Abstract

ALLEN, MELONIE BETH. Effects of Poultry Litter Addition to a 31 year old Longleaf Pine Stand. (Under the direction of Dr. H. Lee Allen).

Nutrient depletion is a concern in longleaf (*Pinus palustris*) pinestands managed for pinestraw production in the Sandhills regions of the southeastern United States. The low-fertility soils associated with longleaf pine stands in the Sandhills region may not be able to sustain the repeated nutrient removal associated with pinestraw raking. Poultry litter, which is abundant in this region, may serve as a useful fertilizer amendment for offsetting nutrient removals. Nutrient cycling, water quality and productivity affects were examined under two poultry litter amendment regimes, a one time application of litter at 134 kg N /ha (134 treatment) applied in the winter of 2000, and a two time application at the same rate applied in 1999 and 2000 resulting in a total application of 269 kg/ha (269 treatment).

Poultry litter addition significantly increased soil temperature, moisture, carbon (C) content, nitrogen (N) content, the effective cation exchange capacity ($CEC_{E)}$, pH, base saturation, as well as the nitrate ($N0_3^-$ N) content in KCl extractable soil samples in the 269 treatment. The KCl extractable N in the surface 15 cm was greatest in the 269 treatment with a cumulative total of 56 kg N/ha of N reported versus 51 kg N/ha in the 0 treatment. Inorganic N enrichment occurred in soil solution measured at 15 and 60 cm deep in both treatments. At 15 cm, the N in solution ranged from 0.02 ppm (134 treatment) and 23.47 ppm (269 treatment). Vertical transport of N in solution was a major fate of the N measured at 15 cm, as solution N ranged from 0.20 ppm (0 treatment) and 33.82 ppm (269 treatment) at 60 cm. The increases in KCl extractable N and soil solution N concentrations following poultry litter application indicate that the litter was successful in enhancing N availability. Pinestraw production exhibited a significant increase of 17% in the 269 treatment as compared to the 0 treatment. Poultry litter is a viable soil amendment to longleaf stands managed for pinestraw production.

Effects of Poultry Litter Addition to a 31 Year Old Longleaf Pine Stand

by
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Biography

Melonie Allen was born in Baltimore, Maryland. She attended Salisbury State University and the University of Maryland Eastern Shore where she received dual B.S. degrees in Biology and Environmental Science.

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Introduction

Longleaf pines (*Pinus palustris*) are indigenous to the southeastern region of the United States. Currently there are over 103,500 hectares of longleaf pine in North Carolina alone (Landers et al, 1995). This number is increasing due to incentives offered to private landowners, who own 43% of long leaf pine acreage in the state, to establish longleaf pine stands (Outcalt, 1996). Production of longleaf pines represents a good investment for landowners for a number of reasons. Longleaf pines have less taper than other southern pines and a higher specific gravity, thus they produce more solid wood volume than similar species. On average 60% of longleaf pine stems per stand (45 y.o.) qualify as poles. Poles have a stumpage value of between 20 – 50 % higher than that of saw timber (Hammond, 1999; The Longleaf Alliance). Longleaf pines are also a low risk management species as they are not susceptible to fusiform rust, annosus root rot, pitch cankor, southern pine beetle and tip moth (Landers et al, 1995). Longleaf pines are also well suited for long rotation.

This extended rotation may enable landowners to supplement intermittent harvest revenue with an annual source of income through pine straw raking. Pine straw is used primarily as an ornamental mulch and is comprised of leaf litter. Longleaf pines, as the common name indicates, produce highly desired long needled pine straw (Coder, 1999). Stands managed for pine straw are generally raked between one to three times annually. Repeated removal of leaf litter may pose a problem due to the concurrent removal of nutrients from the site. Longleaf pine stands are often established on marginal sites where soil nitrogen (N) limitation is prevalent. An estimated 16 kg/ha of N are removed with each raking, which in time, may render pine straw production unsustainable and have an adverse effect on stumpage values of the stand (Blevins, 1996; Moorehead 1998). Fertilization may also increase growth and yield in longleaf pine stands. Increases in diameter at breast height (dbh) and needle yield of up to 49 % and between 40 - 50 % respectively have been documented two years post fertilization in stands managed for pinestraw production (Blevins, 1996; Moorhead, 1998). The poultry industry is very important to North Carolina’s economy and North Carolina in turn is very important to the nation’s poultry production. Broilers, young chickens raised for meat, represented the second ranked farm commodity in the state in 2004. North Carolina ranks third in the nation for poultry production. The poultry industry accounted for over two billion in gross sale value of products in 2004 in North Carolina, with over 720 million broilers produced (The North Carolina Poultry Federation, 2006). These birds in turn produced an estimated 1.55 metric tons of waste product, termed poultry litter. Poultry litter is comprised of uneaten feed, feces, and bedding materials such as wood shavings, sawdust and peanut hulls. Poultry litter is considered the most valuable of animal wastes produced in large quantity because of its value as a fertilizer (Wilkinson, 1997). Although poultry litter is heterogeneous, estimates of typical nutrient contents have been made, which indicate the elemental N, P, and K content in broiler litter at 4%, 2%, and 3% (Beem, F5037*)*.

Poultry litter is also a good source of organic carbon (C) and micronutrients. The organic components of poultry litter make it a good soil amendment for the low organic sandy soils common to longleaf pine stands. One anticipated effect of adding organic C to longleaf pine stands is an increase in the water retention capacity of sandy soils where longleaf pines are commonly found. The N in poultry litter is predominately organic with estimates of only 25-30 % of the total N being found in inorganic forms (Sims, 1987). Organic N requires mineralization to be transformed into plant available N. This mineralization process may result in prolonged periods of plant available N release as compared to the readily available N in chemical fertilizers. Longleaf pines, not being an annual crop, have nutritional requirements which span an entire year and thus may benefit from a slow release nutrient source such as poultry litter.

Historically poultry litter has been applied as fertilizer to annual crops and the application rate has been based solely on the N content of the litter. Due to this application regime, negative affects on water quality have been linked to the use of poultry litter as a fertilizer source. The repeated application of poultry litter based only on the N requirements of the field crop may result in loading the soil with P until the saturation index is exceeded. Phosphorus is typically associated with overland flow when the saturation index has been exceeded and all available soil adsorption sites have been utilized. Thus potential negative water quality impacts such as eutrophication may pose a problem when amending soils with poultry litter based only on the N requirements of the crop (Sims, 1987).

Another water quality concern stems from the application of N fertilizer on the sandy soils typical of longleaf stands. Nitrogen enrichment poses the potential hazard of ground water contamination, as N in its most mobile form of $N0_3^- N$ is associated with vertical transport. Additionally, the relatively high metal (Zn and Cu) content of the litter raises metal toxicity concerns. Poultry litter as a source of weed seed at time of fertilization is often noted as a potential concern; however, this theory is contentious as many studies have found an absence of viable seeds in the litter at the time of application (Rasnake, 1996).

The coexistence of longleaf pines and the poultry industry provide stand owners in the region the opportunity to benefit by using a byproduct of the poultry industry, poultry litter, to enhance growth and sustain pinestraw production on longleaf pine stands. At the same time this would provide poultry producers with a new venue for free disposal of an unwanted byproduct, potentially without compromising regional water quality. The key to maintaining stand productivity, while minimizing negative environmental impacts with regard to poultry litter fertilization on longleaf pine stands, is to establish a sound nutrient management/fertilization regime. This may be accomplished through accurately matching the nutrient requirements of the stand with the existing nutrient availability of the soil and that of the added litter. The first step in this undertaking is to quantify the N mineralization rates of poultry litter and the within system cycling of the N. The second step would be to develop a fertilization regime that would meet the nutrient needs of the stand as closely as possible without compromising water quality or long term soil viability. The third step would be to quantify the growth responses of the litter application to determine feasibility of application. Based on these three requirements the objectives of this thesis were to:

1. Quantify changes in soil chemistry and available N and P associated with the application of two fertilization regimes poultry litter, 134 kg N/ha and 269 kg N/ha, applied to a 31 year old longleaf pine stand
2. Quantify stand growth and pinestraw production response associated with two fertilization regimes of poultry litter to a stand of 31 year old longleaf pines.

Methods

Site Description

The study site was located in Richmond County (34^0 55'00" latitude, 79^0 35'00" longitude) which lies in the Sandhills region of North Carolina (Figure 1.1). The Sandhills region is a unique geologic formation within the Coastal Plain physiographic region characterized by greater relief than is typically found in the Coastal Plain. The average winter temperature is 6.1^o C. The average summer temperature is 25.6 ^{o} C and the yearly precipitation averages 120 cm. The precipitation is evenly distributed between summer and winter with 54 % between April and September. Thunderstorms occur on average 41 day per year and the sun shines 68 % of time possible in the summer and 57% in the winter. The average relative humidity ranges between 54% (mid-afternoon) and 83% (dawn) (*USDA NRCS*). Wakulla and Candor soil series were represented on the site. These sandy soils are very deep and excessively well drained with permeability ratings of moderate to rapid. The average soil water storage capacity is low with a depth to high water table greater than 1.8 meters. These soils are described as droughty and the hazard of soil blowing is severe. The depth to bedrock is on average greater than 102 cm. The typical pedon is A (0-3), E (3-23), Bt (23-35), E1 (35-54), E2 (54-62), Bt1 (62-68), Bt2 (68-80). Wakulla soils are sandy, silicious, thermic Psammentic Hapludults. Candor soils are classified as sandy, silicious, thermic Arenic Paleudults (*USDA NRCS*).

The site is located in the Lumber River Basin in the 03040204 hydrologic unit and is in the Little Pee Dee headwaters watershed, NCDWQ sub basin 55. The study site is located on a broad interstream ridge system between Mill Creek (approximately 863 meters to the north), Camp Branch (approximately 786 meters to the south) and Gum Swamp Creek (approximately 1,221 meters to the east) to which Mill Creek and Camp Branch discharge (Figure 1.2). Gum Swamp Creek flows southward into South Carolina where the name changes to Little Pee Dee River in Marlboro County. The study site is located north of the water divide between Mill Creek and Camp Branch Creek. Therefore, hydraulic gradients in the ground water under the study site are likely toward Mill Creek and Gum Swamp Creek. Surface relief in the vicinity of the study site is low with slope gradients of 1% or less. The site is underlain by the Middendorf aquifer formation with less extensive areas of younger sediments, the Pinehurst formation. These formations are characterized as being comprised of medium to coarse sands with high permeability. The surficial aquifer is characterized as having a lower permeability; clay confining units separate the surficial and underlying aquifers. The aquifers of the Sandhills region of North Carolina are characterized as having rapid recharge rates and moderate base flows, while the surface waters typically exhibit a peak stream flow more pronounced than on the rest of the Coastal Plain due to the steeper slopes.

Stand Description

The longleaf pine stand was established in 1967 and was 31 years old at the time of stand baseline data collection in 1998. The average tree height in 1998 was 15.2 meters and the stand density was 147 trees per ha. The average stand diameter at breast height (dbh) in 1998 was 21 cm and the stand basal area was 130 m^2/ha (Table 1. 1). Foliar nutrient concentrations across all treatments in 1998 did not differ statistically (Table 1.1). The stand was raked for pinestraw on average two to three times per year prior to the initiation of the study. During the study the entire stand was raked in December of 1999, July of 2000, and December of 2000 by hand and bailed automatically.

Experimental Design and Treatments

The experimental design was a complete randomized block design with three treatments replicated three times. A total of nine treatment plots were established (Figure 1.3). Average treatment plot size was 0.148 ha and within each treatment plot measurement plots of 0.035 ha were established. The width of the buffer zone between adjacent treatment plots was a minimum of 15 meters. The low relief and vertical percolation of the soil water precluded any possible mixing of soil water between treatment plots. Plots were blocked based on standing volume and trees per acre in 1999 to reduce within block variation. Competing herbaceous vegetation was controlled through the use of the glyphosate herbicide Roundup throughout the study. The poultry litter applied came from a local source within the Sandhills region of North Carolina. The poultry litter consisted of the uneaten feed, feces, and bedding material used in the broiler houses. The N content of the litter was determined prior to the initial poultry litter application in 1999. The nutrient content of the litter was determined prior to the second poultry litter application in 2000 (Table 1.2). Application rates were based on a target application rate of 134 kg N/ha per year which was established as an optimum rate in similar studies with commercial fertilizers (Blevins, 1996). The poultry litter was applied via a tow behind broadcast spreader at a rate of 9,600 kg/ha in 2000. The treatments were a control, a one time application of 134 kg N/ha applied in 2000, and a two-time application of N at a rate of 134 kg/ha N to equal a total of 269 kg/ha applied in 1999 and 2000. The 2000 fertilization occurred January 9- 11, 2000. Hereafter, the three treatments will be referred to as 0 (control), 134 (one time application in 1999) and 269 (two time application in 1999 and 2000) (Figure 1.3).

Sampling and Monitoring

A total of 10 randomly spaced soil samples were collected per plot to a depth of 15 cm and bulked in February 2000 and again in March 2001 to enable determination of first soil sample and final soil chemical characterization (Figure 1.4). Soil solution was sampled bimonthly between March 2000 and March 2001 (Figure 1.4). Soil solution was collected through porous ceramic cup lysimeters at 2 depths of 15 and 60 cm from three fixed location random sub-sampling sites per plot. Model 1900 Soil Water Samplers (*SoilMoisture Equipment Corp*) of two lengths, 15 and 60 cm PVC tubes with outside diameters of 4.8 cm and a porous ceramic cup at the base with a 2 bar air entry value were used. The sample was collected through the use of a vacuum hand pump by applying a vacuum as measured on the pump of 60 centibars and allowing the sampler to remain under this vacuum for a two week period. The vacuum hand pump was then used to retrieve the sample through creating a vacuum in an Erlenmeyer flask attached to the sampler via plastic tubing. The three sub samples per depth per plot were bulked to result in a total of nine soil solution samples at each depth per sample session. Samples were placed on ice in field and subsequently frozen until analyzed. Soil temperature measurements were collected to a depth of 15 cm with a mobile temperature probe, 3 per plot at time of soil solution collection. Soil moisture measurements were collected with a Tektronix Time Domain Reflectometer, 10 per plot to a depth of 15 cm at time of soil solution sample collection.

Soil N mineralization samples were collected monthly to determine N mineralization rates through the in-situ soil core method (Raison, et al.1986). Five random subplots were established per plot and sequential soil cores to a depth of 15 cm were isolated through covered and uncovered PVC tubes with an inner diameter of 6.35 cm installed via rubber mallet. These in-situ incubations were collected every 30 days between June 2000 and March 2001 along with an initial loose soil sample (Figure 1.4). All five within plot sub samples were bulked to result in a single initial, covered, and uncovered soil sample per month per plot. Net N mineralization rates were equal to the sum of changes in $N0_3^-$ N and NH_4^+ - N as in equation 1.1(Raison, et al.1986). Annual net N mineralization was calculated by summing the monthly mineralization totals. Gravimetric soil moisture was measured on all soil mineralization samples. A soil bulk density of 1.4 g/cm^3 was assumed based on measured average density of similar soils in the region (King et al, 2002).

Equation 1.1 Net N Mineralization

Net N-Min= (net $N0_3^-$ - N + NH_4^+ - N occurring during the incubation period in the uncovered soil columns) – (initial values net $N0_3^-$ - N + NH_4^+ - N in loose soil samples collected at start of 30 day incubation period)

All trees within the measurement plots were measured in December of 1998, 1999, and 2000. Total height and dbh (1.3 m) of each tree was determined with a vertex hypsometer and dbh tape. Foliage was collected from five co-dominant trees per plot each year. Fascicles from the first flush of the new growth on lateral branches in the upper third of the canopy were analyzed for nutrient content and fascicle weight. All within plot foliage samples were bulked prior to analysis. Leaf litterfall (pinestraw) was collected from two sub-plots within each measurement plot and weighed in the field with a hand scale on each rake date to enable pinestraw production estimates.

Laboratory Analysis

The initial soil characterization samples collected in March 2000 and the final soil characterization samples collected March 2001 were analyzed with a Carbon/Hydrogen/Nitrogen (CHN) elemental analyzer to determine changes in soil C and N (CE instruments-model NC2100, CE Elantech Inc, Lakewood, NJ). These samples were passed through a 2 mm sieve to separate fine and coarse fractions of the soil, and ground to pass through a <2 mm size screen to ensure uniformity for analysis. Soil Ca, K, Mg, and Na were extracted using 10:1 soil/solution 1M ammonium chloride (NH_4Cl) solution and the content determined through the use of a Varian Liberty Series II inductively coupled plasma atomic emission spectrometer (ICP-AES) analyzer on the same initial and final soil characterization samples (Klute, 1986). The pH was determined on the same soil samples through the electrometric measurement method (EPA, 1979). Exchangeable acidity was also determined through the NaOH titration method (Page, 1982).

Lysimeter collected soil solution was analyzed for $N0_3^-$ - N, NH_4^+ - N, and PO_4^{3-} through flow injection colorimetry analysis on the lysimeter soil solution samples (Lachat, 1986). Inorganic N from the loose and soil core soil samples were extracted with 2M KCl, mixed via automated shaker for one hour, and centrifuged for 15 minutes. The supernatant was then filtered and frozen until analysis. Extracts were then analyzed for $N0_3^-$ - N and NH_4^+ - N through colorimetric flow injection analysis using a Lachat autoanalyzer (Lachat, 1986).

Foliage was dried at 71 ^{0} C for a minimum of 24 hours and ground to pass through 0.5 mm screen prior to nutrient determination. Foliar C and N concentrations were analyzed through a dry combustion technique with a CHN elemental analyzer. Foliar P, K, Ca, Mg, S, Mn, Zn, B, and Cu content was determined through nitric wet acid digestion followed by ICP analysis (Jones and Case, 1990).

Statistical Analysis

Treatment, time, and treatment x time interaction affects were conducted through statistical analysis software using the proc mixed procedure with time as a fixed variable and soil moisture, soil temperature, soil solution N and phosphate, and N mineralization as dependent variables (SAS Institute, 1999). Due to the highly variable nature of soil solution in macropores and absence of a block affect, soil solution analysis was performed on completely randomized designed data sets and only data sets with a minimum of two samples per treatment per sample date were included in the analysis. Soil chemical properties were examined using one-way ANOVA analysis to examine pre and post treatment effects and paired t-test analysis was conducted to determine significance of within treatment changes over time. Due to the highly variable nature of the soil, a significance level of P>F of 0.10 was assigned for all soil data sets. The GLM procedure was used to determine effects of treatment, block, and treatment x block interactions on stand dbh and basal area data sets. The t-test procedure was used for treatment effect analysis when only two treatment data sets were available. Statistical significance was assigned at 0.05 for all stand height, dbh and basal area analysis.

Results and Discussion

Soil Temperature, Soil Moisture

Average monthly temperatures by treatment in the upper 15 cm of soil ranged from 3.0^{o} C in winter to 29.5 ^{o} C in summer (Figure 1.5). Soil moisture ranged from 4 g/kg soil in May of 2000 to 158 g/kg soil in August 2000. A general soil temperature increase was evident across all treatments March 2000 through August 2000, where soil temperature exceeded 25 ^{0}C in all treatments in July and August 2000, followed by a decrease in soil temperature through December 2000. Soil temperature steadily rebounded as would be expected January through April 2001. The soil moisture time trend was much more variable with the greatest soil moisture being measured July through August 2000 followed by a general decline in soil moisture during the fall and winter of 2000 and continuing through April 2001 (Figure 1.5). As expected, time had a significant affect on soil temperature and soil moisture. Treatment effects were significant for both soil temperature and soil moisture (Table 1.4).

Daily precipitation data reported by the State Climate Office of North Carolina, Hamlet Cooperative Station 313784, located approximately 11 km west of the study site is presented in Figure 1.5. Average annual precipitation reported for this weather station indicated that the 30 year normal precipitation for the study period, March 2000 through March 2001 at this location would result in 136 cm. The precipitation measured at the same station during the study time period resulted in 111 cm. The months of March, May, June, July, October, and December of 2001 as well as January, February, and March 2001 exhibited total monthly precipitation less than the 30 year averages. April, August, September, and November of 2000 exhibited greater than 30 year normal precipitation.

As soil C increases, concurrent increases in the soil temperature and soil moisture retention capacity would be expected. Soil temperature has the potential to greatly affect the fates of the nutrients applied to the soil through the application of poultry litter. Many of the fates available to the N applied as poultry litter such as mineralization, immobilization, and nitrification, are microbially mediated processes. Temperature greatly affects the viability and rates at which these bacteria and microbes function (Pierzynski, 1994; Campbell, 1993). Mineralization has been found to occur at soil temperatures as low as 0 ^{0}C. At optimum soil temperatures, between 25-35 ^{0}C, mineralization occurs much more rapidly, with estimates of as much as 40-60 % organic N added as poultry manure being mineralized within the first 90-150 days after addition to soil (Sims, 1986).

In nine of the twenty three weeks in which soil temperature was measured, the temperatures recorded were below 15 ^{0}C (Figure 1.5). Optimum, or near optimum soil temperatures for soil microbially mediated processes were recorded in May, June, July, August, and September 2000 (Figure 1.5). It is important to note that the first poultry litter application occurred in 1999, the second application occurred in January 2000 and the temperature data presented begins in March 2000; thus, any temperature modification of the soil due solely to the first application would not be discernable in the data presented. Soil temperature did differ significantly between the three treatments, with the 0 treatment exhibiting lower temperatures than the 134 and 269 treatments on average by 0.41 and 0.59 degrees C respectively (Table 1.4). It is important to note that no discernable treatment trend is evidenced in Figure 1.5, that soil temperature varies greatly in uniform systems, and that landscape position of the treatment plots may have affected soil temperature. In this study, the soil temperature data indicated a positive treatment effect on soil temperature, which may have the potential to increase the rates of mineralization, immobilization, and nitrification. If the increase in soil temperature was a result of the application of poultry litter, it was likely due to the addition of the organic material in poultry litter which is darker in color and may facilitate an increase in the soils solar energy absorptivity (Sparks, 1995).

Soil temperature may affect not only the rate at which chemical changes occur in organically amended soils, but also the end state of the nutrient. A study performed on ground and pelletized chicken litter noted that at 14 ^{0}C, nitrification was delayed and the alternative form of N, NH_4^+ - N, accumulated (Hadas et al, 1983). The same study indicated that at optimum soil temperature, 25-35 ^{0}C, nitrification proceeded rapidly during the initial mineralization phase ,within the first 30 days after application, and that the greatest loss of N occurred at 35 ^{0}C (Hades et al, 1983). Based on these findings and the temperatures presented in Fig. 1.4, the predominate form of N expected to be available during the months of March, November, and December 2000 as well as, January, February, and March 2001 would be NH_4^+ - N. The initial KCl extractable N data supported this supposition with NH_4^+ - N, during these months, being consistently greater than $N0_3^-$ N in all treatments (Figure 1.8). Due to optimum soil temperatures and elevated levels of $N0_3^-$ N and NH_4^+ - N, mineralization was shown to proceed more effectively during the months with optimum soil temperatures (Figures 1.4 and 1.10). Total N loss was not measured in this study.

Soil moisture also plays a vital role in nutrient availability in soil systems. A soil's moisture content will affect microbially and bacterially mediated processes thus determining nutrient availability and the form of nutrient available at any given time in soil solution. Adequate moisture may become of even greater importance when litter is not incorporated into the soil, as in this experiment, due to the increased rate of N volatilization associated with surface application (Rasnake, 1996). Based on a reported field capacity in a nearby similar system, field capacity was assumed to be 0.01.cm^3/cm^3 (10% volumetric water content); field capacity during this experiment was exceeded on sampling dates in March, June, July, and August of 2000 (Luduvici et al, 2002). The soil moisture fell between field capacity and 50% of field capacity in July, September, October, November, December 2000 as well as January and February of 2001. In March, April, May, June, and October of 2000 as well as March and April of 2001 the soil moisture at the time of sample collection fell below 50% of field capacity. Sims (1986) examined poultry litter and found a moisture driven N speciation trend where $N0_3^-$ N dominated under adequate moisture regimes and was limited by lack of moisture. The absence of a moisture driven N species trend in the data presented is most likely due to the dynamic nature of speciation and the lack of a constant moisture regime as the data presented represents only a discreet soil moisture content at time of sample collection.

There was a significant treatment effect on soil moisture in the 269 treatment as compared to the control and 134 treatment. Again the treatment effect reported in Table 1.4 may not be directly attributed to poultry litter application as Figure 1.5 does not indicate a treatment trend. However, with continued application of poultry litter on a regular basis, moisture holding capacity of the soil would be expected to increase due to the addition of organic matter. Organic matter has the capacity to hold up to twenty times its weight in water and is effective at increasing sandy soils moisture retention capacity (Sparks, 1995). This increased moisture retention capacity may in time extend to well below the 15 cm depth reported on in this study. Additions of beef manure and sewage sludge when added to sandy, acidic, Evesboro soils was shown to increase soil water retention capacity to depths below the tillage zone due to the movement of the organic matter into the soil profile (Tester, 1990). This increased retention may be of particular importance in stands raked for pinestraw on a regular basis as removal of litter has been shown to reduce soil moisture at the soil surface through elevated evaporative rates as well as to depths of up to 90 cm, potentially through increased evaporative demands driving increased transpiration (Ginter, 1979).

Soil Carbon, Nitrogen, Nutrients and Chemistry

It is important to note that the soil C, N, nutrients, and chemistry data presented may not account for all soil chemical changes due to the poultry litter application; the 269 treatment represent soils already altered by the initial application of poultry litter in 1999. The upper 15 cm soil C content did not differ significantly between treatments in 2000. In 2001, there was a significant difference in soil C between treatments. A large, though non-significant, within treatment (year effect) increase in soil C content occurred in the 269 treatment with an increase of 0.80% from 1.37 % to 2.17 % between 2000 and 2001 while the 0 treatment exhibited a concurrent decrease of 0.43% in C (Table 1.3). Based on this C content increase in the 269 treatment, an estimated 3,912 kg/ha of C were recovered in the 269 treatment in 2001. This represents a recovery of 64% of the total C added to the soil in the form of poultry litter in 2000.

The upper 15 cm soil N content did not differ significantly in 2000 between treatments. In 2001 the 0 and 269 treatment's N content was significantly different, with the 269 treatment exhibiting a significant increase as compared to the 0 treatment of 0.045 % in soil N (Table 1.3). The only significant within treatment (year effect) on soil N occurred in the 269 treatment with an increase from 0.03% to 0.07% between 2000 and 2001. Based on this N content increase in the 269 treatment, an estimated 126 kg/ha of N were recovered in the 269 treatment in 2001. This represents a recovery of 46 % of the total N added to the soil in the form of poultry litter between 1999 and 2000.

In 2000, there were no between treatment statistically significant differences in the pH of the upper 15 cm of soil. In 2001, there was a significant difference between the 0 treatment and the 269 treatment with pH values of 4.33 and 4.55 respectively (Table 1.3). Examination of the base cation concentrations of the upper 15 cm of soil revealed that in 2000 the 269 treatment exhibited significantly elevated levels of Ca, Mg, and sodium as compared to the 0 treatment. In 2001, the 269 treatment exhibited significant treatment effects on Ca, Mg, and K. Sodium content was no longer significantly different across treatments in 2001. T he within treatment changes (year effect) between 2000 and 2001 were significant for Mg and sodium in the 0 treatment and for

Mg, K, and sodium in the 269 treatment (Table 1.3). Exchangeable acidity in the upper 15 cm of the soil horizon did not differ significantly in 2000 or 2001 between treatments. The within treatment changes (year effect) were also not significant (Table 1.3).

The effective cation exchange capacity (CEC_E) in 2000 differed significantly across treatments with the 269 treatment having the highest CEC_E of 2.89 meq/100 cm^3 and the 0 treatment exhibiting a CEC_E of 1.83 meq/100 cm^3. In 2001, a treatment effect was again exhibited for CEC_E with the 269 treatment exhibiting a $CECE_{value}$ of 5.15 meq/100 cm^3 and the 0 treatment exhibiting a value of 1.49 meq/100 cm^3. The 269 treatment exhibited significant within treatment differences in the CEC_E between 2000 and 2001 with changes in CEC_E of 2.89 (2000) to 5.86 (2001) meq/100 cm^3 (Table 1.3). The base saturation did not differ significantly across treatments in 2000 or 2001. Base saturation exhibited a significant within treatment (year) effect between 2000 and 2001 in treatment 0 with an increase of 4.6 % (Table 1.3).

In addition to the changes in soil temperature and moisture, poultry litter application may affect soil chemical properties. The increase in soil C in the 269 treatment between 2000 and 2001 and the concurrent decrease in soil C in the 0 treatment during the same time frame may indicate a reduction in available soil moisture as compared to the prior year in the 0 treatment during the study. A soil's C content is important not only due to C’s effects on soil temperature and moisture retention capacity, but as an energy source for the bacteria and microbes that mediate soil chemical processes such as mineralization and immobilization. It is important to consider a soil's N content with respect to the C content when examining the efficacy of organic soil amendments due to the C: N ratio determining the fates of the added C and N. Mineralization and immobilization are equivalent to each other when a soils C: N ratio approximates 25:1, while a C: N ratio of 30:1 has been shown to cause an increase in the microbial population with concurrent decrease in available N (immobilization) to render soils N deficient (Pierzynski, 1994). The cellulose added as partially decomposed bedding material to the poultry manure to make it poultry litter may play a role in providing a slower released C source to drive the mineralization process. The manure portion of the litter represents a source of readily available DOC to be immediately utilized by the microbes followed by a more protracted release of C from the more recalcitrant fractions of the litter. Thus, the composition of the poultry litter also plays a role in the C: N ratio and the rate that N becomes available. The poultry litter applied in 2000 had a C: N ratio of 23:1, indicating a slight trend toward the mineralization process over immobilization. This ratio was relatively high in comparison with litter samples reported in other studies (Martin-Olmedo and Rees, 1999; Shephard and Bhogal, 1999; Tyson and Cabrera, 1993), which indicated that the litter may have had an abundance of cellulose in the form of bedding material that may have resulted in a more long term C source. The two time addition of poultry litter in the 269 treatment significantly increased both soil C and soil N in 2001 only. It seems likely that the two time addition of poultry litter applied in two consecutive years had provided not only the readily available C in the form of DOC for N mineralization that would result in elevated levels of soil C, N, and mineralization in the first few weeks to months post application, but also a more slowly released C source to enable continued N mineralization. The soil C and N sampling dates would not have captured the rapid mineralization phase anticipated immediately post application. However, 2001 recovery rates for the C and N added in the form of poultry litter of 64% and 46 % respectively does indicate sustained increases in longer term C and N sources. These additions correlate to a soil C: N ratio for the 269 treatment in 2001 of 31:1. The 0 treatments soil C: N ratio remained 40:1 over both years sampled, while the 269 treatments soil C: N ratio exhibited a reduction from 46:1 in 2000 to 31:1 in 2001. In the absence of an additional C source over the next few years it is anticipated that the 3,912 kg/ha of soil C remaining in the soil in 2001 would be an available nutrient source to the microbes to drive the mineralization of a portion of the 126 kg N/ha also available in 2001.

Soil pH is also important in determining nutrient availability as well as rates of mineralization and mineralization end product N species. The soil pH values in 2000 were acidic and remained acidic in 2001. The only significant difference across treatments for soil pH was observed in the increase in soil pH in 2001 in the 269 treatment to 4.55. This represents the lower range of soil pH conducive for longleaf pine growth. At this pH, N, Ca, Mg, and boron (B) are only moderately available for plant uptake while P, K, sulfur (S), (Cu), and molybdenum (Mo) are marginally to non-available. Only (Z), iron (Fe), manganese (Mn), and aluminum (Al) are readily available at this soil pH (Londo et al, 2006*)*. Poultry litter is often highly alkaline given the relatively high Ca and Mg content generally found in the litter. Rasnake (1996) found that this high cation content in litter likely proved beneficial with repeated application by not acidifying the soils as would be expected to occur with repeated chemical fertilization. While the pH was most likely not increased enough to produce measurable results in nutrient availability, the treatment trend and effect does indicate that with repeated application poultry litter may serve to offset the acidifying effects of nitrification associated with mineralization.

Microbial populations that mediate the mineralization process have been found to perform better in sandy soils under slightly acidic conditions (Gordillo and Cabrera, 1997). Thus, alterations to a soils pH can have a decided affect on the efficacy of a soil amendment. It is not uncommon for poultry litter to initially increase the pH of the soil upon application. This increase is often mediated through time by warm temperatures and adequate precipitation driving nitrification processes which reduce soil pH, often below initial pH levels (Tester, 1990). This may be the cause for the pH in the 269 treatment being lower (no significance) than the 0 treatment in 2000 and continuing to drop significantly from 4.77 to 4.55 between 2000 and 2001. Nitrifiers are also pH sensitive. Nitrification is optimum in soils with pH values between 6-8. Below pH values of 5 nitrification is negligible, thus the low pH of the soil in this study is somewhat limiting the mineralization process and ultimately the plant available N (Alexander, 1977).

Soil pH is also of concern with respect to poultry litter application due to the high concentration of metals potentially added to soils with repeated application. After the second application of poultry litter in 2000, 0.96, 1.92, 3.24, .022 kg/h of Fe, Mn, Zn, and Cu had been added to the study site soil. Metals are mobilized and become soluble at lower pHs; Fe, Mn, Zn, Cu are all optimally available at pHs of approximately 4.0 – 5.0 (Sparks, 1996). Thus in soils such as those associated with this study, the repeated loading of soil with high concentration of metals through poultry litter application could have negative impacts on soil processes, water quality, and stand growth through metal toxicity. A potential solution to negate lowering the pH of already acidic soils may be to compost the litter prior to application. While both composted and uncomposted litter initially increase soil pH, in uncomposted litter, nitrification ultimately decreased the soil pH while composted litter exhibited a sustained soil pH increase (Tyson and Cabrera, 1993).

The base cation concentrations of the soil coupled with the exchangeable acidity are important determinants of a soil's CEC_E. The base cation concentrations exhibited a significant increase in Ca, Mg, and K. Sodium did not exhibit significant across treatment differences 2001. These increases in the soils base cations would be expected due to the relatively large loading rate of these nutrients through poultry litter application (Table 1.2). CEC_E is a valuable estimate of the exchange sites available within a soil for nutrient retention. Coastal Plain soils generally have a CEC of approximately 2.0 meq/100 cm^3 soil. Because poultry litter has a relatively high organic content, it has the potential to increase this relatively low CEC in sandy soils where long leaf pine plantations are common. The calculated CEC_E values for the soil ranged between 1.05 to 5.15 with the highest capacity observed in the 2001 269 treatment. The exchangeable acidity ranged from 0.54 to 0.69 meq/ cm^3 with the highest value in the 0 treatment. The 269 treatment exhibited a 127 % increase in CEC between 2000 – 2001 while the 134 treatment resulted in an increase of 151%. This increase in the 134 and 269 treatments $CEC_{E\ is}$ likely exaggerated as the Ca component of the litter is incorporated into the base cation measurement thereby overestimating the soils available exchange sites. There is a relationship between pH and percent base saturation and at the pH of the soils in question (4.32 - 4.87); the associated base saturation would be expected to be anywhere from 0-25%. The calculated percentage of base saturation in all soils greatly exceeded this expectation in 2001 and the treatment trend reflects the loading of the soils with base cations.

Soil Solution Measures

All treatments exhibited relatively low levels (< 10 mg/l) of available N in soil solution at a depth of 15 cm in March 2000 followed by an increase in NH_4^+-N + $N0_3^-$ - N concentrations through May 2000 in both fertilization treatments (Figure 1.6). The 269 treatment had higher concentrations of NH_4^+-N + $N0_3^-$ - N than did the 0 treatment. Nitrate was the predominate form of N in the soil solution for both fertilization treatments. The 269 treatment had $N0_3^-$ N concentration values consistently greater than the 0 treatment March 2000 through September 2000. The 134 treatment $N0_3^-$ N concentration values were consistently greater than the 0 treatment. The 134 treatment exhibited the greatest $N0_3^-$ N concentrations in 2001 (Figure 1.6). Treatment and time were both significant affects for sum of the NH_4^+-N + $N0_3^-$ - N and the $N0_3^-$ - N at the 15 cm depth (Table 1.5).

The sum of the NH_4^+-N + $N0_3^-$ - N concentrations in the soil solution at a depth of 60 cm follow the same general time and treatment trends as the concentrations at the 15 cm depth. The treatment trend mirrors the 15 cm depth solution graph with the 269 treatment having elevated total N concentrations exceeding the 134 treatment and both the 134 and 269 treatments generally having significantly higher concentrations of N than the 0 treatment (Figure 1.7). Nitrate-N concentrations at the 60 cm depth followed this treatment trend. The 269 treatment exhibited the greatest $N0_3^-$ N concentrations in most months between 2000 and 2001, followed closely by the 134 treatment. The 0 treatment typically fell well below both the 134 and 269 treatments in $N0_3^-$ N and NH_4^+ - N concentrations in most months between 2000 and 2001. All treatments exhibited increases in $N0_3^-$ - N concentrations at the 60 cm depth in March 2001 (Figure 1.7). Treatment and time were both significant effects on the NH_4^+ -N + $N0_3^-$ - N concentrations at the 60 cm depth. The only additional significant effect was observed for treatment on the $N0_3^-$ - N species at the 60 cm depth (Table 1.5).

Ortho-phosphate in soil solution at the upper 15 cm depth remained relatively low at less than 3 mg/l through 2000 in all treatments. In February and March 2001 these levels PO_4^{3-} concentrations increased to levels over 8 mg/l in the 134 treatment and 4 mg/l in the 269 treatments (Figure 1.6). At the 60 cm depth, the initial soil solution sample in March 2000 exhibited the greatest PO_4^{3-} concentration at greater than 5 mg/l in the 134 treatment. In both May and June 2000, PO_4^{3-} concentration in soil solution remained relatively high in both fertilization treatments (Figure 1.7). Ortho-phosphate exhibited no treatment effect at either depth. Time was a significant affect at the 15 cm depth only. There were no treatment by time interactions at either depth (Table 1.5).

It is important to measure soil solution N concentrations to predict potential negative impacts to surface or ground water resulting from forest fertilization. Elevated levels of N in stream waters may induce eutrophication through algal blooms, which in turn deplete the available oxygen in the water column for macrobenthos and other aquatic organisms. Groundwater contamination is of importance in that although uncommon, wells with high concentrations of $N0_3^-$ N may induce methemoglobinemia, or 'blue baby syndrome' where $N0_3^-$ N binds to red blood cells and displaces the oxygen molecules in the bloodstream. This reduced availability of oxygen may lead to oxygen depletion in the very young or ill and cause suffocation.

When examining soil solution N concentrations, $N0_3^-$ N is most commonly measured in forest systems. This is due to $N0_3^-$ N being the predominate form of N in soil solutions in forest systems. Nitrite-N is highly transient and readily oxidizes to $N0_3^-$ N. Ammonia is also not of great concern as only traces of the more toxic form of ammonia-N would be found in the pH ranges of typical forest soils.

As would be expected the bulk of the total N in soil solution in this study occurred as $N0_3^-$ N at both the 15 cm and 60 cm depths. Nitrate-N at the 15 cm depth exhibited significant treatment and time effects. The 269 treatment has the greatest $N0_3^-N$ concentration, which peaked at 18.0 mg/l in May of 2001. This abundance of $N0_3^-N$ in 2000 correlates with the significant pH increase evident in 2001 when $N0_3^-N$ values have decreased.

Soil drainage waters in many different types of forest stands and soils in unfertilized systems have been found to have a $N0_3^-N$ concentration of less than 3 mg/l (Binkley, 1999). This is evidenced in the 0 treatment at both the 15 and 60 cm depths. This low $N0_3^-N$ concentration has been shown to spike to 10 mg/l or higher directly after fertilization and remain at these elevated concentrations for over one year post fertilization in systems where high inputs of N are added on a yearly basis and the systems are irrigated (Binkley, 1999; Sims, 1987). Both the 134 and 269 treatment exhibited concentrations of greater than 10 mg/l on several sampling dates during the summer of 2000. Several studies examining the effects of poultry litter applied at comparable rates to pine stands have reported no treatment effects in macropore $N0_3^-N$ to depths of 60 cm and concentrations as low as 1.8 ppm $N0_3^-N$ at this depth (Samuelson, 1999; Beem F5037; Turton, 1998). This average concentration is well below the EPA designated drinking water standard of 10 mg/l and well below the concentrations reported in both the 134 and 269 treatments for most months of this study in 2000. Safe levels for livestock drinking sources have been established at between 100-300 mg-/l, well above all concentrations reported in this study (Binkley, 1999).

The fate of soil solution N depends on many factors such as $N0_3^-N$ retention in the biota, denitrification processes and often $N0_3^-N$ dilution. Again, the C content of the subsoil plays a vital role in driving the first two processes. The importance of quantifying the DOC content of soils in conjunction with lysimeters placed at different depths in the soil horizon was noted by Shepherd and Bhogal (1998) as the DOC may provide a nutrient source to drive the mineralization/immobilization processes. The differences between the $N0_3^-N$ concentrations at the 15 and 60 cm depths indicated a small reduction in $N0_3^-N$ concentration at the 60 cm depth as compared to the 15 cm depth. As there are many fates available to the $N0_3^-N$ leaching below the 15 and even the 60 cm depths in these systems, no clear conclusion can be drawn as to the fates, sources and sinks of the N between the two depths. The results of this study do indicate elevated levels of $N0_3^-N$ as compared to the control at both the 15 and 60 cm depths for one year post application. The data presented indicates a potential for negative water quality impacts to occur to ground water in areas where shallow aquifer recharge occurs and also to stream if the polluted groundwater discharges to a nearby stream.

KCl Extractable Soil Nitrogen and Calculated Mineralization

Initial soil core KCl extractable N was elevated in July 2000 in all three treatments. By October 2000, soil concentration in all treatments had returned to approximately 0 Kg-N/ha KCl extractable N, with extractable N remaining low in all treatments through January 2001. In February 2001, the 134 and 269 treatments exhibited an increase in NH_4^+-N of over 12 kg/ha followed by a decline to approximately 0 kg/ha again in March 2001. The 0 treatment exhibited elevated levels of NH_4^+-N in March 2001. The predominate N species in the initial KCl extractable N samples was NH_4^+-N. Both the NH_4^+-N and $N0_3^-$-N initial KCl extractable N species followed the same general time trend. The treatment trends varied between the N species (Figure 1.8). The treatment effect on initial samples of KCl extractable N was significant for $N0_3^-$-N only; time was significant across both species and the sum of both species. As would be expected, a treatment by time interaction was significant on N03-N only (Table 1.6).

The uncovered soil core incubation samples also exhibited elevated KCl extractable N content July through October 2000, followed by the same relatively low N contents until January 2001. Again, the control exhibited the greatest sum N content in July 2000. The predominate form of N in the uncovered soil samples is not as pronounced as in the initial soil core samples; however again NH_4^+-N exceeds the $N0_3^-$-N content. The treatment trend varied across N species (Figure 1.9). The only significant treatment effect occurred in $N0_3^-$-N, while time was significant for both $N0_3^-$-N and NH_4^+-N + $N0_3^-$-N. The only significant time by treatment interaction occurred in the $N0_3^-$-N which consistently exhibited the smallest error term (Table 1.6).

The 134 and 269 treatments exhibited negative net mineralization in July 2000 while the 0 treatment exhibited positive mineralization of 10 kg-N/ha in the same month. The 134 and 269 treatments sum of mineralization contents increased in August to 3 and 18 kg-N/ha respectively and again fell below 0 in September and October 2000. A slight but steady increase in mineralization through February 2001 occurred in both the 134 and 269 treatments. In March 2001, both the 0 and 269 treatment exhibited negative mineralization, while the 134 exhibited the greatest mineralization as it approximated 0 kg-N/ha. There were no pronounced predominate N species or treatment trends in the mineralization data (Figure 1.10). This lack of treatment trend is supported by the lack of a significant treatment effect on the mineralization data set. The only significant effects for this data set were time for NH_4^+-N + $N0_3^-$ - N, NH_4^+-N and $N0_3^-$ - N and time x treatment interaction effects for NH_4^+-N + $N0_3^-$ - N and $N0_3^-$ - N (Table 1.6).

There are two ways to view the N mineralization data produced through this study. The KCl extractable inorganic N data presented as initial and uncovered soil core data represents a discreet sample of N content and species availability at a single point in time. The calculated net mineralization data represents an estimate of inorganic N that becomes available on a monthly basis. The KCl extractable soil N is useful in that it provides a measure of soil N content that may be examined independent of the myriad of soil processes that must be considered when interpreting soil mineralization data.

The KCl extractable soil N data indicated a time trend in which the content of total N in the soil remained elevated in both the initial and uncovered soil sample data sets through September 2000. One explanation for this could be the occurrence of near optimum mineralization temperatures approaching 25 ^{0}C being recorded during this time frame (Sims, 1986). Another factor which may have had a positive affect on KCl extractable N availability in August and September 2000 is the above normal precipitation reported during these months, with 16 (5 cm above normal) and 19 cm (8 cm above normal) of precipitation being reported for each month respectively (Figure 1.5).

It is important to note that at the first KCl extractable sample date, July 2000, the last poultry litter application had occurred six months (181 days) prior. Estimates of mineralization rates vary greatly and different fractions of the same litter application will mineralize at different rates depending on the size of the particles. Several studies have attempted to identify the mineralization rates of the coarse fraction of poultry litter versus the finer fractions of the litter. The finer fraction of the litter has been defined as 0.83 mm or less and has been estimated to mineralize at rates of 51% (of total fraction) by day 14 and as soon as between 70-90% by day 1 (Godillo and Cabrara, 1997). Other estimates of litter mineralization report 25-46%, 45%, 66%, and 98% of the total fraction mineralized by day 150, 70, 140 and 112. (Sims, 1986; Castellanos and Pratt, 1981; Bitzer and Sims, 1988; Gordillo and Cabrera, 1997) All of these studies were conducted at constant temperature of 23-25^{0}C and the Gordillo and Cabrera study was conducted at sustained field capacity. Field mediated mineralization with a fluctuating temperature and moisture regime would be expected to reduce mineralization rates. These studies indicate that the elevated N content of the KCL extractable initial and uncovered samples represents the mineralization of the coarser fraction of litter. It is likely that the more readily available N from the finer fraction of the litter was released before the first KCL extractable N soil sample was collected.

The treatment trend through time would seem to confound this assumption in that the 0 treatment exhibited the greatest total soil inorganic N content in July and August of 2000 in the initial soil core samples and in July 2000 in the uncovered soil core samples. The 269 treatment exhibited greater $N0_3^-$ - N + NH_4^+ - N contents July through September than the 134 treatment in the initial core samples. The 134 treatment exhibited greater KCl extractable $N0_3^-$ - N + NH_4^+ - N content than the 269 treatment in the uncovered KCl extractions data set. As Costa et al. (1989) indicated and previously discussed, one anticipated effect of the addition of poultry litter to soils is that through the increase in the organic matter to the soil, an additional supply of C will be available to microbe populations that drive the mineralization process. As indicated through the poultry litter nutrient analysis of the litter applied in 2000, the litter was 32% C which resulted in an addition of 134 kg-N/ha added for the 134 treatment and 269 kg-N/ha in the 269 treatment (over a period of two years). This influx of C may have stimulated microbe populations and may have led to suppressed mineralization in both the initial and uncovered soil core sample data sets as evidenced by the 0 treatment exhibiting the greatest KCl extractable N content July and August of 2000. This supports the time and treatment trends illustrated in both initial and uncovered soil core samples, with the 269 treatment rebounding when temperatures again become conducive to mineralization in early 2001.

When examining N species trends in the KCl extractable soil core samples, again the difference between the initial and uncovered soil cores is evident. The initial soil core samples indicate a predominance of NH_4^+ - N over $N0_3^-$ N as evidenced by the value axis ranges of 4.5 kg-N/ha for $N0_3^-$ N and 14 kg-N/ha for NH_4^+ - N , as would be expected. The uncovered soil core samples indicate not only a more equal distribution of N species but more closely follows the soil moisture trend line. This may be due to water availability being affected by the sampling core in that lateral water movement is not possible within the upper 15 cm of soil.

Examining N on a content basis, again 134 kg-N/ha were added to each of the 134 and 269 treatments in early 2000. As presented previously, both soil C and N levels in the 269 treatment were significantly greater by 2001 than the 134 and 0 treatments. The A horizon of agricultural mineral soils typically have total N values that range between 0.05-0.15%, of which between 1-3 % will mineralize annually producing 15-70 kg-N/ha/yr (Pierzynski, 1994). Estimates of the initial 0 treatment fall within this expected range, at 29 kg-N/ha, with 20 and 30 kg-N/ha recovered in the 134 and 269 treatments respectively between June 2000 and March 2001. A total of 51 kg-N/ha was measured in the 0 treatment in the uncovered soil cores, with 35 kg-N/ha and 63 kg-N/ha reported in the 134 and 269 treatments. The 134 treatment exhibited suppressed N availability as compared to the 0 treatment with a 35% total N recovery rate. The 269 treatment exhibited the greatest recovery rate at 47%. It is important to note that the reported recovery for the 269 treatment is based only on the last application of poultry litter. Bitzer and Sims (1988) reported that the average amount of organic N mineralized in 20 poultry litter samples was 66%, however on average only 35% of the inorganic N measured in these samples was able to be recovered through KCl extraction. Thus, these recovery rates are estimates at best of N availability at the time of sampling and are not truly indicative of mineralization processes in that no estimates of uptake were undertaken as part of this study.

The calculated total N mineralization followed the same time, treatment, and N species trends as did the KCl extractable uncovered soil core values. The appreciable difference in the two data sets are that the calculated mineralization data indicate net negative estimates of N availability in most months across most treatments. Since these calculations were based on equations 1.1 as explained previously, the possibility that the incubation tubes may have a confounding affect on mineralization measurements must be considered. The predominance of calculated negative mineralization rates indicates that a higher content of N was consistently found in the initial soil samples. This comparatively elevated level of N may be due to soil disruption caused by the coring process. The negative mineralization rates increase in the warmer months where mineralization would be predicated to occur more rapidly due to optimum temperatures. A related factor that may have influenced the rate of mineralization being reduced in the soil cores is once again water limitation. In sandy soils with little organic matter, the moisture content of the soil fluctuates rapidly. This rapid flux may have been exacerbated by a slight increase in soil temperatures within the tubes over the 30 day period.

Stand Growth -Diameter and Basal Area

In 1999 the stand dbh in the treatment plots ranged between 21.43 (0) cm, and 21.17 (269) cm and no significant treatment differences were evident for dbh. No treatment effect was evident for dbh in 2000 or for the 1999-2000 growth data. Basal area ranged between 114 (0) – 131 (269) m^2/ha in the treatment plots in1999. There was no significant treatment effect for basal area in either 1999, 2000 or on the 1999 – 2000 growth data (Table 1.7).

While no significant between treatment differences are evident in stand dbh in 1998, 1999, or 2000, a significant increase in dbh growth of 10% is exhibited during the 1999 – 2000 growing season for the 134 treatment as compared to the 0 and 269 treatment (Table 1.7). Tree basal area follows the same stand and growth trend (Table 1.7).

The stand dbh response to poultry litter is expected to occur more rapidly than would stand height response. In a study which examined stand responses to similar application rates with a low treatment of 119 kg-N/ha and a high treatment of 228 kg-N/ha, a dbh increase of 38% was recorded in the high treatment only (Samelson, 1999). It is important to note that the high treatment is similar in application rate to the 269 treatment but that it occurred via a one time treatment rather than over two years as in this study. A similar dbh increase of 33% was reported over two years following a lime stabilized biosolids application to a 33 year old longleaf stand at a rate of 85 lbs-N/ac (Dickens, 1999). The lack of stand growth response by 2000 to fertilization may be due to a delayed response.

Foliar Nutrient Concentrations

Potassium, B, and Cu exhibited the only significant foliar nutrient treatment effects in 1999 with the 269 treatment exhibiting elevated levels as compared to the 0 treatment. The only significant foliar nutrient treatment effect in 2000 occurred in K again with the 269 treatment still elevated as compared to the 0 treatment. Potassium and Cu exhibited significant through time treatment effects. Date was a significant effect for K, Ca, Mg, Zn, B and Cu. Block and treatment by block interactions were not significant on any foliar nutrient (Table 1.8).

Foliar nutrient content is an important measure of a stand's nutrient limitations. Longleaf pine foliar nutrient sufficiency levels for sustained growth response have been suggested to be N 0.95 %, P 0.08%, K 0.30%, Ca 0.10%, Mg 0.06% (Blevins, 1996). There were no between treatment significant differences in foliar mean nutrient content in 1998 (Table 1.1). The pre-treatment nutrient concentrations of the 269 treatment in 1998 indicated N, P, K, Ca, and Mg contents of 0.80%, 0.13%, 0.32%, 0.14%, and 0.04% respectively. Thus the 269 treatment exhibited deficiencies in N (0.15%), and Mg (0.02%) only. The elevated levels of K in the 269 treatment in both years following the initial analysis and the increase in Cu in 1999 are the only two significant foliar responses to the poultry litter application. A study examining foliar nutrient response to poultry litter application with similar application rates of a low treatment of 119 kg/ha N, 53 Kg/ha P and a high treatment where 228 kg-N/ha, 106 kg-P/ha applied to 18 year old loblolly pine stands resulted in increases in the foliar nutrient concentration in the current years foliage four months post application in the high treatment (Samuelson, 1999). Beem et al (2006), found elevated levels of both N and P as compared to the control and to a similar application of chemical fertilizer for the first two years with increases of 0.12% and 18 % in N content and 0.01% and 0.02% in P content in year one and two following poultry litter application at a rate of 134 kg-N/ha, while the North Carolina Forest Nutrition Cooperative (1998) reported increases as high as 50% in N and P at similar application rates. The assumption that N mineralization has been suppressed somewhat in the 134 and 269 treatments would account for the lack of foliar N response to the fertilization.

Pinestraw Production

The initial leaf litter (pinestraw) collection in December 1999 yielded between 7, 516 – 7,958 kg/ha pinestraw for treatments 0 and 269 respectively followed by a decline for the following two rake dates of 3,537 – 3,045 Kg/ha and 3,537 – 4,126 kg/ha for treatments 0 and 269 and July and December 2000 respectively. Treatment, block, date, treatment x date and block x date were all significant general model effects for pinestraw collection (Table 1.9).

The treatment effect was significant for pinestraw production; however, the only significant between treatment difference in means occurred in December 2000 (Table 1.9). This is not unexpected as similar studies have shown fertilization response in pinestraw production at two years post fertilization. No significant response in pinestraw production in the first year post fertilization is to be expected. Litter weight has been shown to be increased by 60% and 62 % by years two and three post fertilization, as compared to the control, in a biosolid application at a rate of 86 lbs available N/acre to a 36 year old longleaf stand (Dickens et al, 1999). A 50% increase in pinestraw mass two years post fertilization at rate of 200 lbs N/ac applied to 55 year old longleaf stands has also been reported (Blevins, 1996). The increase in the 269 treatment falls below both these estimates in December 2000 with a 17% increase as compared to treatment 0 on the same date. However, a 35% increase between July 2000 and December 2000 in the 269 treatment may indicate a trend toward greater response in the future. Pinestraw response to fertilization has been shown to peak three years post application (Dickens, 1999) and may persist for 4-10 years (Dickens, 2003). Again, the 269 treatment was fertilized initially in January 1999, which indicated that the December 2000 pinestraw production is most likely a response at that point to the one time application only. Although not statistically significant, the 134 treatment did exhibit a 58% increase in production over the 0 treatment one growing season post fertilization.

A relationship between pinestraw production, stand basal area and site index has been established which enables estimates of pinestraw production. Maximum needle production is associated with a stand basal area of 21-23 m2/ha (Stanton, 1995). The stand basal area of the study site in 1998 was 31.96 m2/ha and the site index was 50 which resulted in a predicted 2,581 kg/ha/yr dried weight of pinestraw (Blevins, 1996; Schumacker and Coile, 1960). Additional studies which have quantified pinestraw production estimates have noted production values between 3,625 – 5,095 kg pinestraw/ha/yr (Gresham, 1982). A study conducted in the Sandhills region of North Carolina reported 3,206 lbs/ac/year pinestraw production pre-fertilization. However, at 7, 515 kg/ha pinestraw produced in the 0 treatment and 7,957 kg/ha pinestraw produced in the 269 treatment; both treatments greatly exceed these estimates on the first rake date of December 1999 (Table 1.9). While it has been established that extended periods where stands are not raked are not likely to produce more pinestraw due to litter layers greater than three years old being too decomposed to be baled, the time trend of the litter fall indicates that upon first rake approximately three times the estimated pinestraw was available (Stanton, 1995). While not able to be baled, the decomposing litter was included in the reported weight on that rake date. Longleaf litterfall has been shown to exhibit seasonal leaf abscission patterns in which more leaf litter is generally available in spring and fall and availability is generally lower in summer to mid-winter (Gresham, 1982). The rake dates being established in December and July should not capture this season trend in that each rake date per year would allow for an optimal straw production season followed by a couple months of decomposition (Table 1.9). The decline in litterfall reported for the July and December 2000 rake dates indicated that the abundance of litter on the first rake date is likely due to not having been raked regularly prior to the initiation of this study.

On the last sampling date, which would be the first in which the fertilization effect would be expected to be evident, both the pinestraw produced by the 0 and 260 treatments exceed the predicted 2,581 kg/ha/yr pinestraw. The data presented were not dried weight of pinestraw, as it was weighed in the field. Assuming an average of 17% moisture content, those production numbers would be reduced to 2,935 kg/ha (0) and 3,425 kg/ha (269) pinestraw. A typical pinstraw bale weighs approximately 11.3 kg dry weight. Thus a yield comparison between the 0 treatment and the 269 treatment would result in the 0 and 269 treatments producing 259 bales/ha and 303 bales/ha respectively in December 2000 which represents a 44 bale increase in the 269 treatment as compared to the 0 treatment.

As leaf area increases, as evidenced by the significant increase in pinstraw production, stand growth would be expected to follow suit. It is likely that future stand measurements will capture the delayed growth response anticipated. In addition, if mineralization in both treatments were suppressed through immobilization, a foliar nutrient response to the N released through subsequent mineralization would also be expected.

Conclusions

The addition of the poultry litter indicated a positive treatment affect on soil temperature and soil moisture as compared to the control treatment. This affect, if attributable to the application of poultry litter, may have the potential to increase the rates of mineralization, immobilization, and nitrification. The application of poultry litter also affected the soil's nutrient content and chemistry in the 269 treatment by significantly increasing the soil's C, N, pH, Ca, Mg, K content and cation exchange capacity. A total of 64 % of C and 46 % of N added through litter application was recovered in the 269 treatment.

KCl extractable N, a measure of N availability, was also elevated in the 269 treatment as compared to the 0 treatment. A total of 51 kg-N/ha, 35 kg-N/ha and 63 kg-N/ha of KCl extractable N was reported in the 0, 134, and 269 treatments respectively. The 134 treatment exhibited suppressed N availability as compared to the 0 treatment with a 35% total N recovery rate. The 269 treatment exhibited the greatest recovery rate at 47%.

There was a significant treatment effect evident by December 2000 on pinestraw production. Due to the pattern of leaf abscission, this represents the first sampling date that the fertilization effect would be evidenced. The 269 treatment exhibited an increase of 17% in pinestraw production as compared to the 0 treatment. This treatment effect is expected to increase over the next few years as this represent only the affect of the first poultry litter application of 134 kg/N/ha in December 1999 to the 269 treatment.

The application of poultry litter at a rate of 269 kg/N/ha over a period of two years had a positive effect on soil temperate, moisture retention, pH, C, N and nutrient availability. Soil KCl extractable N content, foliar K and Cu content and pinestraw production were also significantly increased through the poultry litter application. Thus, poultry litter applied at a rate of 269 kg/N/ha may provide much needed soil amendments and slow release nutrients which would maximize uptake in year round crops such as longleaf pine stands. Poultry litter should be applied every 3-5 years, in the early spring to reduce $N0_3^-$ N leaching. The rate should be determined through matching the nutritional needs of the stand as determined through foliar nutrient analysis with the nutrient content of the litter to be applied.

The results of this study also indicate elevated levels of soil solution $N0_3^-$ N as compared to the 0 treatment at both the 15 and 60 cm depths for up to one year post application at concentrations well over the EPA established drinking water guidelines of 10 mg/l. The data presented indicated a potential for negative water quality impacts to occur to ground water in areas where shallow aquifer recharge occurs and to streams if the polluted groundwater were to discharge to surface waters. However, it should be noted that there are many fates available to the $N0_3^-$ N well below the 60 cm depth reported in this study that were not examined as part of this study. Poultry litter should be applied in early spring to maximize nutrient uptake and minimize leaching. Poultry litter application should also be avoided on sites with shallow aquifer recharge and where direct overland flow to unbuffered surface waters is possible.

Table 1.1 Summary of Initial Stand Characteristics as measured in December 1998 (P=0.05)

Initial Stand Characteristics										
Treatment	**Height (m)**			**dbh (cm)**			**BA (m2/ha)**			
0	14.69			20.98			112.95			
269	15.77			21.16			146.91			
Stderr	0.18			0.26			0.76			
Initial Foliage Nutrient Concentrations										
	N	**P**	**K**	**Ca**	**Mg**	**S**	**Mn**	**Zn**	**B**	**Cu**
Treatment	----------------------------------%----------------------------------						----------------------- PPM ---------------			
0	0.80	0.14	0.37	0.13	0.04	0.10	258.46	20.13	9.96	2.52
269	0.80	0.13	0.32	0.15	0.04	0.09	235.40	23.90	9.44	2.22
Stderr	0.01	0.01	0.03	0.01	0.01	0.01	35.01	2.38	0.78	0.15
Effect	--P>F ---									
Treatment	0.85	0.77	0.50	0.45	0.90	0.87	0.78	0.49	0.78	0.37

Table 1.2 Poultry Litter Nutrient Content of Litter Applied in January 2000.

Poultry Litter Nutrient Content												
Nutrient Content (%)							Nutrient Content (ppm)					
C	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Na**	**Fe**	**Mn**	**Zn**	**Cu**	**B**
32	1.4	0.35	1.08	0.69	1.9	2.1	3.9	50	100	170	110	151
Application Rate of 134 kg N/ha = 9,600 kg Poultry Litter/ha Nutrient Application Rate (kg/ha)												
C	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Na**	**Fe**	**Mn**	**Zn**	**Cu**	**B**
3063	134	33.5	103.4	66.0	181.8	258.4	0.037	0.48	0.96	1.62	0.011	1.44

Table 1.3 Between and Within Treatment Soil Chemical and Nutrient Content Changes in the Upper 15 cm of the Soil Horizon as Sampled in February 2000 and March 2001 (P =0 .1)*

TRT	C	N	pH	Ca	Mg	K	Na	Ex. Acid	CEC_E	Base Sat.
	%		meq/100cm3							%
2000										
0	1.61	0.04	4.87	0.70 B	0.37 B	0.06	0.37 B	0.69	1.83A/B	23.47
134	1.63	0.04	4.83	0.04 B	0.29 B	0.05	0.18 B	0.67	1.05 B	27.31
269	1.37	0.03	4.77	1.52 A	0.70 A	0.06	0.59 A	0.60	2.89 A	30.10
STD ERR	0.19	0.01	0.03	0.26	0.05	0.01	0.04	0.03	0.29	1.61
2001										
0	1.18 B	0.03 B	4.33 B	0.19 B	0.56 B	0.07 B	0.79	0.68	1.49 C	37.69
134	1.55 B	0.04 B	4.45 A/B	1.02 A/B	1.01 C	0.07 B	1.02	0.54	2.64 B	39.73
269	2.17 A	0.07 A	4.55 A	2.60 A	1.85 A	0.14 A	0.95	0.56	5.16 A	40.04
STD ERR	0.16	0.01	0.04	0.29	0.14	0.01	0.05	0.03	0.41	1.08
Treatment Effects P>F										
2000	0.85	0.66	0.33	0.06	0.01	0.83	0.01	0.39	0.02	0.25
2001	0.01	0.01	0.03	0.01	0.01	0.01	0.22	0.11	0.01	0.65
Year Effects P>F										
0	0.48	0.50	0.02	0.15	0.01	0.83	0.01	0.80	0.32	0.01
269	0.12	0.03	0.02	0.35	0.01	0.01	0.04	0.56	0.10	0.13

*** Letters A and B indicate significant differences between treatments by year (columns)**

Table 1.4 Statistical Summary of Continually Logged Soil Temperature and Soil Moisture (as Measured at time of Lysimeter and Soil Core Incubation Collection) in March 2000 through April 2001 (P=0 .05)

Treatment	Soil Temperature	Soil Moisture g H_20/g soil
0	16.99 B	0.052 B
134	17.40 A	0.051 B
269	17.58 A	0.056 A
STD ERR	.93	.005
Effect	P>F	
Treatment	0.016	0.050
Time	0.001	0.001
Treatment * Time	0.633	0.441

***Letters A and B indicate significant differences between treatments by year (columns)**

Table 1.5 Statistical Summary of Soil Solution Ammonium-N, Nitrate-N, the Sum of Ammonium N and Nitrate-N, and ortho-Phosphate at 15 cm and 60 cm As Collected from Three Randomly Spaced, Stationary Lysimeter Sub-Plots in March 2000 – March 2001 (P=0.1).*

TRT	15 cm depth				60 cm depth			
	NH_4^+ - N	$N0_3^-$ - N	NH_4^+ - N + $N0_3^-$ - N	PO_4^{3-}	NH_4^+ - N	$N0_3^-$ - N	NH_4^+ - N + $N0_3^-$ - N	PO_4^{3-}
0	2.129	1.031 B	3.160 B	0.461	0.806	1.370 B	2.321 B	0.342
134	4.272	6.058 A	8.280 A	0.481	2.203	4.610 A	13.832 A	0.298
269	3.558	11.421 A	14.980 A	0.690	2.540	10.522 A	10.522	0.521
STD ERR	0.469	0.767	0.963	0.087	0.489	0.694	0.814	0.139
Effect	---P>F---							
Trt	0.411	0.001	0.053	0.598	0.227	0.004	0.001	0.406
Time	0.480	0.008	0.001	0.006	0.360	0.161	0.013	0.595
Trt * Time	0.575	0.467	0.547	0.201	0.167	0.390	0.014	0.872

*** Letters A and B indicate significant differences between treatments by year (columns)**

Table 1.6 Treatment Means, Standard Error in Kg/ha and Statistical Summary of Initial and Uncovered Soil Core Samples and Calculated Mineralization in the Upper 15 cm of soil Collected Monthly at Three Randomly Spaced, Stationary within Plot Sub-Plots between June 2000 and March 2001 (P=0.1). *

TRT	Initial			Uncovered			Mineralization		
	NH_4^+N	$N0_3^-$ - N	NH_4^+N + $N0_3^-$ - N	NH_4^+N	$N0_3^-$ - N	NH_4^+N + $N0_3^-$ - N	NH_4^+N	$N0_3^-$ - N	NH_4^+N + $N0_3^-$ - N
	Kg/ha								
0	5.480	1.059 B	6.539	4.142	1.578 B	5.720	-1.337	0.488	-0.819
134	2.190	0.420 B	2.275	2.732	1.150 B	3.883	-1.752	-0.039	-1.792
269	4.983	1.190 A	7.874	4.571	2.505 A	7.076	-0.411	-0.384	0.797
STD ERR	1.596	2.891	1.593	1.227	0.248	1.365	1.557	0.314	1.596
Effect	--P>F---								
TRT	0.911	0.008	0.649	0.5853	0.033	0.351	0.831	0.236	0.884
Time	0.040	0.001	0.004	0.1395	0.001	0.001	0.039	0.001	0.004
TRT * Time	0.660	0.001	0.380	0.2013	0.001	0.036	0.416	0.001	0.036

*** Letters A and B indicate significant differences between treatments by year (columns)**

Table 1.7 Treatment Means, Standard Error, and Statistical Significance of Stand Height, Diameter at Breast Height (dbh), and Basal Area by Treatment and Time as Collected in December of 1998, 1999 and 2000 on all Trees within the Measurement Plot (P=0.05)*

Height, Diameter at Breast Height (dbh), and Stand Basal Area (SBA) Treatment Means, Standard Error, and Significant Differences By Treatment and Year*									
Trt	**1999**			**2000**			**1999-2000**		
	Height (m)	**dbh (cm)**	**BA (m2/ha)**	**Height (m)**	**dbh (cm)**	**BA (m2/ha)**	**Height (m)**	**dbh (cm)**	**BA (m^2/ha)**
0	14.93 B	21.43	113.83	15.30 B	21.51	116.71	0.442	0.450	4.064
269	17.36 A	21.17	131.02	16.85 A	21.44	133.37	0.548	0.681	6.923
Stderr	0.43	0.27	0.63	0.136	1.02	0.65	0.140	0.462	0.400
Effect	---P>F---								
TRT	0.01	0.66	0.74	0.01	0.90	0.19	0.87	0.33	0.33
Block	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.91	0.94
TRT * Block	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.91	0.93

*** Letters A and B indicate significant differences between treatments by year (columns)**

Table 1.8 Treatment Means, Standard Error, and Statistical Significance of Foliar Nutrient Content by Treatment and Time as Collected in December of 1998, 1999 and 2000 on all Trees within the Measurement Plot (P=0.05).*

	Foliar Nutrient									
	N	**P**	**K**	**Ca**	**Mg**	**S**	**Mn**	**Zn**	**B**	**Cu**
1999	-------------------------------------%--|						------------------------- PPM ---------------------			
0	0962	0.119	0.347 B	0.071	0.040	0.090	140.20	27.70	10.043 B	2.569 B
269	1.030	0.128	0.577 A	0.101	0.057	0.070	254.87	36.49	13.593 A	3.929 A
STDERR	0.060	0.004	0.036	0.008	0.005	0.005	31.36	3.15	0.581	0.274
TRT P>F	0.388	0.706	0.002	0.237	0.348	0.330	0.36	0.10	0.009	0.041
2000	-------------------------------------%--|						------------------------- PPM ---------------------			
0	0.807	0.125	0.529 B	0.10 2	0.084	-	229.20	51.20	17.048	4.920
269	0.917	0.132	0.857 A	0.126	0.088	-	374.20	65.79	18.464	5.924
STDERR	0.043	0.005	0.062	0.010	0.005	-	48.67	4.39	0.539	0.355
P>F	0.322	0.624	0.027	0.640	0.678	-	0.53	0.31	0.595	0.154
	General Model Statistical Summary P>F									
Effect	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Mn**	**Zn**	**B**	**Cu**
TRT	0.658	0.656	0.049	0.207	0.350	0.453	0.417	0.167	0.291	0.028
Date	0.273	0.290	0.001	0.007	0.001	0.263	0.162	0.001	0.001	0.001
Block	0.733	0.158	0.889	0.568	0.419	0.413	0.628	0.230	0.825	0.807
TRT * Block	0.820	0.390	0.852	0.707	0.723	0.727	0.596	0.093	0.979	0.416

*** Letters A and B indicate significant differences between treatments by year (columns)**

Table 1.9 Treatment Means of Litterfall (Stderr) in Kg/ha By Year Sampled from Randomly Spaced Sub-Plots within each Measurement Plot in December 1999, July 2000, and December 2000 (P=0.05)*

Year Effects	**Litterfall (kg/ha)**
December 1999	
0	7515. 78
269	7957.88
STDERR	556.00
July 2000	
0	3536.84
269	3045.22
STDERR	161.28
December 2000	
0	3536.84 B
269	4126.31 A
STDERR	357.62
General Model Results	
Effect	--------------------------------------P>F---------------------------------
Treatment	0.001
Block	0.025
Date	0.001
Treatment*Block	0.350
Treatment*Date	0.026
Block*Date	0.046

*** Letters A and B indicate significant differences between treatments by year**

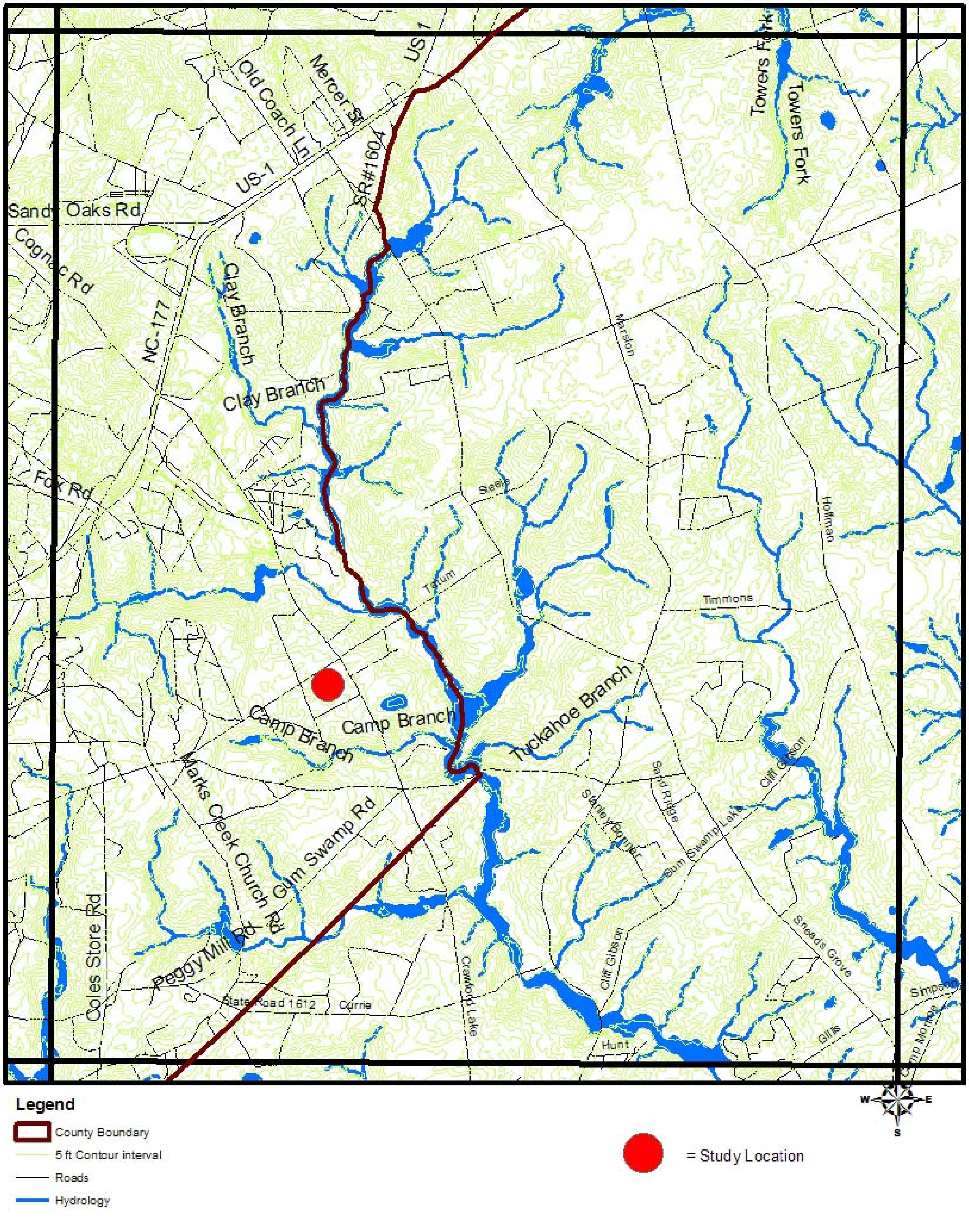

Figure 1.1 Study Site Location (Richmond County, NC: 34^0 55'00" latitude, 79^0 35'00" longitude) on USGS 1:24,000 Marston NC Quadrangle Map

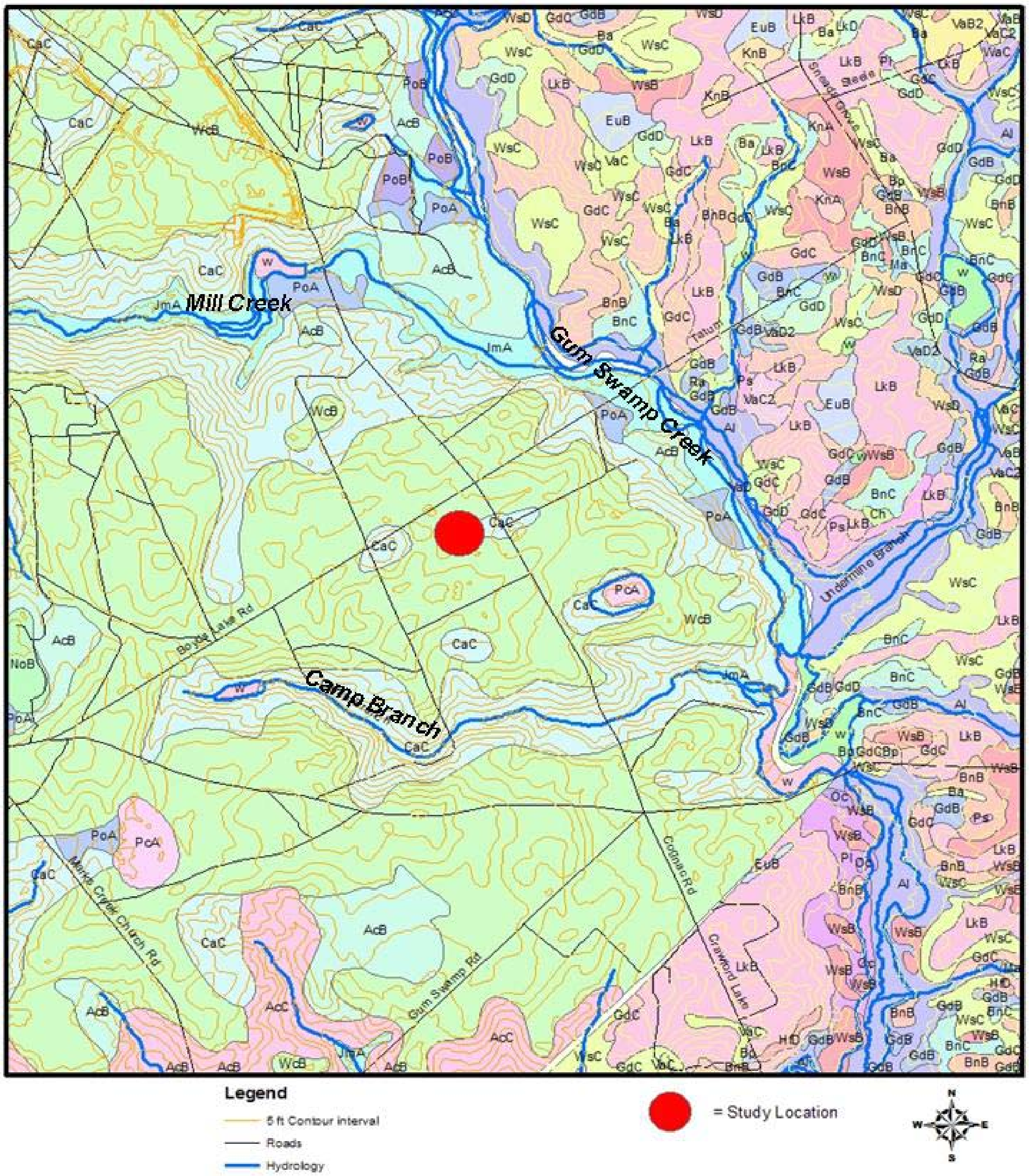

Figure 1.2 Study Site Topography, Hydrography and Soils Map

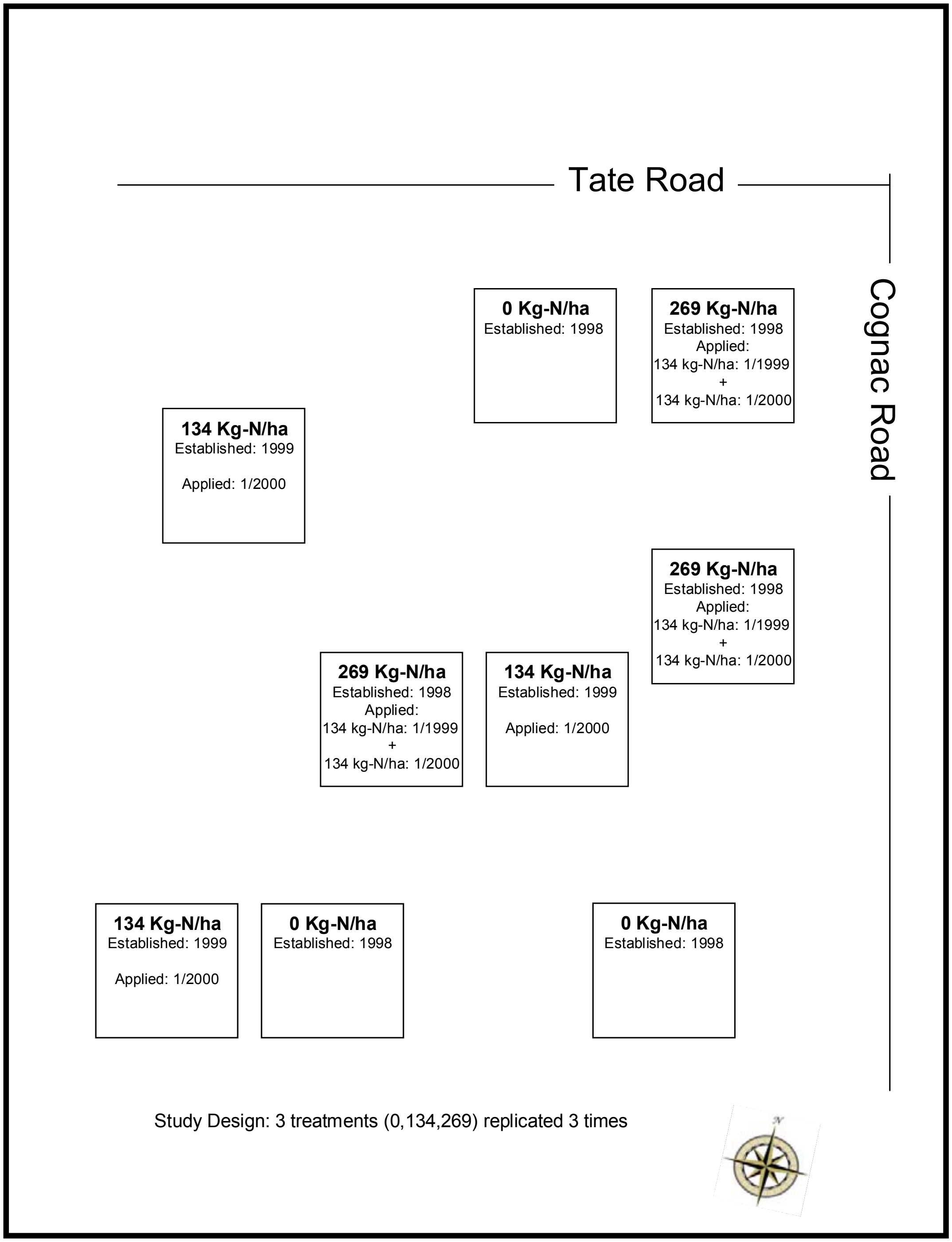

Figure 1.3 Study Site Fertilization Regime, Experimental Design, and Plot Layout and Map

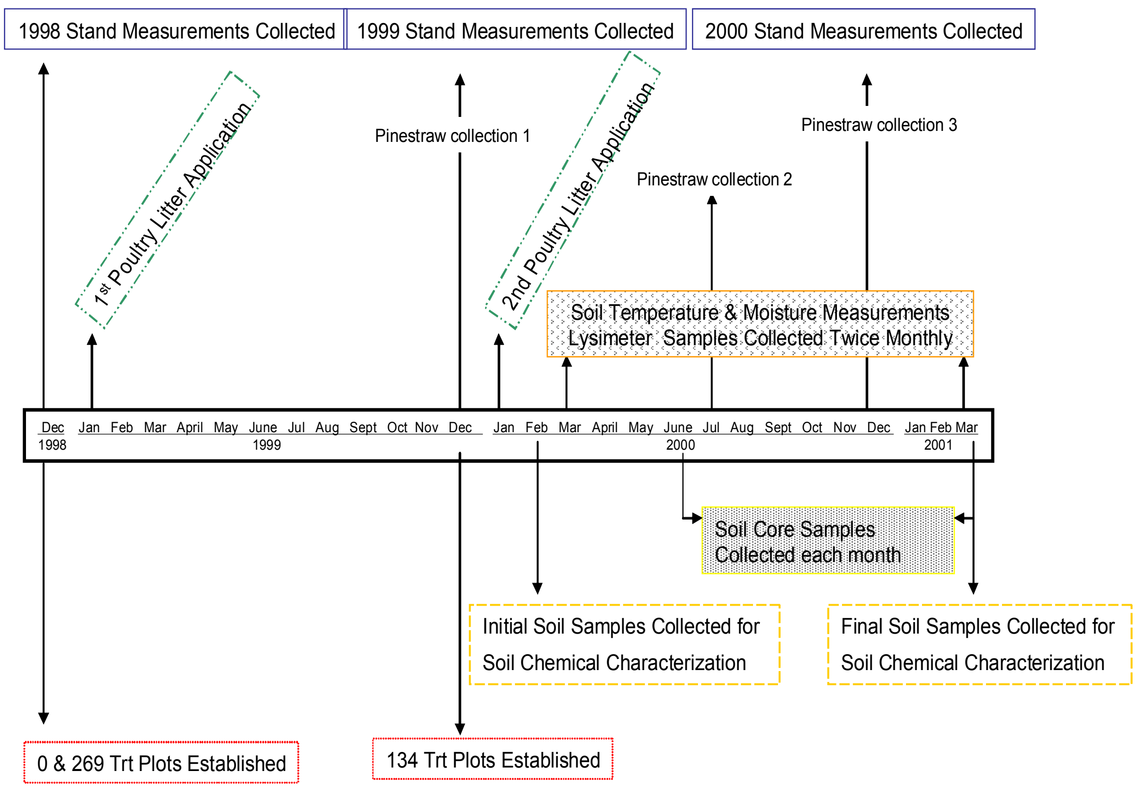

Figure 1.4 Study Time Line of Plot Establishment and Sampling Schedule for all Data Collected and Presented

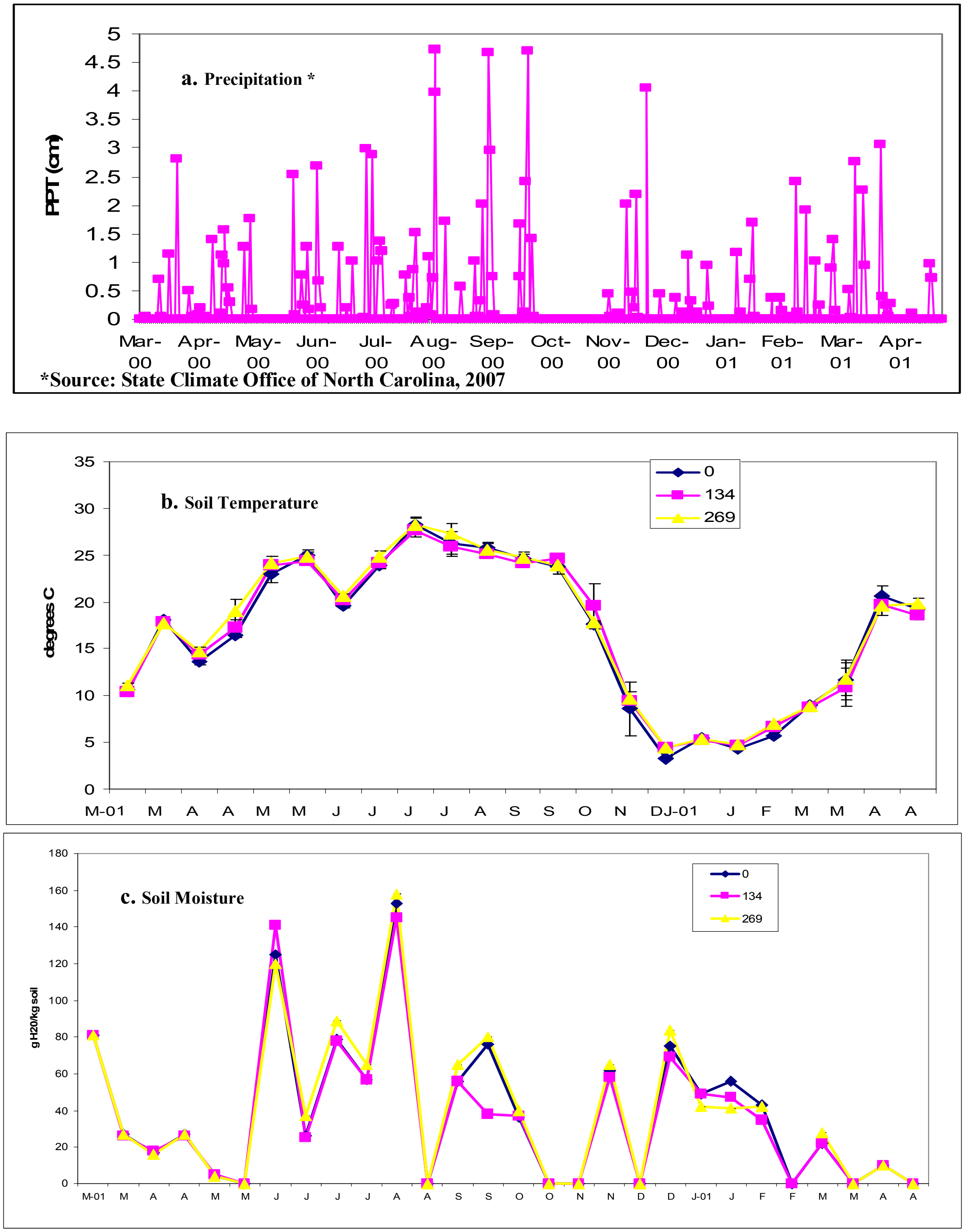

Figure 1.5 Daily Precipitation (cm), Soil Temperature (^{0}C) and Soil Moisture (g H_20/kg Soil) Through Time by Treatment Collected between March 2000 and April 2001.

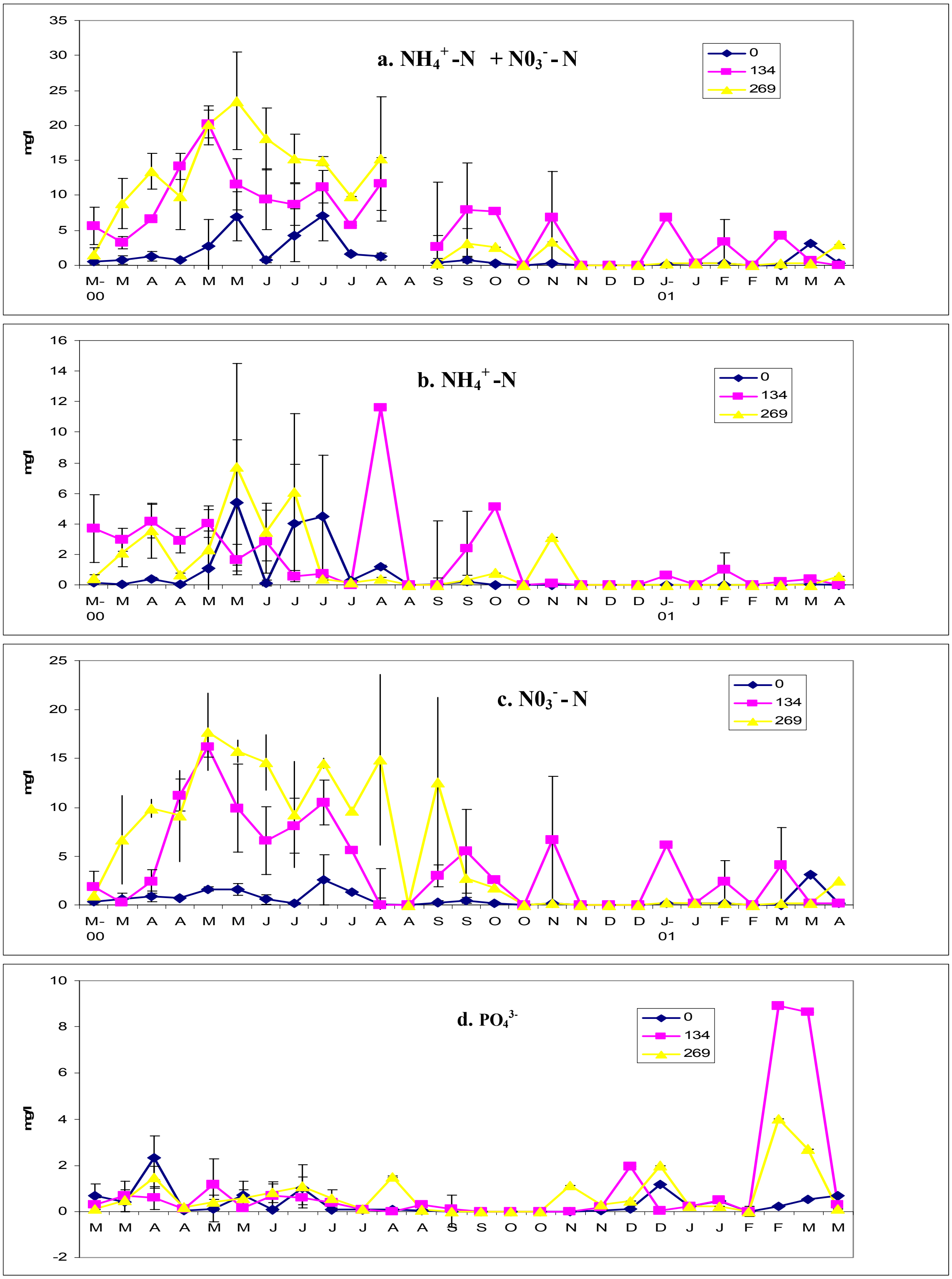

Figure 1.6 Sum of Ammonium-N + Nitrate-N Nitrogen, Ammonium Nitrogen, Nitrate Nitrogen and ortho-Phosphate in Soil Solution Collected at a Depth of 15 cm in mg/l Collected March 2000 through March 2001 from Three Randomly Spaced, Stationary Lysimeter Sub-Plots.

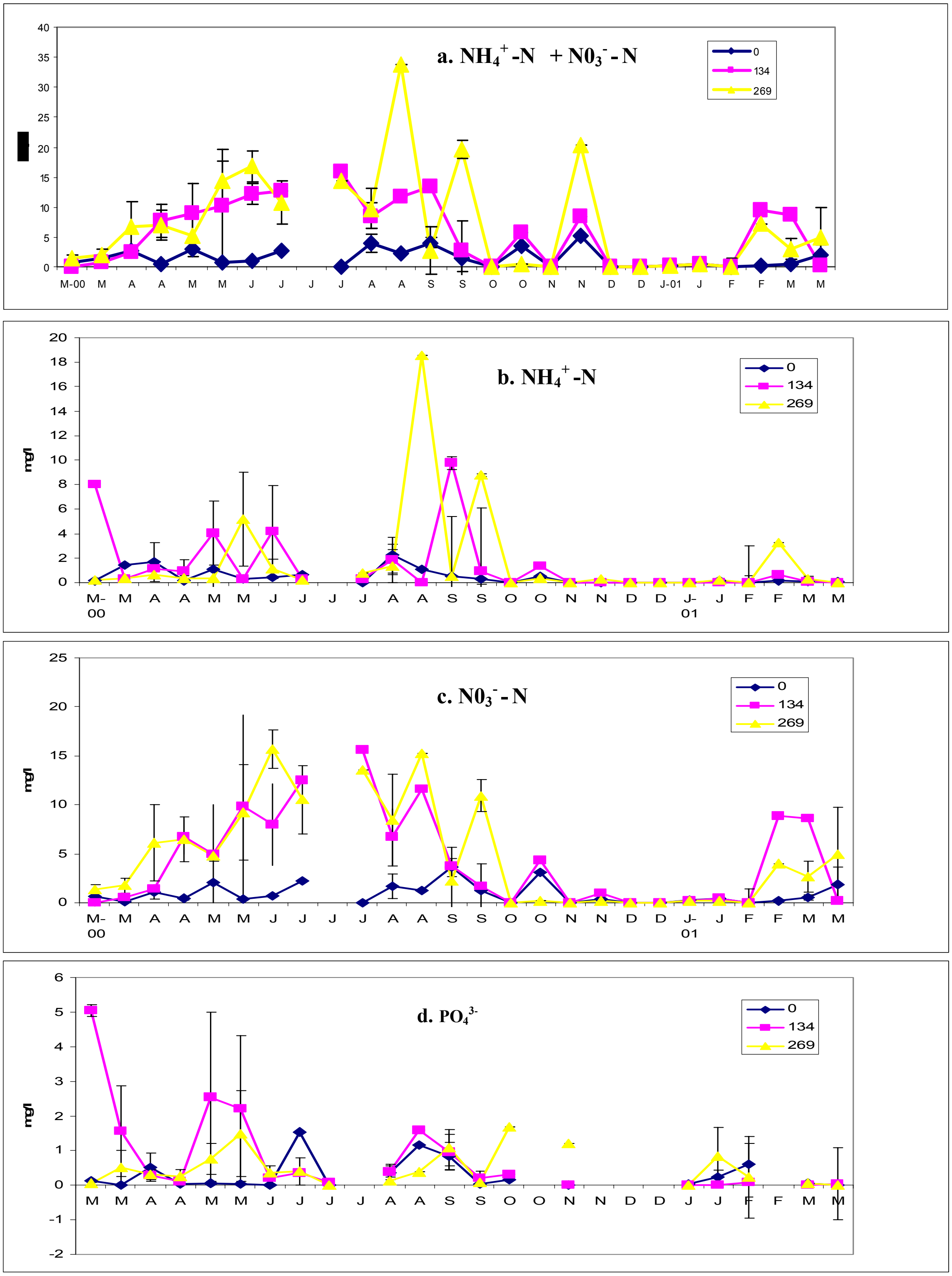

Figure 1.7 Sum of Ammonium-N + Nitrate-N N, Ammonium N, Nitrate N and ortho-Phosphate in Soil Solution Collected at a depth of 60 cm in mg/L Collected March 2000 through March 2001 from Three Randomly Spaced, Stationary Lysimeter Sub-Plots.

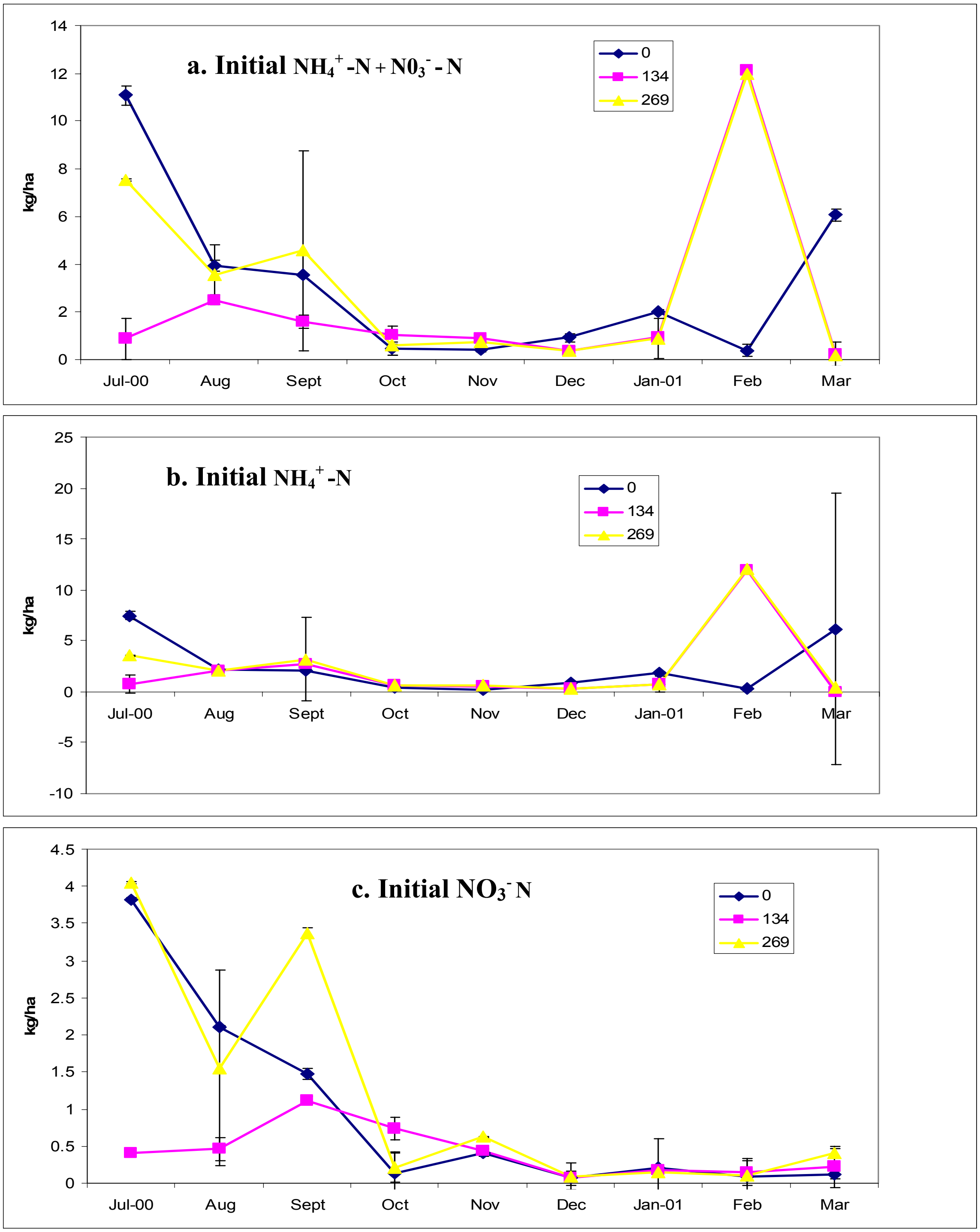

Figure 1.8 Initial Soil Core KL Extractable Ammonium-N + Nitrate-N, Ammonium-N, and Nitrate-N in Upper 15 cm of the Soil Horizon As Collected on a Monthly Basis from Three Randomly Spaced, Stationary Sub-Plots July 2000 through March 2001.

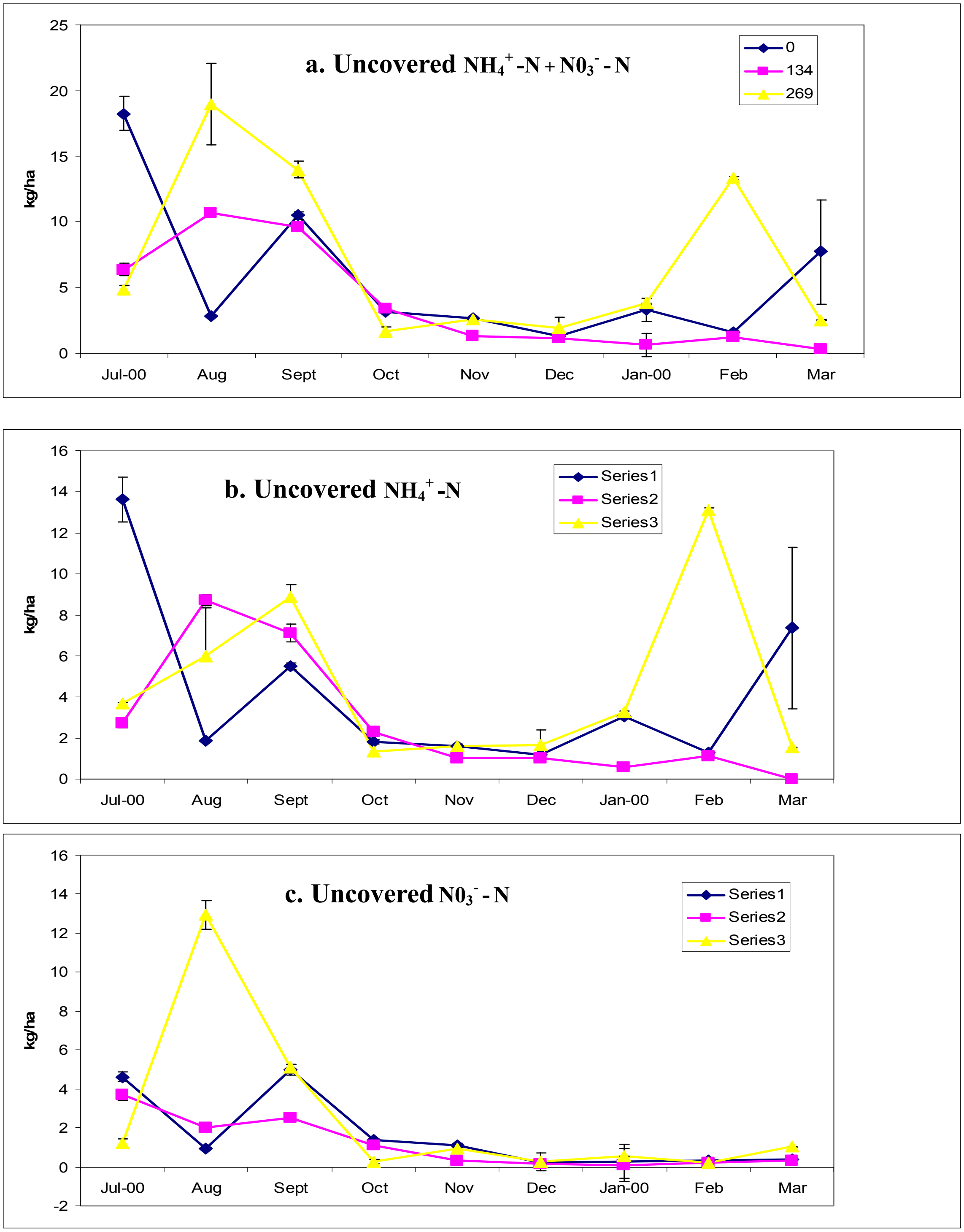

Figure 1.9 Uncovered Soil Core KL Extractable Ammonium-N+ Nitrate-N, Ammonium-N, and Nitrate-N in Upper 15 cm of Soil Horizon As Collected on a Monthly Basis from Three Randomly Spaced, Stationary Sub-Plots July 2000 through March 2001.

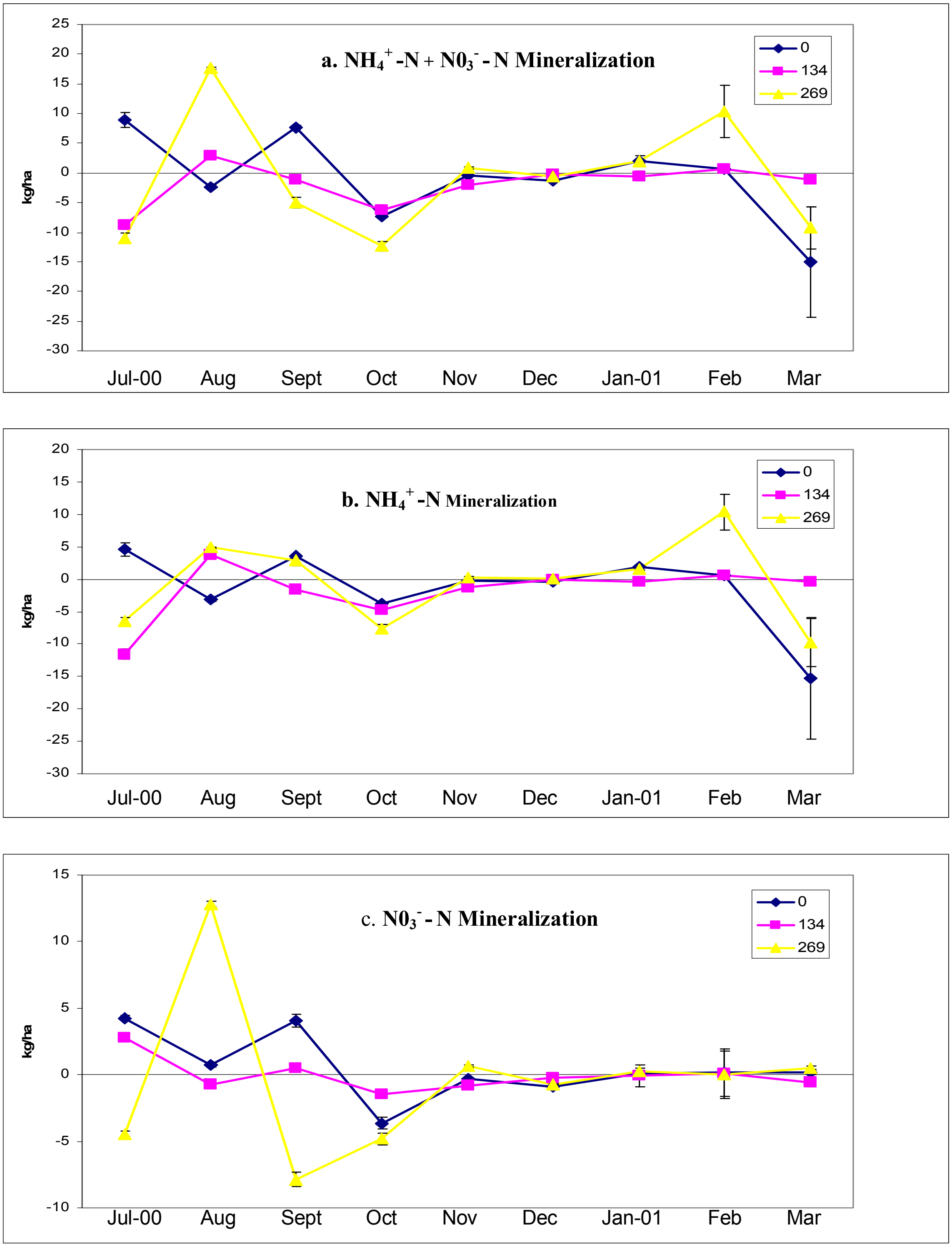

Figure 1.10 Net Mineralization in Uncovered Soil Core Samples As Calculated from Initial and Uncovered Soil Core Samples Collected on a Monthly Basis from Three Randomly Spaced, Stationary Sub-Plots July 2000 through March 2001.

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