EFFECTS OF A CONTROLLED RELEASE FERTILIZER ON THE NITROGEN DYNAMICS OF MID-ROTATION LOBLOLLY PINE PLANTATION IN THE PIEDMONT, VIRGINIA

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Abstract—Nitrogen deficiency is characteristic of many mid-rotation loblolly pine (*Pinus taeda* L.) plantations in the Piedmont region of the Southeast. Fertilization with urea is the most common method used to correct this deficiency. Previous studies show that urea fertilization produces a rapid pulse of available nitrogen (N) with only a portion being utilized by plantation trees. Controlled release fertilizers release available N slowly over a longer period of time and therefore may result in a greater uptake efficiency. The objective of this study was to compare a controlled-release N fertilizer (ureaform) versus urea by measuring the effects of the two fertilizer treatments on total extractable-N, mineralized-N, and ion resin exchangeable-N. Fertilization with the controlled release ureaform resulted in significantly greater and prolonged availability of total extractable-N, mineralized-N, and ion resin exchangeable-N than the fertilization with urea or the control.

INTRODUCTION

Loblolly pine plantations are the dominate form of intensive pine silviculture in the Piedmont physiographic province of the Southeast. The soils of this region are nutrient deficient, especially with limitations in available nitrogen (N) and phosphorus (P) (Pritchett and Smith 1972). Fertilization with N + P has been shown to increase gross stand volume by 239 square feet per acre in Piedmont loblolly pine plantations (Allen and Ballard 1982). Therefore, fertilization with N and P during establishment and mid-rotation is a major practice. Recent estimates from 2003 show that 1.4 million acres are fertilized annually with N and P. However, the increased growth from fertilization has been shown to decline to pre-treatment levels over a 5 to 8 year period (Ballard 1981). From a physiological standpoint, measured N and P uptake efficiency has been shown to be very low, with recovery percentages between 13 and 21 percent (Strader 1982). The fertilizer which is not utilized by growing trees is lost through pathways of immobilization, leaching, and volatilization (Allen and Ballard 1982; Kissel and others 2004; Mattos and others 2004). Furthermore, Mudano (1986) reported that total soil available N declined to pre-fertilization levels after only 160 days.

These patterns of low N uptake and high ecosystem N loss are associated with traditional fertilizers, especially urea, which are most commonly utilized in commercial forestry because of their low cost. Controlled-release N fertilizers reportedly increase N retention in soils, N uptake in plants, and decrease N loss through leaching (Alexander and Helm 1990; Rose 2002). Though frequently used in agriculture and tree nurseries, controlled-release N fertilizers are currently not utilized in southern pine plantation forestry due to uncertainties surrounding cost effectiveness. This study investigates the ability of ureaform, a controlled-release N fertilizer, to successfully increase soil N retention in a mid-rotation loblolly pine plantation in the Piedmont of Virginia. The effects from ureaform fertilization are compared to those of a traditional water-soluble urea fertilization, as well as to a control.

MATERIALS AND METHODS

Site

The study site was located on the Reynold's Homestead Forest Resources Research Forest in the Piedmont physiographic province of Patrick County, VA (36° 39' N, 80° 09' W). The soils are highly weathered, kaolinitic, Typic Kanhapludults of the Cecil and Lloyd soil series. Due to soil erosion from past agricultural use, the O and A horizons are very shallow (≤ 5 cm thick), with an exposed Bt clay horizon beneath. The pretreatment stand was a 9 acre, 22-year-old loblolly pine plantation, with an average basal area of 150 square feet per acre and site index (25 year) of 67 feet.

Experimental Design and Treatments

The experimental design was a randomized complete block design with four blocks. Plot installation occurred in the summer of 2003 with 12, 0.23-acre treatment plots and 0.10-acre measurement plots centered within. The plots were blocked on pre-treatment basal area and height to account for any residual growth differences since the time of stand initiation. Continuous complete vegetation control occurred in all treatment plots beginning in the winter of 2003. Herbaceous vegetation was sprayed with a 5 percent solution of Roundup (Monsanto Corporation, St. Louis, MO). Arborescent competing vegetation was manually felled with a chainsaw. All slash from vegetation control was left on site. Due to the high stocking levels found in this stand, a mechanical thinning operation using chainsaws was implemented during the winter of 2004, reducing each treatment plot basal area to 110 ± 10 square feet per acre.

Treatments were implemented in this study as three fertilization regimes: (1) no fertilization, (2) fertilization with 200 pounds N per acre as urea plus 100 pounds per acre Triple Super Phosphate (TSP), and (3) fertilization with 200 pounds N per acre as Slow-release Ureaform (Nitroform Blue-chip, Nu-Gro Corporation, Brantford, Ontario, Canada) plus 100 pounds P per acre as TSP. The fertilization was done by hand on August 1, 2004. Hereafter, the no fertilization treatment will be referred to as the control (CO), fertilization with urea + TSP

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will be referred to as (UR), and fertilization with slow-release Ureaform + TSP will be referred to as (CR).

N-Mineralizaion and Extractable-N Methods

In-situ N mineralization sampling took place in all measurement plots following the Raison and others (1976) sequential coring method. Two cores made of polyvinyl chloride, 1.5 inches in diameter and 8 inches in length, were inserted into the mineral soil to a depth of 6 inches. Caps were placed on the cores to prevent precipitation from entering but loosely enough to allow for gas exchange within each core. One core was immediately removed for processing in the lab, while the second incubation core remained in place for 14 days. The incubation core was then removed for lab processing. Sequential in-situ incubations were implemented monthly at two random locations within each measurement plot, beginning July 1, 2004, and continuing through December 14, 2004. During sampling, a digital thermometer and soil moisture meter (HydroSense™, Campbell Scientific Inc., Ogden, Utah) were both inserted 8 inches into the mineral soil immediately adjacent to the incubation cores to measure soil temperature and volumetric water content. In the lab, soil from each core was sieved with a #10 mesh screen, placed in sample bags, and stored at 4 °C until extraction. At the time of extraction, 5 g of field moist soil was dried in a 105 °C oven for 24 hours to determine water content. A second 5 g of field moist soil was placed in a centrifuge tube with 50 ml of 2 M KCl and shaken on a reciprocating shaker for 1 hour. After shaking, the samples were centrifuged for 10 minutes, filtered through Whatman #42 paper, and the extracts frozen in scintillation vials. All extracts were analyzed colorometrically using a TRAACS 2000 Auto Analyzer (SEAL Analytical, Mequon, WI). N concentration data from each initial core was subtracted from its respective incubation core data to estimate N mineralization. Data from the initial cores were also used as an estimate of total KCl extractable-N as $NH_4^+ + NO_3^-$.

Resin Exchangeable-N Methods

In-situ resin exchangeable-N sampling occurred in all measurement plots following procedures utilized by Cooperband and Logan (1994) and Huang and others (1996). Cation- and anion-exchange membrane sheets (Ionics Incorporated, Watertown, MA), 360 square inches in total area and packed in ethylene glycol, were first cut into 12.25-square-inch squares. This size is equivalent to 6.32 grams of dry resin with a capacity of 1.77 $cmol_c$ anion/cation – exchange capacity. Cation and anion membrane squares were kept separate, washed with de-ionized water, and soaked inside plastic carboys containing a 1 M NaCl solution for 24 hours before use in the field. Just before insertion into the mineral soil, membranes were removed from the solution and washed with de-ionized water. Two sets of membranes were installed at random locations within each measurement plot. Within each set, cation and anion membranes were inserted in both horizontal and vertical positions. Membranes were inserted horizontally by cutting a square of O horizon material down to the mineral soil with a serrated stainless steel spatula, carefully lifting the intact O material, and placing the membrane beneath it. Membranes were inserted vertically in the mineral soil from 4.75 inches to 1.25 inches deep by opening a vertical slit with the stainless steel spatula and placing the membrane into the mineral soil at the specified depth. The slit was firmly closed from either side with the spatula to ensure proper contact between membrane and soil. Within each set, the cation and anion membranes were situated adjacent to one another with 3 to 5 inches between each membrane. The location of each membrane was marked with flagging and cable-ties for relocation. After a 14-day incubation period, the membranes were carefully removed from their locations, and large soil aggregates sticking to the membranes were removed. Individual membranes were then sealed in labeled plastic bags and stored at 4 °C until extraction. At the time of extraction, each membrane was placed in a 100-ml-square plastic container with 25 mL of 1 M KCl and shaken on a reciprocating shaker for 1 hour. The membranes were then removed and the extract filtered through Whatman #42 filter paper into scintillation vials. The samples were analyzed colorometrically on a TRAACS 2000 Auto Analyzer (SEAL Analytical, Mequon, WI).

Design and Statistical Analysis

All statistical analyses were performed using SAS statistical software (SAS Institute 2002). Analyses of variance were performed using the general linear models procedure to test treatment main effects on monthly KCl extractable N, mineralized N, and resin exchangeable N. All within-plot samples were averaged by plot, and the plot was used as the experimental unit for all analyses. Means separations between treatment effects were performed for each sampling date using Fischer's least significant difference. Significance was accepted at $\alpha \leq 0.05$ for all analyses.

RESULTS

Extractable-N

Pre-treatment total mineral extractable-N concentrations were extremely low in all plots, ranging from 4.30 to 7.19 mg N/kg soil. Total extractable-N was significantly affected by the fertilization treatments at each sampling date, except during October (fig. 1). CR total extractable-N ranged from 1.7 times that of CO in August to 6.6 times greater than CO in November. In comparison to UR, CO total extractable-N ranged from 1.6 times that of UR in August to 5.4 times greater than UR in November. UR treatments were not found to be significantly different than CO treatments throughout the sampling period (fig. 1). In September, 1 month after fertilization, CR total extractable-N increased by 173 percent, UR increased by 58

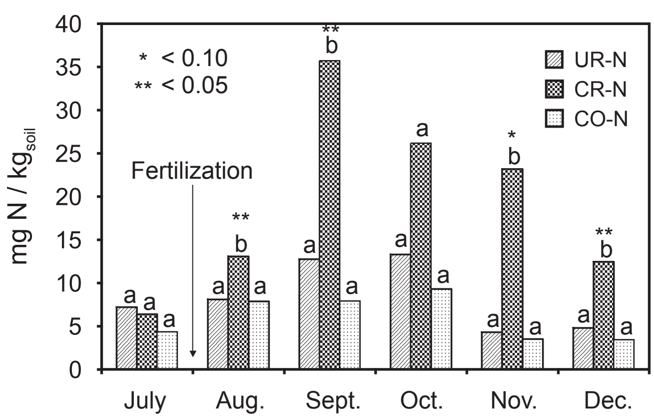

Figure 1—Monthly total extractable-$NH_4^+ + NO_3^-$ during a 6 month period in 2004. Means with same letters are not significantly different.

percent, and CO increased by 0.03 percent. From September to December, all treatments decreased in total extractable-N. However, the CR extractable-N during December was 1.9 times the pre-treatment CR extractable-N during July, whereas UR and CO extractable-N during December was, respectively, 0.34 and 0.21 times less than pre-treatment extractable-N during July.

In Situ N-Mineralization

Pre-treatment N mineralization ranged from 0.04 mg N/kg soil to 2.25 mg N/kg soil across the three treatments. There were significant treatment effects ($P<0.1$) on N mineralization during August and November and highly significant treatment effects ($P<0.05$) on N mineralization during October (fig. 2). Net N immobilization occurred in all treatments during September; however, there were no significant differences between treatments. During October, CR net N mineralization was 5.36 mg N/kg soil, while UR and CO net N mineralization was -5.1 and -5.6 mg N/kg soil respectively (fig. 2). CR net N mineralization during November was 9.4 times UR and 23.8 times CO net N mineralization ($P<0.1$). UR and CO net N mineralization in December was, respectively, 0.99 and 1.31 mg N/kg soil < pre-treatment levels in July, while CR net N mineralization in December was 0.92 mg N/kg soil > pre-treatment levels in July.

Resin Exchangeable-N

O-Horizon exchangeable-NH_4^+—Treatment effects on O horizon resin exchangeable-NH_4^+ were highly significant ($P<.05$) across all sampling dates, except during November when only slightly significant ($P<0.1$). During August, UR and CR exchangeable-NH_4^+ concentrations were, respectively, 15.8 and 12.8 times CO concentrations (fig. 3a). In September, CR exchangeable-NH_4^+ levels were 5.6 times > CO, while UR levels were only 3 times > CO. During October, CR exchangeable-NH_4^+ remained significantly > CO, while UR levels were 2 mg NH_4^+/m^2 < CO. In November, CR levels decreased to 15 mg NH_4^+/m^2 but were 3 times as great as CR pre-treatment levels in July. UR and CO during November were 2.1 mg NH_4^+/m^2 and 2.3 mg NH_4^+/m^2 < pre-treatment levels, respectively (fig. 3a).

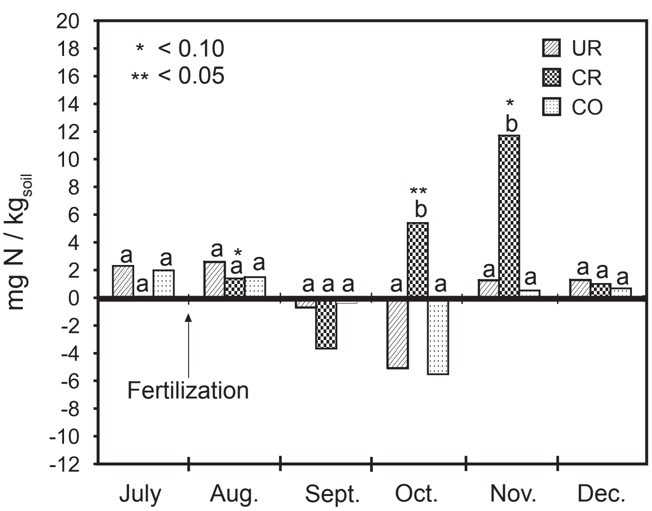

Figure 2—Average monthly N-mineralization during a 6 month period in 2004. Means with same letters are not significantly different.

Mineral soil exchangeable-NH_4^+—Treatment effects on mineral soil resin exchangeable-NH_4^+ were highly significant across all sampling dates except July (fig. 3b). UR and CR concentrations were > CO across all sampling dates. From September to November, CR concentrations were 1.4 to 3.0 times > UR and 2.8 to 7.1 times > CO (fig. 3b).

O-Horizon exchangeable-NO_3^-— Treatment effects on O horizon exchangeable-NO_3^- were significant only during July and August (fig. 3c). In August, CR was 3.9 and 3.1 times > CO and UR, respectively. During November, CR NO3- was 4.3 mg NO_3^-/m^2 > pre-treatment levels, while UR and CR NO_3^- levels were, respectively, 0.7 and 0.8 mg NO_3^-/m^2 > pre-treatment levels.

Mineral Soil exchangeable-NO_3^-—Treatment effects on mineral soil exchangeable-NO_3^- were highly significant during July, August, and October. During July, concentrations ranged from 0.13 mg NO_3^-/m^2 in CR to 2.57 mg NO_3^-/m^2 in CO. In August, CR and UR increased to 1.8 mg NO_3^-/m^2 and 2.9 mg NO_3^-/m^2, respectively, while CO decreased to 0.59 mg NO_3^-/m^2. In October, CR levels were 12.2 times > CO and 18.3 times > UR. In November, UR and CR were, respectively, 2.46 and 4.70 mg NO_3^-/m^2 > pre-treatment levels, while CO was 2.19 mg NO_3^-/m^2 < pre-treatment levels.

DISCUSSION

Initially, it is clear that this stand was N deficient, with total extractable-N ranging between 4 and 7 mg N/kg soil in all treatment plots. The data also show that after fertilization, UR and CR both increased total extractable-N concentrations; however, CR demonstrated significantly greater concentrations of total extractable-N at each post-treatment sampling date. There was no significant difference between UR and CO total available-N throughout the sampling period. The most striking trend in this data is the prolonged availability of N after fertilization with controlled release ureaform in comparison to the rapid increase and decline in available N after fertilization with urea. This is consistent with the results of Mudano (1986), which showed a rapid pulse of soil-available N after fertilization with a water soluble N fertilizer, followed by a decline over 5 months to pre-fertilization levels.

A similar trend was seen in the N-mineralization data, with CR demonstrating significantly greater mineralized-N during October and November than both UR and CO. The most notable difference in treatment effects was during October, when UR and CO demonstrated N-immobilization while CR demonstrated N-mineralization. This is reflected in the resin exchangeable-N data for this same time period, where CR had significantly greater concentrations of mineral NH_4^+ and NO_3^- than UR and CO. Most likely, the retention of higher N-mineralization rates over the sampling period is due to the increased C as a microbial energy source provided by the controlled-release ureaform fertilizer.

In the resin exchangeable-N data, evidence of increased nitrification was found in CR during October. This is demonstrated by the significant 1:1 exchange in CR mineral soil NH_4^+ and NO_3^-, with CR mineral soil NH_4^+ decreasing by 7.2 mg N/m^2 and CR mineral soil NO_3^- increasing by 6.8 mg N/m^2. Only in CR was there evidence of nitrification present during the sampling period. UR demonstrated no significant increases in NO_3^- above CO throughout the sampling period, most likely due to a depression in microbial activity.

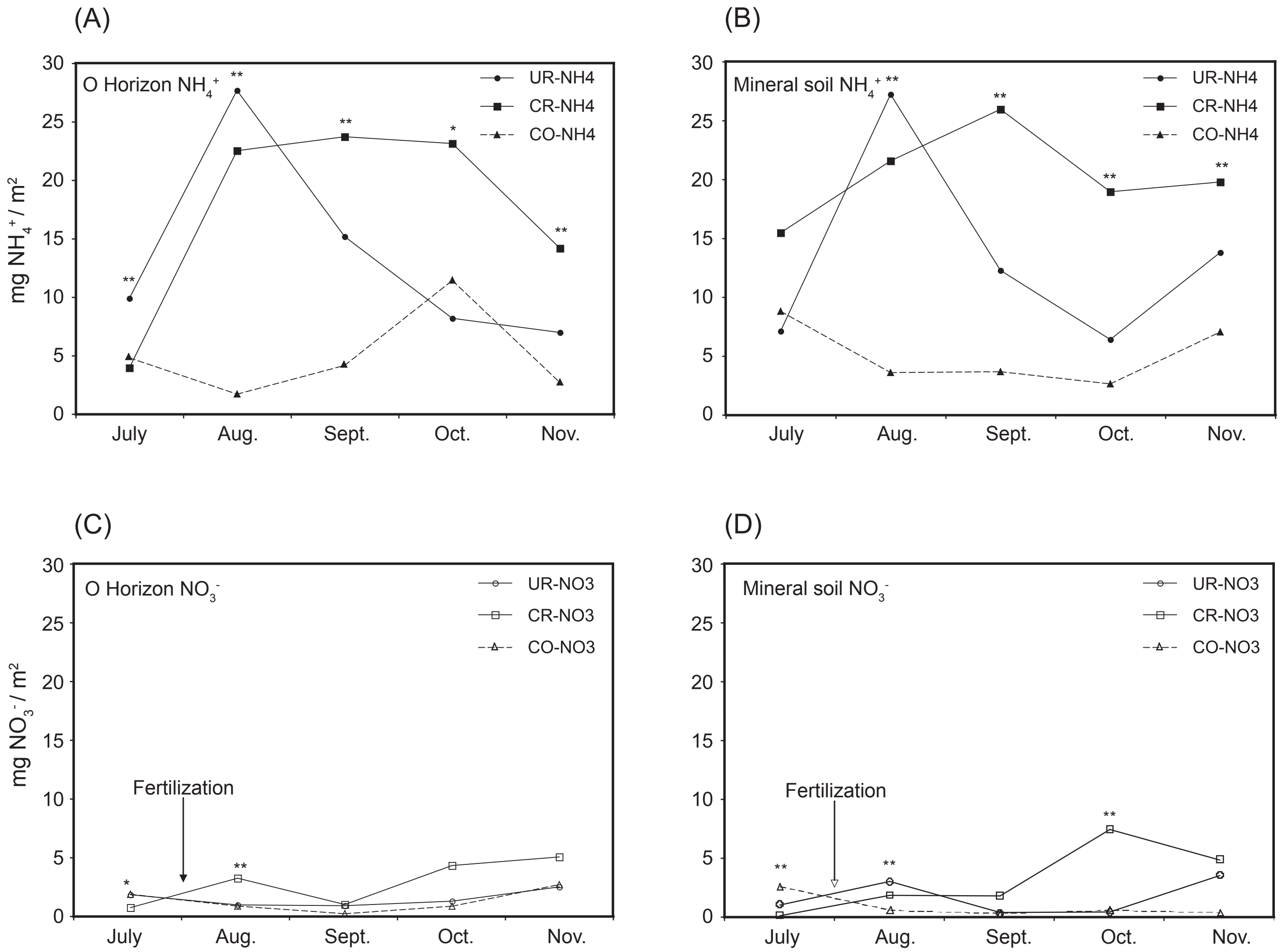

Figure 3—Monthly resin exchangeable-N during a 5 month period in 2004: (A) O Horizon NH_4^+-N, (B) mineral soil NH_4^+-N, (C) O Horizon NO_3^-–N, and (D) mineral soil NO_3^--N. * and ** show significance at the 0.01 and 0.05 level, respectively.

UR demonstrated greater positive response during the first month after fertilization, while not being significantly > CO for the remainder of the sampling period. These data are consistent with previous studies; fertilization with urea provides a brief spike in available NH_4^+ for 30 to 60 days. Over all, the most notable trend in the data was that CR demonstrated more positive stimulatory effects in soil N-dynamics with increased N-mineralization, nitrification, and total extractable-N pool in the mineral soil.

Further sampling is necessary to determine if and how far these trends continue through the following growing season. Also, in order to determine whether controlled-release ureaform fertilizers increase tree N-uptake efficiency throughout the growing season and rotation, foliar N analyses will be required and are currently being performed. From this data, it appears that over a 5 month period, N-retention in the soil is significantly greater when fertilized with controlled-release ureaform.

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LITERATURE CITED

Alexander, A.; Helm, H.U. 1990. Ureaform as a slow release fertilizer: a review. Zeitschrift für Pflanzenernährung und Bodenkunde. 153: 249-255.

Allen, H.L.; Ballard, R. 1982. Forest fertilization of loblolly pine. Symposium on the loblolly pine ecosystem (east region). Raleigh, NC: North Carolina State University, School of Forest Resources: 163-181.

Ballard, R. 1981. Optimum nitrogen rates for fertilization of loblolly pine plantations. Southern Journal of Applied Forestry. 5: 212-216.

Cooperband, L.R.; Logan, T.J. 1994. Measuring in situ changes in labile soil phosphorus with anion-exchange membranes. Soil Science Society of America Journal. 58: 105-114.

Huang, W.Z.; Schoenau, J.J. 1996. Microsite assessment of forest soil nitrogen, phosphorus, and potassium supply rates in-field using ion exchange membranes. Communications in Soil Science and Plant Analysis. 27: 2895-2908.

Kissel, D.E.; Cabrera, M.L.; Vaio, N. [and others]. 2004. Rainfall timing and ammonia loss from urea in a loblolly pine plantation. Soil Science Society of America Journal. 68: 1744-1750.

Mudano, J.E. 1986. Assessment of soil nitrogen availability following nitrogen and phosphorus fertilization of a loblolly pine stand. Raleigh, NC: North Carolina State University. 52 p. M.S. thesis.

Pritchett, W.L.; Smith, W.H. 1972. Fertilizer response in young pine plantations. Soil Science Society of America Proceedings. 36: 660-664.

Raison, R.J.; Connell, M.J.; Khanna, P.K. 1987. Methodology for studying fluxes of soil mineral-N in situ. Soil Biology and Biochemistry. 19: 521-530.

Rose, R. 2002. Slow release fertilizers 101. National proceedings: forest and conservation nursery associations 1999, 2000, and 2001. RMRS-P-24. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 304-308.

SAS Institute. 2002. SAS user's guide. Version 9.1. Cary, NC: SAS Institute.

Strader, R.H. 1982. Nitrogen fertilization of two loblolly pine plantations: biomass production and nitrogen recovery and distribution after 10 and 11 years. Raleigh, NC: North Carolina State University. 40 p. M.S. thesis.