 cm) went up, which is clear evidence that some nitrates were leached down. In the succeeding sampling, nitrate concentrations in these depths were found to have decreased. This reduction could be due to the transformation of nitrate into other forms of further leaching to lower depths would have occurred between the fourth and fifth sampling. According to Kimble *et al.* (1972), a decrease in nitrate leached in the profile is associated with higher denitrification rates.

IMPLICATIONS OF THE STUDY

Manure is always viewed as a source of nutrients for crops and a good soil ameliorant as it can improve the soil's chemical and physical properties. However, in areas where manure is available in excessive quantities as in dumping sites, its effect on the environment is often overlooked. In this study, nitrate from the deposited manure was found to accumulate at the surface and large fraction of it has moved to greater depths. The movement of nitrate was

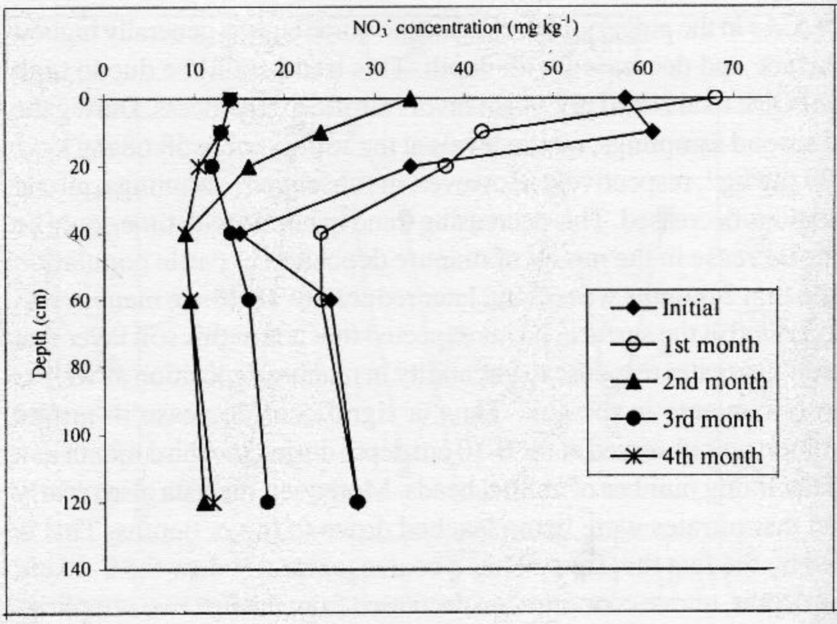

Figure 5. Nitrate concentration (mg kg^{-1}) in soil as a function of time and soil depth in Beef Cattle area

triggered by the presence of abundant rainfall and the loose texture of the soil. Although the nitrate monitoring activity in this study was confined only to the upper 120 cm depth of the profile, there was a potential for this ion to leach further and reach the groundwater. Once nitrate contaminates the groundwater, remediation is known to be extremely difficult.

The health implications of nitrate in the groundwater include the condition of infant methemoglobinemia in which infants ingest high levels of nitrate through their drinking water. Recent evidence shows that nitrate also enhances the formation of cancer causing agents, and nitrous amines.

With the above mentioned findings of this study and some reported health implications, it should be a concern for the animal industry to have an effective disposal strategy for the large quantities of manure. Continuous loading of nitrate in the soil could pose a more serious threat to the groundwater. Waste management strategies should include proper waste disposal as well as proper waste storage facilities especially in highly vulnerable area (sandy soils with abundant rainfall).

CONCLUSION AND RECOMMENDATIONS

Conclusions

1. The piggery and beef cattle areas have high organic matter content, and total N while pH was lower in the former and higher in the latter area.
2. Nitrate concentration in soil extracts both in piggery and cattle areas was generally highest at the surface and decreased with depth and sampling time.
3. Significant leaching of nitrate occurs in the piggery area when precipitation was abundant.

Recommendations

It is recommended that a follow up study be conducted to examine further the fate of nitrate beyond the depth of sampling employed in this study. Furthermore, it is equally important to measure/determine extent of denitrification in the two sites.

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