Soil Property and Landscape Position Effects on Seasonal Nitrogen Mineralization of Composted Dairy Manure

Dexter B. Watts, H. Allen Torbert, and Stephen A. Prior

Abstract: To develop better management practices that optimize the N derived from manure, additional research is needed regarding the mineralization and dynamics of N under field conditions. Thus, an *in situ* field study using three different soil types located in an agricultural field was conducted to evaluate N mineralization patterns during the summer and winter months. The three Coastal Plain soils (Ultisols) investigated were Bama (sandy loam), Lynchburg (loam), and Goldsboro (loam), representing the landscape position of a summit, drainageway, and sideslope, respectively. Composted dairy manure was incorporated into *in situ* soil cores, at a rate of 350 kg N ha^{-1}, to evaluate mineralization rates of the soils and their landscape position during the summer and winter months. Addition of composted dairy manure on N mineralization was impacted by season and soil type. This was most evident during summer months (N mineralization was 24%), suggesting that seasonal timing of application will influence mineralization. The seasonal patterns of N mineralization were affected mostly by temperature; N mineralization was minimal during winter (N mineralization was 2%) when temperature was low ($\sim$10 °C) but was greater during summer with higher temperatures (25 °C–30 °C). Landscape and soil texture played an additional role in mineralization. The soil type with the greatest percentage of sand and located in a low-lying area, although N mineralization was low during the winter months, significantly lost more of the added N from dairy compost (80%–90% more) compared with the other soils. During the summer, the loam soil with the greatest water-holding capacity mineralized the most N, significantly mineralizing 9% to 10% more than the other soils. These results show that soil variability, temperature, and landscapes need to be considered when applying manure to agricultural fields.

Key words: N mineralization, manure, landscape position.

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In crop production, nutrient availability from manure has been recognized for many centuries. Before the introduction of inorganic fertilizers, manure was the primary source of nutrients for crop production. Recently, there has been a renewed interest in use of manure because of the large amounts generated by increased animal production in confined areas. This interest is attributed to concerns for maintaining sustainable agricultural production while preserving the environment. Therefore, to develop management practices that increase N use efficiency (NUE), more knowledge is needed on manure mineralization rates as it affects inputs, losses, and transformation of N in the soil during the growing (summer months) and fallow (winter months) seasons.

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When applying manure during these periods, farmers usually apply at uniform rates, with the assumption that N sources, sinks, and mechanisms for loss are constant across fields (Delgado, 2002), thus failing to account for variability within fields. Such practices indicate that agricultural fields can be vulnerable to N loss. Estimates of worldwide NUE are about 30% to 50% in most agricultural soils, subjecting the excess to leaching or runoff. Soil type is an important factor affecting NUE. For a coarse soil (e.g., sandy soil), N losses are potentially subjected to NO_3 leaching. If the soil is a fine textured (e.g., clay loam), soil N loss may be less because of a higher retention capability of the soil (Delgado, 2002). In addition, it has been reported that manure increases NO_3 leaching compared with inorganic N fertilizer when applied at equivalent N rates (Roth and Fox, 1990; Jemison and Fox, 1994). This is attributed to N mineralization of manure during winter months, resulting in NO_3 generation during periods without crop N uptake.

Nitrogen mineralization is the process by which organic N in manure and other organic material is transformed into inorganic forms that are more readily available to plants. This mineralization process is affected by several factors such as the organic composition of the residue (Whitmore, 1996), soil temperature and water content (Katterer et al., 1998), drying and rewetting events (Kruse et al., 2004; Watts et al., 2007), soil texture (Torbert and Wood, 1992), and other soil characteristics (Schjonning et al., 1999; Gordillo and Cabrera, 1997). Some laboratory studies have reported differences in N transformations when the same organic residues are incorporated into different soils (Whitmore and Groot, 1997; Gordillo and Cabrera, 1997; Thomsen and Olesen, 2000). Observed differences may be attributed to adsorption capacity of the soil to bind organic N (Van Veen et al., 1985), increased aeration in sandier soil (Thomsen et al., 1999), and different carbon (C) to N ratios (Hassink, 1994; Hassink et al., 1994).

Numerous studies have evaluated the effects that soil physical and chemical characteristics have on mineralization rates of soils amended with manure. Although these studies have been important in helping to achieve an understanding of manure mineralization, most work has been conducted under laboratory conditions (Castellanos and Pratt, 1981; Chae and Tabatabai, 1986; Bonde and Lindberg, 1988; Cabrera et al., 1993), which often overestimates mineralization patterns occurring under normal field conditions. This is because laboratory studies do not account for the interactions and temporal changes between soil variations in organic matter, temperature, moisture, and different soil types often found in the field.

The *in situ* resin core method has been developed to measure N mineralization under field conditions. This method has been used to observe N mineralization rates in forest ecosystems (DiStefano and Gholz, 1986; Binkley et al., 1992). This method was also used by Kolberg et al. (1997) to study mineralization rates in dryland agroecosystems and by Eghball (2000) in evaluating N mineralization of beef cattle manure and beef cattle compost during the growing season. Although often costly and labor intensive, the *in situ* core method with the use of undisturbed soil may be invaluable in developing an index of the amount of N mineralized under natural field conditions (Eghball, 2000). The information obtained can also be useful toward understanding the potential rate of mineralization and dynamics of N from applied manure under different climatic conditions.

Information is needed on the relative rate of N being mineralized (released), retained (bound), and potentially lost (leached) from soils treated with manure. Nitrogen mineralization rates in previous studies using the *in situ* core method have not taken into account the variability often encountered in agricultural fields. Most large-scale agricultural fields have varying soil types. Nitrogen pools in one soil type may differ from those in another soil type because of inherent soil-forming properties. In addition, timing of manure application (summer or winter) could be impacted differently by soil type. Therefore, the objective of this study was to determine N mineralization during the growing (summer) and nongrowing season (winter) from composted dairy manure applied to three soils with different properties.

MATERIALS AND METHODS

Soil Description

Soil samples were collected from Auburn University's E.V. Smith Experiment Station located in Macon County, Alabama. Soils were collected from field plots that had not received manure within the last 10 years.

The climate in Macon County consists of long hot summers caused by moist tropical air from the Gulf of Mexico. Mean annual precipitation is 1,422 mm, with most of this (52%) occurring between April and October. The average daily temperature is 17 °C. The three soil series evaluated were Bama, Goldsboro, and Lynchburg. These three soils, formed from the same parent material, were chosen because they are proximate to one another within a field, but are different in texture. These soils were located on three different landscape positions consisting of the summit, drainageway, and sideslope. The Bama series (sandy loam) consists of very deep well-drained soils that formed in loamy sediments. Slopes range from 0% to 5%. These soils are fine-loamy, siliceous, subactive, thermic Typic Paleudults. Goldsboro series (loam) consist of very deep moderately well-drained soils that formed in loamy sediments. Slopes range from 0% to 2%. These soils are fine-loamy, siliceous, subactive, thermic Aquic Paleudults. The Lynchburg series (loam) consists of very deep somewhat poorly drained soils that formed in loamy sediments. Slopes range from 0% to 2%. These soils are fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults. The farming practice for all soil types consisted of conventional tillage, which received inorganic fertilizer in a continuous cotton/corn rotation.

Laboratory Analysis

Air-dried samples were ground to pass through a 2-mm sieve and subjected to chemical and physical analysis. Total C and N were determined by the DUMAS dry combustion method using a CN LECO 2000 analyzer (LECO, St. Joseph, MI). Soil characteristics (pH, soil effective cation exchange capacity [CEC], soil extractable nutrients [Ca, Mg, K, P, Fe, Mn, Zn, Cu, B, and Na], and particle size analysis) were measured (Table 1) by Auburn University Soil Testing Laboratory using the methodology described by Hue and Evans (1986).

In Situ Mineralization Study

The field *in situ* mineralization study was conducted by placing polyvinyl chloride plastic cylinders in the surface 20 cm of the soil profile according to procedures described by Honeycutt et al. (2005) to measure N mineralization rates. These *in situ* soil core (microplot cylinders) incubation chambers were 6.25 cm in diameter and 20.32 cm in length. Intact cores were collected by driving the polyvinyl chloride cylinder into the top 20 cm of the soil profile using a hydraulic core sampler. Vegetation was removed from the surface portion of the cylinder, and roots were severed to prevent N loss to plant uptake. The core samples were then collected and brought to the laboratory. The top 4 cm of soil in the microplot cylinders was removed and an appropriate amount of composted dairy manure was added and thoroughly mixed to give 350 kg N ha^{-1} (Fig. 1) The composted dairy manure–amended soil was gently packed back into the microplot cylinder. To maintain the same level of disturbance, the control soil cores underwent the same process but without the addition of composted dairy manure. Anion and cation exchange resin (A554, Cl^- form Type 2 Beads 16–50 mesh; JT Baker Inc, Phillipsburg, NJ) was placed in the bottom of each cylinder to capture leachate (25 g dry weight bases). The ion exchange resin bags were kept in plastic bags before installation to maintain humidity. Soil cores were transported back to the field and inserted in fallow ground in the same place from where they were originally taken. Dataloggers (HOBO Weather Station, Onset Computer Corporation, Pocasset, MA) were also used to continuously monitor soil temperature and moisture. A total of six additional soil cores were used for monitoring soil temperature (n = 3) and soil moisture content (n = 3) during the 70-day field incubation. Soil moisture probes (254 × 32 × 1.0 mm; ECH20) were placed on the top of the soil core to a depth of 254 cm. Soil temperature was measured by inserting a temperature probe (6 mm × 32 mm; S-TMA-002) at a soil depth of approximately 7.62 cm by drilling a 6.35-mm-diameter hole into the side wall of the tube. The tubes were placed in the ground on January 12, 2004, and on May 25, 2005.

Soil cores were collected and returned to the laboratory for analysis on 0, 3, 7, 14, 21, 49, and 70 days after composted dairy manure application by randomly selecting and removing six cylinders from each plot. On each sampling day, soil cores were collected and transported to the laboratory in a cooler. Inorganic N content was determined for each incubation sample by extraction using 2 M KCl (5 g moist soil in 50 mL of extractant). Extractions were carried out by shaking the soil samples for 1 h in an orbital shaker at 180 r.p.m. Resin beads were also extracted by shaking with 250 mL of 2 M KCl for 1 h. Soil extracts were allowed to settle for 2 h and then passed through a No. 42 Whatman filter paper. The extracts were frozen until analysis (Keeney and Nelson, 1982). Ten-gram soil subsamples were also taken from the core and dried for 24 h at 105 °C to determine gravimetric moisture content of each sample.

TABLE 1. Dairy Composted Manure Characteristics as Sampled, Wet Value Basis

	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn	B	Co	Moisture
	g kg^{-1}					mg kg^{-1}						g 100 g^{-1}
Manure	6.9	4.9	2.2	30.7	12.5	50	3,603	261	91	24	3	

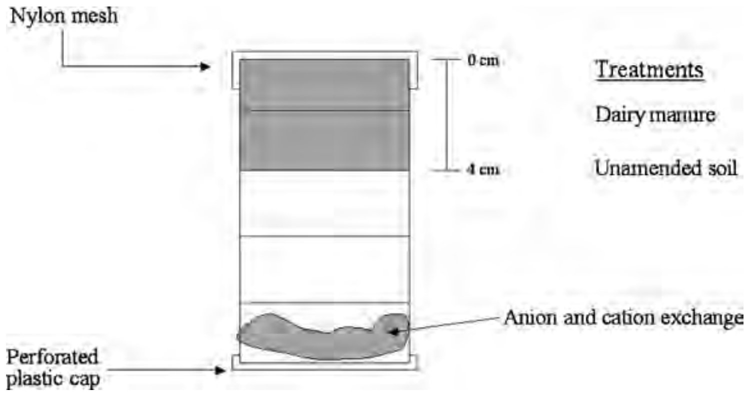

FIG. 1. Design of the microplot cylinder used in the winter 2004 and summer 2005 *in situ* mineralization study.

The amount of net N mineralized from substrate addition was corrected by subtracting soil amended with composted dairy manure from the unamended soils. The amount of N mineralized was expressed as mass of N per unit mass of dry soil.

Statistical Analysis

The treatments of the *in situ* study consisted of a total of three soils with composted dairy manure additions × 6 replications × 8 sampling dates, giving a total of 288 experimental units. The experiment was analyzed as a completely randomized factorial design with three soil types with a composted dairy manure amendment. Statistical analysis was performed using a GLM procedure of SAS (SAS Institute, 1985). Statistical comparisons were made overall and by study day at an *a priori* 0.10 probability level.

RESULTS AND DISCUSSION

Microplot Cylinder Nitrogen

Nitrogen mineralization was observed *in situ* through the use of microplot cylinders to evaluate the effects of soil interactions in its natural environment during summer and winter months. Microplot cylinders used in this study were designed and constructed similar to that of Honeycutt (1999), so that the N leached from soil in the cylinder would be captured and retained by an ion exchange resin. This procedure allows for a better understanding of the mineralization capacity and the movement of N in soil. An evaluation of inorganic N (i.e., extracted from the soil and resin) using the microplot cylinders suggests that a substantial amount of N was mineralized in the soil and transported to the resin (Table 2). Inorganic N extracted from the resins increased with time in both the summer and winter months. During both seasons, more inorganic N was observed in the resin compared with that retained in the soil ($P < 0.0001$), suggesting that the N in the soil was very dynamic. Most of the resin inorganic N was mainly in the form of NO_3^-. This was probably caused by NH_4-N ions being strongly adsorbed by soil particles or rapidly transformed to NO_3^- in the process of nitrification, thereby leaving most of the N leachate in the form of NO_3^-. The use of microplot cylinders was effective in collecting inorganic N mineralized from the soil. These results suggest that microplot cylinders may be a useful tool toward furthering our understanding of N transformation in soils under normal field conditions. This information may aid in choosing better management practices for agronomic fields compared with other studies performed under laboratory conditions.

Seasonal Mineralization

Mineralization of N was determined by subtracting the N measured in the unamended soil from the N measured in the soil amended with composted dairy manure. Nitrogen loss from volatilization was considered to be minimal because compost was used in this study, and it was incorporated into the soil. Denitrification was also assumed to be negligible because of

TABLE 2. The Amount of Mineralized Inorganic N (NO_3^- + NH_4^+) Retained in the Soil and Captured in the Resin After Manure Application

	Days After Dairy Compost Addition								
	0	3	7	14	21	28	49	70	
	mg kg^{-1}								$LSD_{0.10}$
Winter 2004									
Soil	12.74†	12.74	11.73	10.15	8.81	7.26	6.49	5.43	2.39
Resin	0.00	1.41	3.35	5.28	5.86	8.23	10.50	10.76	2.58
Summer 2005									
Soil	12.32	16.36	15.85	14.84	19.82	15.23	12.37	12.36	3.36
Resin	0.00	2.34	6.26	9.78	24.45	39.39	63.69	71.36	8.35

†Mean value shown; mean of all six replicates averaged across the three soil types.
LSD: least significant difference.

TABLE 3. Physical Characteristics of Soils Used in This Study

	BD	Sand	Silt	Clay	
Soil Series	g cm^{-3}	--------%-------			Soil Type
Bama	1.68†	66.25	21.25	12.5	Sandy loam
Lynchburg	1.64	46.25	41.25	12.5	Loam
Goldsboro	1.61	33.75	48.75	17.5	Loam

†Mean value shown are for 3 subsamples from each soil series.

the sandy nature of this soil (Table 3), which promotes soil aeration and water infiltration. In addition, the moisture content was not above field capacity for prolonged periods (Fig. 2).

A comparison of N mineralization rates between the winter and summer months indicates that mineralization was greatly affected by season (Tables 4 and 5). As expected, the total amount of inorganic N mineralized (soil + resin) was significantly higher during the summer months (ranging from 78.91 to 89.73 kg N ha^{-1}) compared with that during the winter months (ranging from 14.47 to 22.72 kg N ha^{-1}).

During the winter months, the concentration of inorganic N observed in the soil compartment of the *in situ* cores (Fig. 3) linearly decreased over time (ranging from 11.21 to 13.06 kg N ha^{-1} on Day 0 to 6.24 to 6.64 kg N ha^{-1} on Day 70). This decrease in inorganic N with time suggests that N mineralization was minimal, and that the added inorganic N from the composted dairy manure was leaching because of the dynamic properties of N in the soil. However, during summer months (Fig. 3), the amount of inorganic N observed in the soil compartment experienced periods of fluctuating concentrations from Day 0 to Day 70. This fluctuating concentration of inorganic N during the summer may be attributable to mineralization and the accumulation of plant-available N followed by periods of leaching caused by rainfall events. Under normal conditions, inorganic N continues to accumulate in the soil until it is taken up by a plant or lost to leaching.

Concentrations of inorganic N extracted from the ion exchange resins increased over time during the summer and winter months (Table 4 and Fig. 4). The inorganic N observed in the resins during the summer months was significantly higher than that collected during the winter months, suggesting that as mineralization increases, so does the potential for N loss. Because mineralization was minimal (maximum mineralization was ~2% of the added dairy compost N) during the winter months, inorganic N collected in the resins was mainly attributable to NO_3^- leaching of plant-available N contained in the composted dairy manure. In general, the water-holding capacity of a soil is normally higher during winter months and plant growth is minimal, suggesting that the NO_3^- that is retained by or added to the soil has a greater chance of being lost. Inorganic N concentrations observed in the resins during summer months were mainly attributable to the mineralization of the added composted dairy manure (maximum mineralization was ~24% of the added dairy compost N).

Seasonal mineralization rates corresponded to soil moisture and soil temperature.

During winter months, temperature seemed to be the most limiting factor. Cool soil temperatures of approximately 10 °C or less were observed for the first 45 days after composted dairy manure application (Fig. 5). This probably accounted for a low mineralization rate resulting in slow decomposition of the added manure. However, during the summer months, soil temperature ranged from 25 °C to 35 °C, which likely increased microbial activity and subsequent N mineralization. In general, maximum N mineralization occurs when soil temperatures

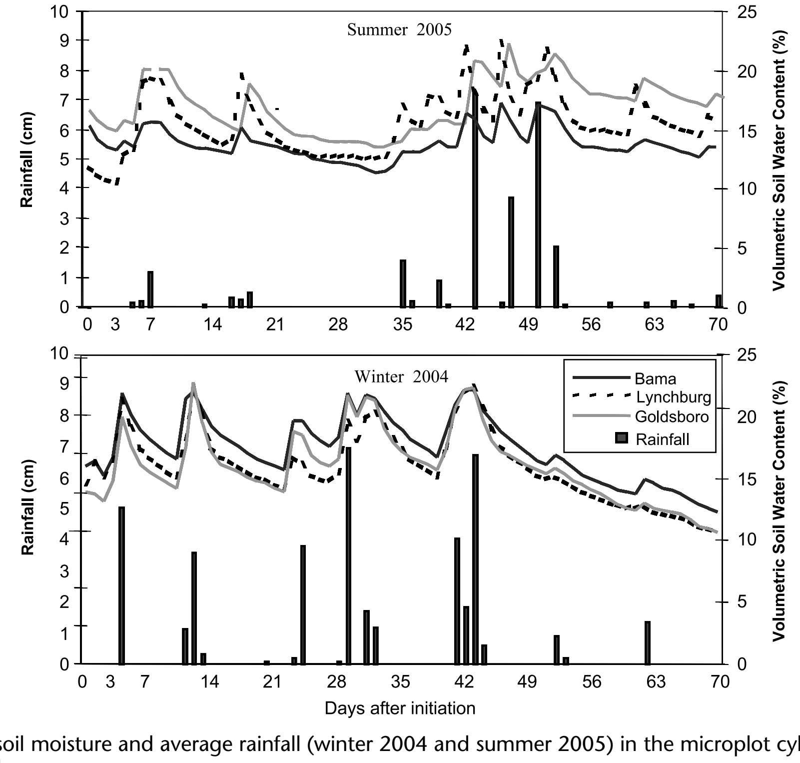

FIG. 2. Seasonal mean soil moisture and average rainfall (winter 2004 and summer 2005) in the microplot cylinders for the three soil types during the season.

TABLE 4. The Amount of Mineralized Inorganic N (NO_3^- + NH_4^+) Retained in the Soil and Captured in the Resin After Manure Application

	Days After Dairy Compost Addition								
	0	3	7	14	21	28	49	70	Mean
	mg kg^{-1}								
Winter 2004									
Bama	12.55	13.00	13.60	13.58	13.77	13.47	13.79	14.48	13.53 b[†]
Lynchburg	11.82	16.27	15.73	17.66	19.22	19.36	19.81	22.72	17.83 a
Goldsboro	13.14	13.19	14.23	12.75	13.30	12.99	14.18	14.57	13.54 b
Summer 2005									
Bama	13.06	19.01	19.97	18.55	39.31	51.67	73.78	81.51	39.61 b
Lynchburg	11.22	20.32	21.43	19.05	47.04	49.18	73.96	79.92	40.26 b
Goldsboro	12.67	17.33	24.92	36.28	46.45	63.00	80.94	89.74	46.42 a

[†]Means within column followed by the same letter do not differ significantly (0.10 level).

are between 25 °C and 35 °C (Watts et al., 2007; Wang et al., 2006; Nicolardot et al., 1994; Stark and Firestone, 1996). In addition, Ladd et al. (1996) reported that an increase in decomposition of soil organic substance occurs from a combination of warmer soil temperature and better aeration. This is often observed during the summer months because of warmer temperature and lower water-holding capacities.

Moisture also affected the amount of N retained in the soil compartment. As previously stated, during the winter months, the amount of inorganic N observed in the soil compartment decreased over time. This decrease in inorganic N concentrations was probably attributed to higher water volumes observed, the first month after composted dairy manure addition, during winter months, causing the N in soil to be more susceptible to leaching. These findings are similar to those of Watts et al. (2006) who observed N loss during winter months after rainfall events from fall application of manure. During the summer months, soil moisture also affected N mineralization (Fig. 2 and Table 6). Fluctuations in soil moisture content were observed to correspond to multiple rainfall events. This was most evident between Day 28 and Day 49 (highest N mineralization observed) where there was an increase in moisture content after a dry period that lasted from Day 21 to Day 35. A combination of the two events resulted in an increase in N mineralization. Higher field moisture content during this period was probably the overriding factor increasing N mineralization, suggesting that an increase in soil moisture caused an increase in microbial activity. Between Day 28 and Day 49, the average water filled pore space was approximately 62% compared with 44% as observed between Day 21 and Day 35. It has been stated that microbial activity is optimal at water filled pore space of 60% (Linn and Doran, 1984).

Effect of Soil Type on N Mineralization

The impact that different soil types within a production agricultural field have on the potentially mineralizable N from organic amendments is important for manure management because it allows for a better prediction of the effects that soils have on the release of plant-available N to the crop. Differences in mineralizable N from composted dairy manure addition to the different soil types were observed in the 70-day *in situ* incubation study. Concentrations of inorganic N on Day 0 ranged from 11 to 13 kg N ha $^{-1}$ (Table 4), suggesting that the added N from the composted dairy manure was plant available immediately after incorporation into the soil. This is similar to the findings of other researchers (Shi et al., 2004; Eghball, 2000; Gordillo and Cabrera, 1997) who have reported that approximately 4% of the total dairy compost is in inorganic forms (NO_3 and NH_4).

Nitrogen mineralization in the manure-amended soils was greatly affected by soil types (Table 6). However, these soil types were impacted differently by season, as evidenced by the soil × season interaction (Table 6). Averaged across sampling days for the winter season, the Lynchburg soil, a loam soil (located in a

TABLE 5. Analysis of Variance for the Amount of Mineralized Inorganic N (NO_3^- + NH_4^+) Retained in the Soil and Captured in the Resins After Manure Application at the Eight Sampling Days

	Days After Dairy Compost Addition							
	0	3	7	14	21	28	49	70
	$P > F$							
Winter 2004								
Soil compartment N	0.86	0.27	0.95	0.41	0.59	0.30	0.92	0.97
Resin N		0.73	0.63	0.83	0.10	0.01	0.28	0.10
Total mineralized N	0.86	0.39	0.82	0.42	0.22	0.23	0.28	0.15
Summer 2005								
Soil compartment N	0.78	0.31	0.95	0.25	0.81	0.11	0.03	0.54
Resin N		0.47	0.18	0.01	0.55	0.09	0.56	0.92
Total mineralized N	0.78	0.47	0.43	0.02	0.59	0.16	0.80	0.80

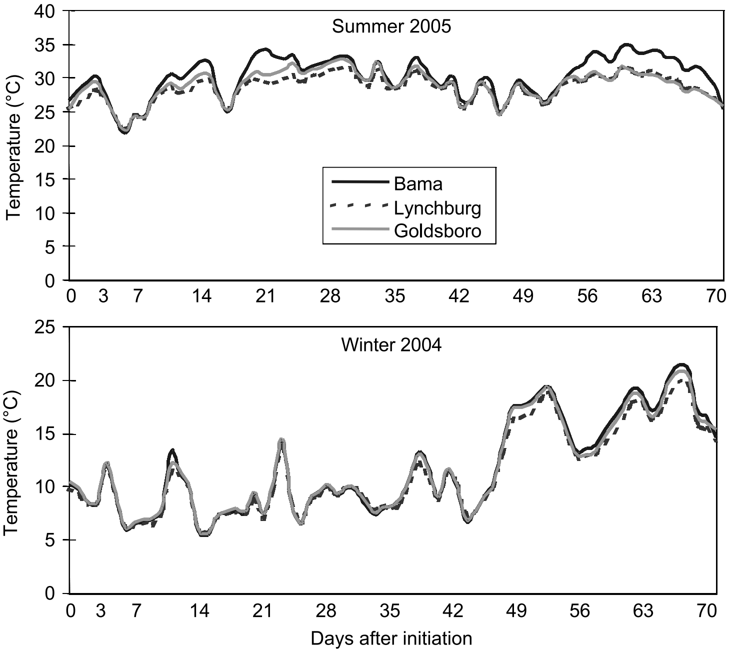

FIG. 3. Seasonal N mineralization (winter 2004 and summer 2005) of inorganic N in the soil compartment of the microplot cylinder for the three different soil types amended with composted dairy manure at eight sampling times during the season.

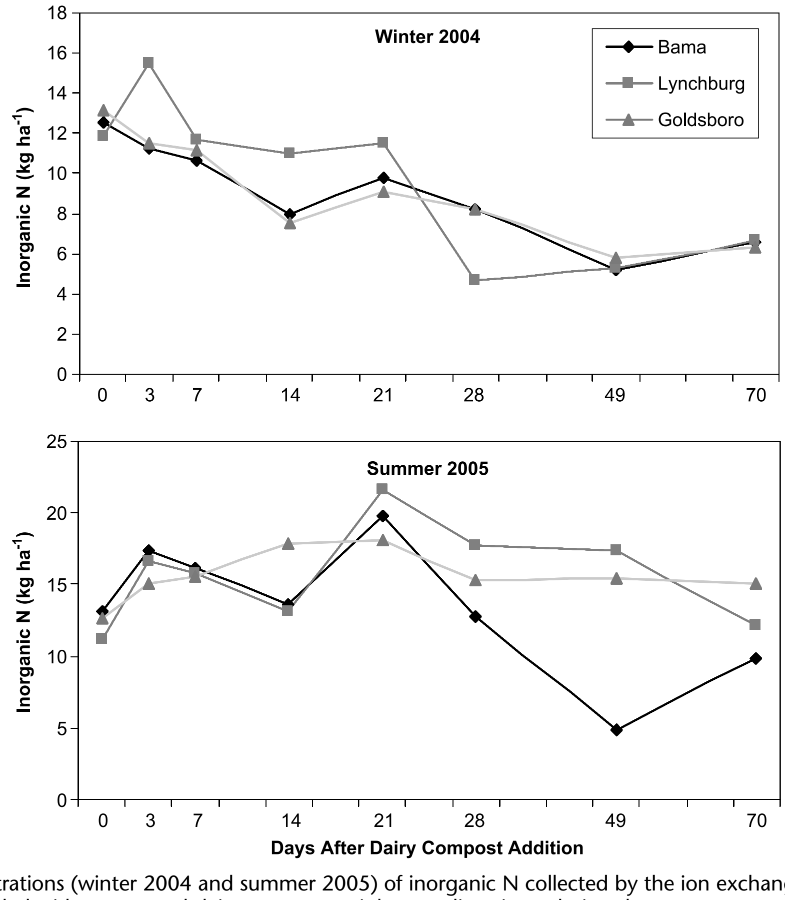

FIG. 4. Seasonal concentrations (winter 2004 and summer 2005) of inorganic N collected by the ion exchange resin for the three different soil types amended with composted dairy manure at eight sampling times during the season.

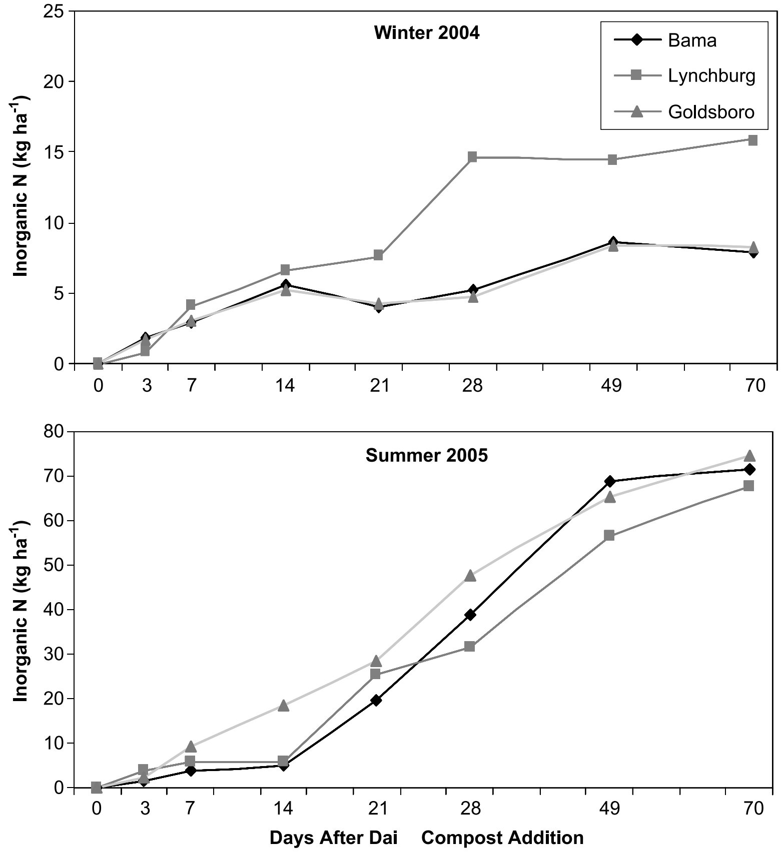

FIG. 5. Seasonal mean soil temperature (winter 2004 and summer 2005) in the microplot cylinders for the three soil types during the season.

depression), had the highest total N mineralization (soil + resin) during the winter months ($P < 0.04$) (Table 4). Significant differences were observed for N retained on the ion exchange resins as affected by the different soil types on Days 21, 28, and 70 (Table 5 and Fig. 4). This increase in inorganic N could be attributed to more inorganic N in the soil compartment (Fig. 2) compared with the other soils from Day 3 up until Day 21; by Day 28, leaching resulted in the capture of this inorganic N by the ion exchange resin. During the course of the study, slightly higher N mineralization over time resulted in significantly higher inorganic N in the resin by Day 70. It is possible that the soil properties, which were the result of soil-forming properties including location, affected the mineralization capacity and movement of N in soil. For instance, the Lynchburg soil had a higher CEC, total C, and total N (Table 7) compared with the other soils. As a result of the soil fertility, microbial activity, which mediates the mineralization process, most likely contributed to a higher N availability. In addition, the inherent nature of

TABLE 6. Analysis of Variance for the Effects of Soil Type, Day, and Season

	Total Inorganic N (NO_3^- + NH_4^+) $P > F$		
Parameter	Soil Compartment N	Resin N	Total Mineralized N
Season	<0.0001	<0.0001	<0.0010
Soil * season	0.3862	0.0056	0.0061
Winter 2004			
Soil	0.6818	<0.0001	0.0009
Day	<0.0001	<0.0001	<0.5052
Soil * day	0.7633	0.1731	0.9613
Summer 2005			
Soil	0.1257	0.0859	0.0466
Day	<0.0039	<0.0001	<0.0001
Soil * day	0.2059	0.9232	0.9491

TABLE 7. Characteristics of Three Soil Types Used in the *In Situ* Field Study Reported on a Dry Weight Basis

		CEC	Total C	Total N	C:N
Soil Series	pH	cmol kg^{-1}	-----g kg^{-1}-----		Ratio
Winter 2004					
Bama	6.31	5.84	4.42	0.48	9.21
Lynchburg	6.10	5.46	5.57	0.51	10.92
Goldsboro	6.24	6.09	3.77	0.41	9.20
Summer 2005					
Bama	6.26	5.70	3.77	0.39	9.67
Lynchburg	6.25	7.79	6.12	0.58	10.56
Goldsboro	6.86	5.12	4.02	0.54	7.41

CEC: cation exchange capacity.

this soil (sand, silt, and clay more evenly distributed compared with other soils), which is located in a depression area, probably had a higher infiltration rate. This argument can be supported by the fact that there was less water held in the soil, suggesting that water percolation through this soil was greater. Thus, increased soil aeration most likely contributed to higher mineralization. It has been reported that soil texture influences how rapidly N mineralization occurs (Hubbard et al., 2008; Sistani et al., 2008). Similarly, Thomsen and Olesen (2000) observed that increased sand content generally led to increased N mineralization, which is a response to increased aeration in sandy soils.

On the other hand, although N mineralization was significantly less overall during the winter (~2%), observed increases of available N in the Lynchburg soil were susceptible to loss. Concomitantly, as N mineralization increased with time, the amount of inorganic N captured in the resin also increased. This suggests that sandy soils located in depression areas in agronomic fields are potentially susceptible to leaching during winter months. This influence of soil texture is documented by Delgado et al. (1999) and Delgado (2001) who observed more N leaching in sandy soils (Follett and Delgado, 2002).

Goldsboro soil mineralized the most N (soil + resin) compared with the other two soils (Table 4) during the summer months. This was likely caused by the ability of the soil to maintain a higher soil moisture content than the other soils. The percentage of sand, silt, and clay in the Goldsboro soil was more evenly distributed than in the Lynchburg soil. This suggests that the greater silt and clay content of this loam soil was integral in maintaining higher moisture content compared with the other soils, corresponding to a higher N mineralization capacity in this soil. Although other researchers have observed higher N mineralization rates occurring in manure-amended soil with the highest percentage of sand (Sistani et al., 2008; Hubbard et al., 2008; Shi et al., 2004; Thomsen and Olesen, 2000) moisture was the overriding factor affecting mineralization in this study. For instance, the Bama soil had the highest percentage of sand, but the Goldsboro soil had the highest mineralization capacity. However, although there is a larger difference in the sand and silt content (Bama vs. Goldsboro), the clay content was minimal. Thus, the clay content was just enough to maintain higher moisture content. In addition, during the first 35 days after manure application, the average water-filled pore space for the three soils was 44% (Fig. 2). However, the Goldsboro soil maintained higher moisture content compared with the other soils. As a result, microbial activity, which mediates N mineralization, was probably greater, providing the soil with more plant-available N.

Significant differences were observed in the soil compartment on Day 28 and Day 49 (Table 5 and Fig. 3), resulting in lower concentrations of inorganic N in the Bama soil compared with the other soils. The lower retention capacity for N in the Bama soil was attributed to its soil texture (percentage of sand). It has been reported that as the percentage of sand increases, the adsorption sites (NH_4^+ can be adsorbed by clay minerals) decrease, resulting in lower concentrations of inorganic N in the soil (Sistani et al., 2008). Thus, the lower concentration in soil was probably a result of limited adsorption sites in the soil. In addition, higher precipitation observed from Day 43 to Day 53, which corresponded to higher soil moisture, contributed to leaching of inorganic N from the soil compartment.

CONCLUSIONS

If managed properly, N derived from manure can be an important source of plant nutrients, but improperly managed manure N can potentially contaminate surface water and groundwater. The information obtained in this study may be useful toward maximizing the benefits of manure as an N source while minimizing the adverse effects of water contamination derived from variations in N mineralization often found in most agricultural fields. The use of microplot cylinders with ion exchange resins in an *in situ* N mineralization study during winter and summer months was effective in providing information on N release from composted dairy manure under field conditions. Nitrogen mineralization of composted dairy manure added to soil was greatly affected by season and soil type. Mineralization was minimal during the winter months, which was probably caused by low temperatures (~10 °C) resulting in reduced microbial transformation of N. Although mineralization was low during the winter months, the added N from manure was more susceptible to leaching. On the other hand, during summer months, an increase in inorganic N concentration was observed resulting from an increase in mineralization. This increase in mineralization was most likely caused by increased microbial activity observed at temperatures greater than 25 °C. The effect of soil type on the N mineralization of composted dairy manure was also impacted by season. During winter months, the soil that is commonly located in depressed areas of the field had the greatest N mineralization capacity. Although mineralization was minimal (2% of added composted dairy manure), the added N in these sandy soils were susceptible to leaching. During the summer months, N mineralization also was greatly affected by moisture. Concomitantly, soils with the highest water-holding capacity contained the highest inorganic N concentrations. These results indicate that predictions of N mineralization rates should not be based entirely on the mineralization capacity of the organic amendment, but also on the field scale variability of the soil and landscape. This indicates that precision management of manure applications based on soil type and season of year could be advantageous for improved fertility management.

ABBREVIATIONS

NUE: nitrogen use efficiency;
CEC: cation exchange capacity;
LSD: least significant difference.

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