NITROGEN DYNAMICS AFTER SITE PREPARATION IN THREE LOBLOLLY PINE PLANTATIONS ON THE VIRGINIA PIEDMONT

by

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(ABSTRACT)

Intensive site preparation practices and their effect on nitrogen cycling have been implicated as possible causes of productivity declines on forest sites in Australia and New Zealand. This study was initiated in order to determine the effects of site preparation intensity upon N distribution and availability in loblolly pine (*Pinus taeda* L.) plantations in Virginia. In the summer of 1982, three forest sites at the Reynolds Homestead Research Center on the Virginia Piedmont were clearcut. In the fall of the same year all three sites were prepared for planting using one of the following treatments: 1. shear, rake, disk (S,R,D) (3-passes); 2. shear-disk (S-D) (1-pass); and 3. chop, burn (C,B) (high intensity burn). During March of 1983, 1-0 genetically improved loblolly pine seedlings were planted on all sites. Pine biomass was greatest on the S,R,D area after three growing seasons. Total biomass and N content (NCONT) of native vegetation and forest floor were greatest in the S-D area. Total N in the upper 15 cm of

mineral soil was also greatest in the S-D area. Total system N was highest in the S-D area and this treatment is more N-conservative than either of the more intensive treatments. During the third growing season potentially mineralizable N levels were highest on the two disked treatment areas, 157 and 144 kg N/ha for the S-D, and S,R,D areas, respectively. Pine foliar nutrient concentrations determined after the second and third growing seasons provided no evidence of existing or impending nutrient deficiencies. These results show that short-term pine nutrition and growth were not adversely affected by reductions of N capital on these sites. However, if wasteful practices, such as raking and burning with high intensity fires, are also used to establish subsequent stands on these same sites, cumulative losses of N could result in productivity declines.

DEDICATION

To

my wife Lisa,

my children Jesse Lee, Dana and Ryan Hart,

my mother and father

and my grandfather,

with love.

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INTRODUCTION

Site preparation may be defined as the deliberate manipulation of site factors to ensure rapid establishment, and enhanced early growth of the desired vegetation (Daniel et al., 1979), and is widely accepted as being an essential measure in the establishment of new forest stands after logging (Balmer and Little, 1978; Neary et al., 1984). Since different site conditions result in site specific obstacles to regeneration, a variety of site preparation techniques have evolved. All of these site preparation techniques alter the condition of the organic material of the site in some fashion. There is growing concern that the intensive site preparation techniques commonly employed in the South, may lead to long-term declines in site productivity as organic-matter-mediated N pools are temporarily disrupted or permanently depleted. Since N is typically deficient in Piedmont forest soils (Burger and Kluender, 1982; Neary et al., 1983; Wells and Morris, 1982), it is important to understand how different management alternatives affect site organic matter so that valuable N reserves can be conserved and utilized more efficiently.

The purpose of this study was to examine the effects of three commonly prescribed site preparation treatments on organic matter and N dynamics, and to relate these effects to short-term tree growth and N nutrition.

HYPOTHESES

1. Site preparation alters the distribution of N among major N pools on a site by altering the quantity and/or quality of site organic matter.

2. Changes in N dynamics due to site preparation affect the growth of planted loblolly pine.

OBJECTIVES

1. Quantify changes occurring in all major N pools, due to site preparation, during the second and third growing seasons.

2. Compare changes in potentially mineralizable N (N_o) levels among treatments, during the second and third growing seasons.

3. Determine whether disturbance-mediated changes in N pools and N_o affected growth and foliar nutrient status of planted loblolly pine.

LITERATURE REVIEW

Site Preparation

Objectives: Intensive site preparation is widely used as a method for the establishment of pine plantations in the South. Various treatments differ in the duration of their effects, the quality of tree response and cost. The objective of site preparation is to improve the probability of successful stand establishment by:

1. reducing competition for light and moisture;
2. reducing fuel loads and thus fire hazard;
3. clearing the site for planting;
4. improving soil physical properties;
5. improving soil chemical properties.

Specific Practices: Land managers are faced with regeneration problems on any harvested site. In order to successfully establish a new stand, the critical factors resisting establishment must be determined and then controlled. In order to maximize the probability of regeneration success, and early growth, as many site preparation objectives as possible must be achieved. Achievment of all objectives is seldom possible due to problems with equipment or personnel availability, cost constraints, or site limitations such as steep slopes or proximity to other landholders. In order to adapt to a variety of stand and site conditions, different site preparation practices have been developed and can be used alone or in combination with others to formulate a specific site preparation recommendation. Five of the most commonly used practices are:

1. chopping;
2. burning;
3. shearing;
4. raking;
5. disking.

Chopping: Conversion to pines commonly occurs where low quality, and thus low value, hardwoods occupy a site. In the process of harvesting such a stand, a great deal of unmerchantable material, slash and debris may be left on site where it hinders the mobility and efficiency of planters, and reduces plantable area. For these reasons, it is a common objective of site preparation to clear the site so that more effective planting can occur (Balmer and Little, 1978; and Burns, 1977).

Chopping is accomplished by a tractor pulling a large, heavy drum, often filled with water, and edged with cutting blades. The drum knocks down, crushes and chops residual trees and logging debris. Wherever the blades make contact with the soil surface they churn the soil, incorporating organic material and cutting roots. This site preparation technique is often used prior to burning in order to create a more uniform fuel bed by concentrating the fuel close to the ground and breaking it into smaller pieces so that drying is more rapid (Balmer and Little, 1978; Haines et al., 1975).

Burning: A primary objective of burning is to clear the site so that effective planting can occur (Balmer and Little, 1978; Burns, 1977). Knight (1966) showed that fires with temperatures greater than 200C began to volatilize substantial amounts of N. Nitrogen losses due to volatilization during prescribed fires can be extensive, and have been reported in the range of 14-64% of the original N content of the fuels (DeBell and Ralston, 1970; Grier, 1975; Klemmedson et al., 1962; Knight, 1966; Kodama and Van Lear, 1980). Still more N can be lost after burning, as ash is eroded by wind or water (Wells, 1983; Pritchett and Wells, 1978).

Because the intensity of fires vary depending upon specific weather conditions, relative humidity, and the amount and moisture content of fuels (York and Buckner, 1983), it is reasonable to separate the discussion of burning into two parts:

1. low intensity burns (temperatures $< 200^{o}C$);
2. high intensity burns (temperatures $> 200^{o}C$).

Low Intensity Burns: This type of fire essentially leaves the forest floor intact, but still burns much of the target debris (Burns, 1977; Vitousek et al., 1983). Covington and Sackett (1986) reported no significant reductions in total soil N for sites exposed to low intensity burn treatments. Nitrogen losses due to volatilization from this type of fire have been estimated by others to be near 100 kg N/ha (Pritchett and Wells, 1978; Vitousek et al., 1983). Van Lear et al. (1983) reported volatilization of from 94-160 kg N/ha for three low-intensity prescribed burns on the South Carolina Piedmont. Though some localized volatilization is inevitable, the majority of the N contained in fuels remains on the site. Lewis (1974) found that the nitrate and ammonium concentrations in surface soil did not change immediately after fire, though the concentrations of other nutrients increased. However, he did report an increase in plant available N concentrations after a short lag. He surmised that the increased availability of other nutrients, along with the altered structure of organic matter after fire, promoted microbial activity, which resulted in accelerated decomposition of organic material and the subsequent mineralization of N.

High Intensity Burns: Treatments with high intensity burns are typified by large losses of volatilized N because more of the logging debris and forest floor is consumed. Stronger convection currents due to greater heat production carry volatilized nutrients and particulate matter away farther and faster, and a larger proportion of nutrients which are left on site are in the form of ash, which is susceptible to being carried off site by wind or displaced downhill by surface water flow (Harwood and Jackson, 1975; and Lewis, 1974).

Kodama and Van Lear (1980) reported that losses of N in convection ash ranged from 4-26 kg/ha. Pritchett and Wells (1978), Flinn et al. (1979), and Vitousek et al. (1983) estimated volatilization losses at between 50 and 300 kg N/ha for this type of burn. According to Wells (1971) a single burn on the South Carolina Coastal Plain volatilized 112-337 kg N/ha. Grier (1975) reported a combined volatilization, ash convection loss of 855 kg N/ha, for a severe fire in Washington.

Generally, burning does not destroy all of the forest floor on a site and is less of an erosion hazard than mechanical site preparation methods (Nutter and Douglass, 1978; and Wollum and Davey, 1975). However, in situations where the forest floor is destroyed along with the logging debris, the surface soil is exposed to raindrop impact and resultant compaction. Higher surface soil densities may lead to reduced infiltration and increased overland flow. Surface runoff can carry dissolved nutrients, ash, and unburned organics off the site. Also, as runoff increases, so does the danger of erosion and permanent site degradation due to loss of topsoil (Hewlett and Nutter, 1969). Increased overland flow also means that less water is available for utilization by planted pines. Since the main mode of nitrate transport from soil solution to plant roots is by mass flow, reduction of available water may lead to reductions of N uptake, and the subsequent reduction of tree growth.

In a natural forest setting the forest floor serves to insulate the soil from extreme fluctuations in temperature. When the forest floor is destroyed by a high intensity burn soil temperature rises, increasing microbial activity, and thereby increasing decomposition of soil organic matter and the mineralization of nutrients (Pritchett and Wells, 1978). Since soil organic matter contributes a significant proportion of the cation exchange capacity of Piedmont soils, the reduction of this component may result in an initial flush of nutrients, followed by a long-term decrease in soil fertility (Wells and Morris, 1982).

Shearing: Shearing is accomplished by shearing residual stems after harvest, using a cutting blade mounted on the front of a tractor. Shearing is generally followed by some other treatment, such as raking, disking or burning but is used alone under some circumstances.

Raking: The purpose of raking is to clear a site of debris and the practice is typically preceeded by shearing and often followed by disking. A root rake mounted on the front of a tractor is used to push all large debris into windrows. On a Piedmont site, Glass (1976) estimated that, in addition to most of the logging debris and forest floor, the upper five cm of mineral soil was also moved to windrows. Morris et al. (1983), and Wells (1983) also reported substantial movement of topsoil to windrows. Morris et al. (1983) estimated total N displacement into windrows to be 373 kg N/ha for a Florida flatwoods site. Tuttle et al. (1985) reported lower N concentrations in the surface soil of three-year-old loblolly pine plantations where 2.5-7.6 cm of surface soil had been removed during site preparation. Swindel et al. (1986) reported reduced growth of slash pine with increased distance from windrows. They concluded that raking had reduced overall site productivity by the relocation of topsoil to windrows.

Raking exposes surface soil to the impact of raindrops, which reduces infiltration, increases runoff and thus increases the potential for soil erosion. Though erosion can cause severe site degradation, Wells (1983) stated that soil displacement associated with raking and windrowing is much more significant with regard to the loss of site productivity. He further stated that raking and windrowing have a greater, negative effect on the nutrient status of forest sites than the sum of all other practices. The importance of the surface soil with regard to loblolly pine productivity was shown by Coile and Schumacher (1953) who reported that depth of surface soil has a highly significant positive relationship to site index. Tuttle et al. (1985) warned that reduction of surface soil depth caused by mechanical site preparation may result in long-term nutrient deficiencies and the subsequent reduction of site productivity.

The organic matter which is raked into windrows is material that would otherwise constitute a high percentage of the potentially mineralizable fraction of the soil. Vitousek et al. (1983) reported greater N losses from windrowing than would likely be replenished by natural inputs under the short rotations common to loblolly pine forestry. Pritchett and Morris (1982) warned that serious shortages of available N can develop as a result of raking and windrowing. Adams (1978), Flinn et al. (1979), Jorgensen et al. (1975), Lantagne (1984), Miller (1983), Swindel et al. (1986), Vitousek et al. (1983), Wells (1983), Whilhite and Mckee (1985), and Wells and Morris (1982) all have warned of potential productivity declines as a result of raking and windrowing.

Disking: Most compaction resulting from harvest operations, and shearing or raking is alleviated by this treatment. Organic materials remaining on the soil surface are also incorporated into the soil. On sites that have been raked, this incorporated material is generally the finer debris component and forest floor, since fine material is more likely to slip between the tines of the rake and thus remain on the site. Decomposition of this fine material is rapid, and as decomposition occurs, N is mineralized which provides an almost immediate, but possibly short-lived, condition of excess available nutrients for planted pines (Pritchett and Wells, 1978).

On sites which have not been raked prior to disking, organic materials incorporated into the soil tend to be larger, and have higher proportions of decay-resistant, woody materials. The finer materials provide the nutrient flush characteristic of any disking treatment, but the larger debris decompose more slowly and provide a slow release source of N, and possibly better long-term N nutrition. Burger and Pritchett (1984) found evidence of significant increases of available N after intensive site preparation and an associated decline in levels of potentially mineralizable N. Pritchett and Morris (1982) also found lower levels of potentially mineralizable N on intensively prepared sites.

After N has been mineralized it either becomes available for plant or microbial uptake as NH_4^+ or undergoes nitrification to NO_3^-. Nitrate, being an anion, is more susceptible to loss by leaching, runoff or denitrification (Pritchett and Wells, 1978; Vitousek et al., 1983; Wells, 1983).

Disking also subjects soils to increased risk of runoff and erosion due to removal of the protective layer of surface organic materials (Hewlett and Doss, 1984; Wells, 1983).

Nitrogen Availability After Site Preparation

Nitrogen Mineralization: Harvest and site preparation activities lead to increased soil temperatures and improved soil moisture conditions (McGee, 1976; Morris and Pritchett, 1983). In addition, all site preparation practices involve some incorporation of organic material into mineral soil, either directly through tillage effects, or indirectly from leaving the roots of killed above-ground vegetation behind to decay. Several researchers have reported increased N mineralization resulting from higher soil temperatures, increased soil moisture, and more mineralizable substrate (Burger and Pritchett, 1984; Campbell et al., 1974; Cassman and Munns, 1980; Morris and Pritchett, 1983).

Though levels of total N are generally reduced by site preparation, N availability increases initially as a result of increased mineralization (Morris and Pritchett, 1982 and 1983), with the the trend being that more available N is present in the least intensively prepared areas (Wells, 1971; Vitousek and Matson, 1985: Burger and Pritchett, 1984). The initial flush of N following site preparation may however, be short-lived. As vegetative cover increases, soil temperatures decrease, and moisture is removed from the soil by plant uptake (McGee, 1976). These conditions would tend to favor decreased N mineralization as well as uptake of some of the previously mineralized N by the vegetation. Morris and Pritchett (1983) reported that by the second growing season levels of potentially mineralizable N had already begun to decline under Florida flatwoods pine plantations.

Tree Response to Intensive Site Preparation

Initial Response: Early growth of Southern pines on the Piedmont has often been reported to be best on sites recieving intensive site preparation treatments. Stafford et al. (1984), found the highest volumes (volume index x trees/ha) for those treatments which included disking, followed by the less intensive chop and burn treatment, for three-year-old loblolly pine (*Pinus taeda* L.) on the Georgia and South Carolina Piedmont. They also reported more volume for the intensive shear,rake treatment at age three than for the low intensity herbicide,burn treatment. DeWit and Terry (1983) reported better volume and height growth for intensely prepared loblolly pine plantations at age eight.

<u>Duration of Response</u>: Tuttle et al. (1985), and Burger and Kluender (1982) proposed that the beneficial effects of intensive site preparation may decline with stand age, and further, that at rotation age, less intensively prepared sites may produce better yields. In two 19-year-old loblolly pine plantations on the North Carolina Piedmont, Glass (1976), presented evidence of this growth reversal. He found that a site which had been prepared by burning had more volume than an adjacent area which had been raked. Stransky (1981) and Stransky et al. (1985) reported height growth for five and eight-year-old loblolly pine plantations that had been prepared by chop and burn or shear and rake treatments. At age five the average tree height on the shear and rake areas was 3.71 m compared to 3.38 m on the chop and burn areas. At age eight the trend had been reversed and the average height was greater for the chop and burn areas, 6.80 m compared to 6.25 m for the shear and rake areas. Arbour and Ezell (1981) also reported better growth at age ten for loblolly pine in Texas, on areas which had been chopped and burned rather than sheared and raked.

Trousdell (1970) reported no significant difference in loblolly pine height at age six between burned and disked treatment areas. Haywood et al. (1981) reported nearly identical mean volumes for 7-year-old loblolly pine plantations, across a number of soil types, that had been prepared with chop and burn or shear, rake, and disk treatments. Pehl (1983) found no difference in height, diameter, or total biomass after five years between loblolly pine plantations that had been site prepared using chop and burn or shear, rake, and disk treatments.

Schultz (1975) also presented data that supports the idea of comparable or even better growth associated with less intensive site preparation. He found that sites which had been intensively site prepared showed lower relative volume increases over control sites as stand age increased. Schmidtling (1973) reported average heights of loblolly pine for two plantations. The control area had been harvested, with logging debris left on-site, and planted. The other area had been harvested, raked, disked, and planted. At age nine the average height of trees on the intensively prepared area exceeded the control height by just under one meter, 6.71 to 5.79 m, respectively. By age 22 the difference had decreased to just over one half meter, 11.60 to 11.05 m, respectively, and diameters were nearly identical between treatments (Schmidtling, 1984). Pehl and Bailey (1983) also found that growth advantages for loblolly pine on intensively prepared sites, relative to control sites, declined with increasing plantation age. They concluded that if the trend of diminishing effects continued, all benefit from intensive site preparation practices would be lost by plantation age 25.

Just as tree response to an intensive site preparation treatment can decline in a single rotation, and even be surpassed by a less intensive treatment, so can the response to that treatment decline over successive rotations on the same site. This situation has been documented by productivity declines of radiata pine (*Pinus radiata* D. Don) in Australia (Keeves, 1966) and New Zealand (Stone and Will, 1965; Whyte, 1973). Stone and Will (1965), proposed that declines of this nature were related to destruction or depletion of N pools, and subsequent N deficiencies. If this is in fact the case, forest productivity in the Southeast may be poised for significant declines if more is not learned about management effects on N dynamics, and if appropriate conservation or corrective measures are not initiated.

Maintenance of Site Productivity

Increased Nutrient Demand: The increase in nutrient demand associated with intensive forestry may be satisfied initially by a site's soil nutrient reserves. In many cases however, especially on low quality sites where these reserves are small, the nutrient demands of planted pines will eventually exceed the site's rate of supply. The length of time needed to reach this point will depend on the initial fertility of the site, rotation length, degree of harvest utilization, and the intensity and duration of site preparation disruption of naturally conservative nutrient cycles (Switzer and Nelson, 1974; Adams, 1978).

Ballard (1978) argued that the success of most management activities are based on short-term results, and less on possible long-term effects on site quality. Jorgensen et al. (1975) and Adams (1978) both predicted that intensive forest management will require inputs of fertilizer in order to maintain productivity levels. However, Ballard (1978) suggested that the effects of nutrient removal in organic matter and soil loss may not be completely relieved, even by the addition of fertilizer. Wollum and Davey (1975) warn specifically of the possible development of N deficiencies under prolonged intensive management.

<u>Nitrogen Conservation</u>: Many researchers have proposed ways to conserve nutrients under intensive management practices. Swindel et al. (1986) recommended that soil removal during site preparation should be avoided in order to maintain site nutrient supplies and maintain productivity. Bengtson

(1981), and Nutter and Douglass (1978) agreed that site disturbance should be held to the absolute minimum necessary to achieve the required silvicultural objectives. Miller (1983) suggested that vegetative cover should be maintained on disturbed sites, even if that cover is composed of weed species, in order to reduce erosion and retain nutrients. Retention of the forest floor and logging slash on site is an important method of conserving nutrients, and organic matter (Bengtson, 1981; Flinn et al., 1979; Flinn et al. 1980; Van Lear et al., 1983; Squire, 1983). In addition, forest floor and logging debris improve soil moisture condition by acting as a mulch (Flinn et al., 1980; Squire, 1983).

Bengtson (1981) recommended that fire be used only sparingly as a management tool because of its potential for large nutrient losses. Squire (1983) reported that most second rotation radiata pine plantations in southern Australia that have shown evidence of productivity declines were established using high intensity burns to clear the sites for planting. When second rotation plantations were established without fire, leaving all litter and logging debris on site, he found no evidence of productivity decline. Though his was only one study, it does provide evidence that site productivity can be maintained when nutrient-conservative management techniques are utilized.

METHODS AND PROCEDURES

Field Sampling

Study Site: This study is part of an ongoing site preparation study already in place at the Reynolds Homestead Research Center located in Patrick county on the Virginia Piedmont. The study involved four forest sites varying in size from 1.5 to 3.5 ha. Three of the four sites were clearcut between April and October 1981, with the bulk of the cutting occurring during the growing season, while the fourth was left uncut to serve as a control area for soil data. Each of the clearcut sites was prepared in July 1982 with one of the following treatments:

1. chop and burn (C,B);
2. shear-disk (S-D) (1 pass);
3. shear, rake, and disk (S,R,D) (three passes).

Each of the prepared sites was planted with 1-0 genetically improved loblolly pine in March, 1983.

Nitrogen Characterization: During the summers of 1984 and 1985, either four or five randomly selected transects, depending on the shape of the prepared area, were installed on each of the three pine plantations. On each of these transects a number of sampling points were picked at random, with the total number of points sampled on each site being as follows:

1. C,B - 30 points;
2. S-D - 40 points;
3. S,R,D - 50 points.

The number of sampling points was based on the site area, with the goal of equal sampling intensity for all areas. At each point a 1 m^2 square sampling frame was randomly placed and the following samples were collected:

1. all above-ground succulent vegetation;
2. all woody stems;
3. a subsample of above-ground logging slash and debris;
4. a subsample of the forest floor;
5. a subsample of below-ground organic residue (such as dead roots and material incorporated during disking) to a depth of 15 cm;
6. a subsample of living roots to a depth of 15 cm;
7. a subsample of the surface soil to a depth of 15 cm (1985 only).

Subsamples were taken above/below a 22.5 cm diameter circle which was randomly located within the sampling frame at each plot.

In August, 1984 fifteen pines were selected at random from each plantation and destructively sampled. In August, 1985 a single tree was sampled at each sampling point (120 total). All trees were separated into the following components:

1. leaves;
2. stems and branches;
3. roots, to a diameter of one mm or less (1984 only).

All three components of each tree were dried and weighed to obtain biomass estimates and then analyzed for total N.

During the summers of 1984 and 1985 composite soil samples were collected from each of ten permanently located sample points on each site, including the control (40 samples). These samples were used to determine levels of potentially mineralizable N (N_o) for both years and total N for 1984. Total N was estimated from soils collected at each of the vegetation sampling points in 1985 (120 samples).

Pine Growth: In March of 1984 permanent measurement plots were installed in each of the three plantations for the purpose of estimating the average volume index (d^2h), and stems/ha of planted pines. The number of plots established on each area was based on the individual site area and was aimed at achieving a 10% sampling intensity for all areas. The plots were established randomly in the following fashion:

1. C,B - six 0.04 ha plots;
2. S-D - six 0.04 ha plots;
3. S,R,D - eleven 0.04 ha plots.

Root collar diameter and height were measured for all trees in all measurement plots in March of 1984, March of 1985 and November of 1985. Estimates of the number of trees/ha for a given plantation were used, along with biomass estimates and the N concentrations derived from the total N analysis, to estimate total N present in planted pines in each plantation.

Pine Nutrition: In November of 1984 and 1985 pine foliage samples were collected from each planted pine in all measurement plots. Samples consisted of needles from the uppermost, fully elongated whorl on the south side of the tree, as recommended by Powers (1984), and Wells and Metz (1963). Individual tree foliage was composited to form a single sample per plot. Foliage samples were then analyzed for total N and the concentrations were compared to a critical level of 12,000 mg N/kg to determine if a N deficiency was present or imminent in any of the plantations. Foliar N levels were also compared among plantations. The foliar concentrations of P, K, Ca and Mg were also determined at this time and compared to their respective critical levels or other reported values, in order to formulate a more balanced assessment of tree nutrition.

Laboratory Analyses

All tissue samples were ground to pass through a 20-mesh screen, oven-dried to constant weight at 65C for 12-24 hours, and analyzed for total N using a modified micro-Kjeldahl technique (Bremner and Mulvaney, 1982). In order to correct for soil contamination of tissue samples, samples of all organic components (except pine leaves, pine stems and hardwood stems) were ashed at 500C for twelve hours to determine ash correction factors, which were then applied to all dry weights.

Phosphorus concentrations in pine foliage were determined using the ascorbic acid technique detailed by Fogg and Wilkinson (1958). Cation concentrations were determined from dry ashed samples using atomic absorption spectrophotometry.

Soil samples collected at permanent sampling points underwent a 12-week aerobic incubation to determine N_o, as presented by Stanford and Smith (1972). Mineral N was extracted from soil using a 0.01 $\underline{M}$ $CaCl_2$ solution and was determined from the initial leachate of the N_o procedure. The value of extractable mineral N was then added to the N mineralization potential to obtain a measure of potentially available soil N.

In addition, soil samples from permanent sampling points were used to estimate total soil N levels in 1984. Soil samples collected from the vegetation sampling points were used for total N analysis in 1985. All soil samples analyzed for total N were digested using a micro-Kjeldahl procedure, with the salicylic acid modification for nitrate recovery as described by Bremner and Mulvaney (1982).

All N analysis, for both tissue and soil digests, were performed using a Technicon AutoAnalyzer II. Phosphorus analysis was performed colorimetrically using a Bausch & Lomb SPECTRONIC 100 spectrometer. Cation determination was done using a Perkin-Elmer Model 460 Atomic Absorption Spectrophotometer.

Statistical Analysis

In order to compare parameters among plantations, or within a plantation from one year to the next, analysis of variance techniques were utilized along with Duncans New Multiple Range Test. A significance level of 0.05 was used in all instances unless specified otherwise.

The data set for woody stems contained values of zero where no woody stems happened to fall within the sampling frame. The data from all three areas contained different proportions of zeros, resulting in unequal variances among the three populations. A log transformation was therefore used on all woody stem data.

Linear regression was used to relate pine leaf and stem biomass to pine root biomass for trees sampled in 1984. The relationship which was determined was used to predict pine root biomass in 1985 when that parameter was not sampled directly.

RESULTS

Stand and Site Characterization

Pre-harvest: All four study areas were forested with mixes of hardwoods and conifers. The ratio of hardwood:conifer stems/ha is shown in Table 1. All stands were similar in composition, basal area, volume, soil type, slope, and site index with the exceptions that the S-D area was dominated by hardwoods and was more gently sloped.

Pre-harvest soil N concentrations (NCONC) were highest for the S-D area and total soil N (NCONT) levels were quite similar for the S-D, S,R,D and control (CON) areas (Table 2). The C,B area had the lowest levels of soil NCONC and NCONT.

Pre-harvest forest floor biomass levels were similar for the CON, S-D, and C,B areas, ranging from 17,672 kg/ha on the CON area to 22,500 kg/ha on the C,B area (Table 3). The S,R,D area had nearly twice the forest floor biomass as any of the other areas. The same pattern followed for the NCONT of the forest floor with the pre-harvest levels of the CON, S-D, and C,B areas ranging from 82.0 to 97.6 kg/ha, while the S,R,D area had 151.0 kg/ha total N.

Post-Site Preparation: Soil N concentrations three and nine months after site preparation are presented in Table 2,

Table 1. Pre-harvest stand and site characterization of four forested research areas located at the Reynolds Homestead Research Center, in Patrick county, on the Virginia Piedmont (adapted from Fox, 1984).

Treatment Area	Area (ha)	Ave. Slope (%)	Major Soil Series	[1]Site Index Yellow-poplar (m)	[2]Hardwood: Conifer Ratio	Basal Area (m^2/ha)	Total Volume (m^3/ha)
S,R,D	3.2	17	Cecil	28	1.7	23.8	115.9
C,B	1.5	17	Cecil, Hayesville	28	1.1	24.6	112.2
S-D	1.7	11	Cecil	28	9.4	22.2	121.4
CON	1.5	16	Cecil, Appling	29	0.7	21.7	94.6

[1] Base age 50 years.

[2] Ratio of stems/ha

Table 2. Pre-harvest and post-site preparation N characterization of the upper 15 cm of mineral soil of four research areas located at the Reynolds Homestead Research Center, in Patrick county, on the Virginia Piedmont (adapted from Fox, 1984).

Treatment Area	Pre-harvest N Concentration (mg/kg)	Post-site Preparation N Concentration (mg/kg)		Post-site Preparation N Content (kg/ha)	Potentially Mineralizable N, (N_o) (kg/ha)
		3 Months	9 Months		
S,R,D	687	803	806	1,166	107
C,B	450	591	581	850	79
S-D	978	793	937	1,123	147
CON	631	594	549	1,244	121

Table 3. Pre-harvest and post-site preparation forest floor characterization of four research areas located at the Reynolds Homestead Research Center, in Patrick county, on the Virginia Piedmont (adapted from Fox, 1984).

	Pre-harvest		Post-Site Preparation	
Treatment Area	Biomass (kg/ha)	N Content (kg/ha)	Biomass (kg/ha)	N Content (kg/ha)
S,R,D	36,642	151.0	12,998	38.9
C,B	22,500	97.6	38,159	114.5
S-D	19,693	88.7	87,134	261.4
CON	17,672	82.0	------	-----

along with soil NCONT values for the three areas. The C,B area had the lowest level of NCONT of the four areas immediately after site preparation. Potentially mineralizable N varied from site to site with the highest level of N_o noted for the S-D area and the lowest found on the C,B area (Table 2).

Forest floor biomass increased sharply for the S-D, and C,B treatment areas after site preparation, rising from 19,693 to 87,134 kg/ha and 22,500 to 38,159 kg/ha, respectively (Table 3). There was a sharp decrease in the biomass of the forest floor on the S,R,D site after site preparation with biomass dropping from 36,642 to 12,998 kg/ha.

Post-site preparation NCONT levels in the forest floor were greatest for the S-D treatment area with 261.4 kg/ha, followed by the C,B area with 114.5 kg/ha (Table 3). The S,R,D area, which had had the highest pre-harvest forest floor N levels, had the lowest post-site preparation levels with only 38.9 kg N/ha remaining.

Native Vegetation

Woody Stems: During the summer of 1984, the second full growing season of the plantation, there was a greater biomass of hardwood sprouts on the S-D area than on the

S,R,D area (Table 4). The C,B treatment area was found to have a woody stem biomass intermediate to the other two areas but not significantly different from either.

During the third growing season the S-D area had the greatest amount of hardwood stem biomass of the three areas, and no difference existed between the S,R,D and C,B areas. The S-D treatment area had nearly twice the woody stem biomass of either of the other two areas with a biomass of 2,305 kg/ha, compared to 1,318 kg/ha for the S,R,D area and only 984 kg/ha for the C,B area (Table 5).

The only change in woody stem biomass which occurred between the second and third growing season was on the S,R,D area (Table 6), where biomass increased from 166 to 1,318 kg/ha, respectively. The S-D area showed a significant increase in woody stem biomass over the same period when the alpha level was increased to 0.10.

Nitrogen concentration in the woody stem tissue was higher for the disked treatment areas than for the C,B area, during the second growing season, with no difference between the S,R,D or S-D areas (Table 4).

During the third growing season the NCONC of woody stems had declined on the S-D area to a level not significantly different than the C,B area (Table 5). The S,R,D area maintained higher NCONC levels than either of the other two areas through the third growing season.

From the second to the third growing season no change

Table 4. Native vegetation biomass, N content (NCONT) and N concentration (NCONC) during the second growing season of three loblolly pine plantations on the Virginia Piedmont.

Sample	Treatment Area	Biomass (kg/ha)	NCONC (mg/kg)	NCONT (kg/ha)
Succulent Leaves and Stems	S,R,D	2,155 b	15,751 a(a)	31.9 a(b)
	C,B	1,777 b	12,387 b(c)	21.7 b(c)
	S-D	3,197 a	14,086 ab(b)	41.0 a(a)
Woody Stems	S,R,D	166 b	5,085 a	0.7 b
	C,B	466 ab	3,749 b	1.4 b
	S-D	943 a	4,741 a	4.0 a
Roots	S,R,D	1,234 b	10,356 a	14.3 b
	C,B	1,985 b	6,634 c	9.3 b
	S-D	4,518 a	8,549 b	33.3 a
Total	S,R,D	3,555 b	------	46.9 b
	C,B	4,228 b	------	32.4 b
	S-D	8,658 a	------	78.3 a

Comparisons are made only within columns, by sample. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test. Significance levels in parentheses are for tests conducted at alpha=0.10.

Table 5. Native vegetation biomass, N content (NCONT) and N concentration (NCONC) during the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Sample	Treatment Area	Biomass (kg/ha)		NCONC (mg/kg)		NCONT (kg/ha)	
Succulent Leaves and Stems	S,R,D	2,635	b(b)	13,780	a	37.3	a
	C,B	2,002	b(c)	11,702	b	23.8	b
	S-D	3,529	a(a)	13,473	a	47.3	a
Woody Stems	S,R,D	1,318	b	5,447	a	8.3	a
	C,B	984	b	3,895	b	3.0	b
	S-D	2,305	a	3,874	b	7.6	a
Roots	S,R,D	1,948	b	9,079	a(a)	15.3	b
	C,B	2,511	b	6,131	b(c)	13.2	b
	S-D	4,050	a	7,963	a(b)	27.3	a
Total	S,R,D	5,901	b	------		60.9	ab(b)
	C,B	5,497	b	------		40.0	b(b)
	S-D	9,884	a	------		82.2	a(a)

Comparisons are made only within columns, by sample. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test. Significance levels in parentheses are for tests conducted at alpha=0.10.

Table 6. Changes in woody stem biomass, N concentration (NCONC) and N content (NCONT) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)		NCONC (mg/kg)		NCONT (kg/ha)	
S,R,D	2	166	b	5,085	a	0.7	b
	3	1,318	a	5,447	a	8.3	a
C,B	2	466	a	3,749	a	1.4	a
	3	984	a	3,895	a	3.0	a
S-D	2	943	a(b)	4,741	a	4.0	a(b)
	3	2,305	a(a)	3,874	b	7.6	a(a)

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test. Significance levels in parentheses are for tests conducted at alpha=0.10.

was noted in woody stem NCONC within the S,R,D, or C,B areas (Table 6). The S-D area, however, did show a decline in the NCONC of woody tissue from the second to the third growing season.

The NCONT of woody stem tissue was greatest on the S-D area than on either of the other two areas during the second growing season (Table 4). Total N content of hardwood stems did not differ between the S,R,D area and the C,B area.

During the third growing season the S-D and S,R,D areas had higher NCONT values than did the C,B area (Table 5). No difference was present between the disked treatment areas.

From the second to the third growing season the NCONT of woody stem material increased on the S,R,D area but not on either of the other two areas (Table 6). When the alpha level was increased to 0.10 an increase was also noted on the S-D area.

Succulent Tissue: The biomass of hardwood leaves and other succulent (non-woody) above-ground vegetation was greater for the S-D area than for either of the other two areas during the second growing season (Table 4). No significant difference was found between the S,R,D and C,B treatment areas.

During the third growing season the same pattern persisted. The S-D area had the greatest succulent tissue biomass, followed by the other two areas, with no difference between the S,R,D and C,B areas (Table 5). If the alpha level was raised to 0.10 the biomass of the S-D area was found to be greater than that of the S,R,D area, which was in turn greater than that of the C,B area.

No significant increases in succulent tissue biomass occurred within any of the treatment areas from the second to the third growing season (Table 7).

During the second growing season the NCONC of succulent tissue was greater for the S,R,D area than for the C,B area (Table 4). The NCONC of the S-D tissue was intermediate between the two and was not different from either of the others. When an alpha of 0.10 was used the differences between areas were clearer. The NCONC of the S,R,D area was greatest, followed by the S-D area which was greater than the C,B area.

During the third growing season the two disked treatment areas had nearly identical NCONC values in succulent tissue, while the tissue of the C,B area had significantly lower NCONC (Table 5).

From the second to the third growing season the NCONC of succulent material on the S,R,D area declined. No such decline was found for the other two treatment areas (Table 7).

The NCONT of succulent tissue during the second growing season was not significantly different for either of the disked treatment areas (Table 4). However, both the S,R,D,

Table 7. Changes in succulent leave and stem biomass, N concentration (NCONC) and N content (NCONT) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)		NCONC (mg/kg)		NCONT (kg/ha)	
S,R,D	2	2,155	a	15,751	a	31.9	a
	3	2,635	a	13,780	b	37.3	a
C,B	2	1,777	a	12,387	a	21.7	a
	3	2,002	a	11,702	a	23.8	a
S-D	2	3,197	a	14,086	a	41.0	a
	3	3,529	a	13,473	a	47.3	a

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

and S-D areas had greater NCONT succulent tissue than did the C,B area. At alpha level 0.10 the S-D area had the greatest NCONT in succulent tissue, followed by the S,R,D area which was greater than the C,B area.

During the third growing season, succulent tissue NCONT values were not different for the S,R,D and S-D areas, and both were greater than those of the C,B area (Table 5).

No differences were found between the second and third growing season NCONT values for any of the three treatment areas (Table 7).

Roots: During the second growing season root biomass was greater for the S-D area than for either of the other two areas (Table 4). No difference in root biomass was found between the S,R,D and C,B treatment areas.

The same pattern was found during the third growing season (Table 5). The S-D treatment area had greater root biomass than either the S,R,D or C,B areas which did not differ.

The root biomass of the S,R,D area increased from the second to the third growing season (Table 8). No increases occurred in root biomass for either the C,B or S-D areas during the same time period.

Root NCONC was greater for the S,R,D area than for the S-D area, and the S-D area was greater than the C,B area during the second growing season (Table 4).

Table 8. Changes in native vegetation root biomass, N concentration (NCONC) and N content (NCONT) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)		NCONC (mg/kg)		NCONT (kg/ha)	
S,R,D	2	1,234	b	10,356	a(a)	14.3	a
	3	1,948	a	9,079	a(b)	15.3	a
C,B	2	1,985	a	6,634	a	9.3	a
	3	2,511	a	6,131	a	13.2	a
S-D	2	4,518	a	8,549	a	33.3	a
	3	4,050	a	7,963	a	27.3	a

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test. Significance levels in parentheses are for tests conducted at alpha=0.10.

These differences in root NCONC became less sharply defined during the third growing season (Table 5). The S,R,D area still had a greater root NCONC than the C,B area, as did the S-D area, but no difference was present any longer between the two disked treatment areas. When an alpha level of 0.10 was used the same pattern was exibited as in the second growing season. The root NCONC of the S,R,D area was greatest, followed by the S-D area, followed by the C,B area.

No changes in root NCONC were noted for any of the three treatment areas from the second to the third growing season (Table 8). When the alpha level was increased to 0.10 however, a decline in the NCONC of root tissue on the S,R,D area was found for this period.

During the second growing season the S-D treatment area contained much greater quantities of total N in root tissue than either of the other areas (Table 4). The S-D area had 33.3 kg N/ha in root tissue versus 14.3 kg/ha for the S,R,D area or 9.3 kg/ha for the C,B area. No difference in root NCONT was present between the S,R,D and C,B areas.

The pattern was the same for the third growing season with the S-D treatment area still having a greater root NCONT than either of the other two areas (Table 5). There was no difference in root NCONT between the S,R,D and C,B areas during the third growing season.

No differences were found in root NCONT for any treatment area between the second and third growing season (Table 8).

Totals: During the second growing season the S-D treatment area had approximately twice the total native vegetation biomass of either of the other treatment areas (Table 4). The biomass of native vegetation on the S-D area was 8,658 kg/ha compared to 4,228 kg/ha on the C,B area and 3,555 kg/ha on the S,R,D area. No difference was present between the S,R,D area and the C,B area.

The same pattern was present in the third growing season (Table 5). The S-D area exhibited greater native vegetation biomass than the other two areas, and the other two areas did not differ.

The only increase in total native vegetation biomass, between the second and third growing seasons, occurred on the S,R,D area (Table 9).

During the second growing season more N had been sequestered in the tissue of native vegetation on the S-D area than on either of the other areas (Table 4). The S-D area had an NCONT of 78.3 kg/ha as compared to 46.9 kg/ha for the S,R,D area and 32.4 kg/ha for the C,B area.

During the third growing season the S-D treatment area still had a higher native vegetation NCONT than the C,B area, but was no longer greater than the S,R,D area (Table 5). The S,R,D area NCONT was intermediate with respect to

Table 9. Changes in total native vegetation biomass and N content (NCONT) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)	NCONT (kg/ha)
S,R,D	2	3,555 b	46.9 a
	3	5,901 a	60.9 a
C,B	2	4,228 a	32.4 a
	3	5,497 a	40.0 a
S-D	2	8,658 a	78.3 a
	3	9,884 a	82.2 a

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

the others and differed from neither. When tests were made with alpha=0.10, the same pattern seen during the second growing season was found. The S-D area had the greatest total native vegetation NCONT, and that of the other two treatment areas did not differ.

No differences in the NCONT of native vegetation were found for any of the three treatment areas from the second to the third growing season (Table 9).

Planted Pines

Pine Stems and Branches: During the second growing season pine stem and branch biomass was greater on the S,R,D area than on either the C,B area or the S-D area (Table 10). The S,R,D area had a pine stem biomass of 86 kg/ha while the C,B area had 33 kg/ha and the S-D area had only 29 kg/ha.

During the third growing season the pine stem biomass differences were equally striking with the S,R,D area having 393 kg/ha compared to 265 kg/ha for the C,B area and only 143 kg/ha for the S-D area (Table 11). The S,R,D biomass was greater than that of the C,B area, which was greater than that of the S-D area.

All treatment areas showed increases in pine stem and branch biomass from the second to the third growing season (Table 12). Increases of 355, 695 and 389% were found for

Table 10. Planted pine biomass, N concentration (NCONC) and N content (NCONT) during the second growing season of three loblolly pine plantations on the Virginia Piedmont.

Sample	Treatment Area	Biomass (kg/ha)		NCONC (mg/kg)		NCONT (kg/ha)	
Pine Leaves	S,R,D	115	a	15,638	a(a)	1.8	a
	C,B	51	b	13,658	a(b)	0.7	b
	S-D	42	b	15,373	a(a)	0.7	b
Pine Stems and Branches	S,R,D	86	a	4,466	a(ab)	0.4	a
	C,B	33	b	4,244	a(b)	0.1	b
	S-D	29	b	4,900	a(a)	0.2	b
Pine Roots	S,R,D	43	a	4,508	a(a)	0.2	a
	C,B	16	b	3,354	b(c)	0.1	b
	S-D	12	b	3,957	a(b)	0.1	b
Pine Total	S,R,D	244	a	------		2.4	a
	C,B	100	b	------		0.9	b
	S-D	83	b	------		1.0	b

Comparisons are made only within columns, by sample. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test. Significance levels in parentheses are for tests conducted at alpha=0.10.

Table 11. Planted pine biomass, N concentration (NCONC) and N content (NCONT) during the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Sample	Treatment Area	Biomass (kg/ha)		NCONC (mg/kg)		NCONT (kg/ha)	
Pine Leaves	S,R,D	387	a	14,139	b	5.5	a
	C,B	284	b	12,492	c	3.5	b
	S-D	131	c	15,082	a	2.0	c
Pine Stems and Branches	S,R,D	393	a	3,837	b	1.4	a
	C,B	265	b	3,358	c	0.8	b
	S-D	143	c	4,317	a	0.6	b
Pine Roots	S,R,D	149		------		0.7	
	C,B	111		------		0.4	
	S-D	52		------		0.2	
Pine Total	S,R,D	929	a	------		7.6	a
	C,B	660	b	------		4.7	b
	S-D	326	c	------		2.8	c

Comparisons are made only within columns, by sample. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

Table 12. Changes in pine stem and branch biomass, N content (NCONT) and N concentration (NCONC) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)		NCONC (mg/kg)		NCONT (kg/ha)	
S,R,D	2	86	b	4,466	a	0.4	b
	3	393	a	3,837	b	1.4	a
C,B	2	33	b	4,244	a	0.1	b
	3	265	a	3,358	b	0.8	a
S-D	2	29	b	4,900	a(a)	0.2	b
	3	143	a	4,317	a(b)	0.6	a

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test. Significance levels in parentheses are for tests conducted at alpha=0.10.

the S,R,D, C,B and S-D areas, respectively.

During the second growing season no differences in pine stem NCONC were present at a significance level of 0.05 (Table 10). When the alpha level was raised to 0.10 the S-D area was found to have a greater NCONC than the C,B area, but no difference was present between the two disked treatment areas or between the S,R,D area and the C,B area.

The NCONC of pine stem and branch material during the third growing season was greatest on the S-D area with a concentration of 4,317 mg N/kg. The S,R,D area was the next greatest with 3,857 mg N/kg, followed by the C,B area with a NCONC of 3,358 mg N/kg (Table 11).

The NCONC of both the S,R,D and C,B areas displayed significant declines from the second to the third growing season (Table 12). The NCONC of the S-D area also declined but was only different from the previous year at alpha=0.10.

During the second growing season the pine stem and branch NCONT of the S,R,D area was greater than that of either of the other two treatments (Table 10). The NCONT of the S-D and C,B areas did not differ.

The third growing season was much the same in that the pine stem NCONT of the S,R,D area was greater than those of the other areas, and the S-D and C,B areas did not differ from each other (Table 11).

All treatment areas showed increases in the NCONT of pine stems and branches from the second to the third growing season (Table 12).

Pine Leaves: During the second growing season the biomass of pine leaves was greater for the S,R,D treatment area than for the other two areas (Table 10). The S,R,D pine leaf biomass was 115 kg/ha while the C,B biomass was 51 kg/ha and the S-D biomass was only 42 kg/ha.

Pine leaf biomass during the third growing season was greater for the S,R,D treatment area than for the C,B area, which was greater than for the S-D area (Table 11). Pine leaf biomass was 387 kg/ha for the S,R,D area, 284 kg/ha for the C,B area and only 131 kg/ha for the S-D area.

All treatment areas showed increases in pine leaf biomass from the second to the third growing seasons (Table 13).

No pine leaf NCONC differences were found among any of the treatment areas during the second growing season (Table 10). When an alpha level of 0.10 was used however, both of the disked treatment areas showed greater pine leaf NCONC levels than did the C,B area.

During the third growing season the pine leaf NCONC for the S-D area was greater than that for the S,R,D area, which was greater than that for the C,B area (Table 11).

A decline in pine leaf NCONC, from the second to the third growing season, was found for both the S,R,D and C,B areas (Table 13). No decline in concentration was found for

Table 13. Changes in pine leave biomass, N concentration (NCONC) and N content (NCONT) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)	NCONC (mg/kg)	NCONT (kg/ha)
S,R,D	2	115 b	15,638 a	1.8 b
	3	387 a	14,139 b	5.5 a
C,B	2	51 b	13,658 a	0.7 b
	3	284 a	12,492 b	3.5 a
S-D	2	42 b	15,373 a	0.7 b
	3	131 a	15,082 a	2.0 a

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

the S-D area.

More N was found in pine leaf tissue on the S,R,D area, during the second growing season, than on either of the other two treatment areas (Table 10). No difference was found in pine leaf NCONT between the C,B area and the S-D area.

During the third growing season pine leaf NCONT was greater for the S,R,D area than for the C,B area, which was greater than for the S-D area (Table 11). Pine leaf NCONT was 5.5 kg/ha for the S,R,D area, 3.5 kg/ha for the C,B area and 2.0 kg/ha for the S-D area.

All treatment areas showed substantial increases in pine leaf NCONT between the second and third growing seasons (Table 13).

Pine Roots: Pine root biomass was greater on the S,R,D area than for either of the other two areas during the second growing season (Table 10). The S,R,D area had 42.7 kg/ha of pine roots while the C,B area had just 16.4 kg/ha and the S-D area had the least with only 12.4 kg/ha.

Pine roots were not sampled during the third growing season but biomass estimates determined using second year pine stem and leaf relationships are presented in Table 11 and second growing season pine root biomass and third growing season biomass estimates are presented together in Table 14.

Table 14. Estimated changes in pine root biomass, N content (NCONT) and N concentration (NCONC) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)	NCONC (mg/kg)	NCONT (kg/ha)
S,R,D	2	43	4,508	0.2
	3	[1]149	-----	[2]0.7
C,B	2	16	3,354	0.1
	3	[1]111	-----	[2]0.4
S-D	2	12	3,957	0.1
	3	[1]52	-----	[2]0.2

[1] Values estimated by regression using stem and leaf relationships from second growing season.

[2] Estimates obtained by multiplying estimated biomass by second year NCONC.

The pine root NCONC during the second growing season was greatest for the two disked areas (Table 10). When an alpha level of 0.10 was used the pine root NCONC of the S,R,D area was found to be greatest, followed by the S-D area, which was followed by the C,B area. The NCONC for the S,R,D area was 4,508 mg/kg, compared to 3,957 mg/kg for the S-D area and 3,354 mg/kg for the C,B area.

Since no pine roots were sampled during the third growing season no new estimates of pine root NCONC were calculated and therefore no comparisons could be made of NCONC changes within treatment areas by growing season.

Higher NCONT values were found for pine root tissue on the S,R,D area during the second growing season, than for either of the other two areas (Table 10).

Using the estimated pine root biomass values and the second growing season NCONC values, pine root NCONTs were estimated for all treatment areas for the third growing season and are presented in Tables 11 and 14.

Totals: Total planted pine biomass was greatest for the S,R,D treatment area during the second growing season (Table 10). The other two treatment areas did not differ. Total pine biomass was 244 kg/ha for the S,R,D area, 100 kg/ha for the C,B area and just 83 kg/ha for the S-D area.

The third growing season showed the S,R,D treatment area to have more total pine biomass than the C,B area which in turn had more biomass than the S-D area (Table 11). The S,R,D area had 929 kg/ha total pine biomass while the C,B area had 660 kg/ha and the S-D area had 326 kg/ha.

Total pine biomass increased on all treatment areas from the second to the third growing season (Table 15). Increases in total pine biomass were 280, 558 and 290% for the S,R,D, C,B and S-D areas, respectively.

During the second growing season the NCONT of pine tissue was greater on the S,R,D area, than on the other treatment areas (Table 10). The S,R,D area contained 2.4 kg/ha N in pine tissue, while the S-D contained 1.0 kg/ha and the C,B area just 0.9 kg/ha.

The S,R,D treatment area had a larger amount of N stored in pine tissue during the third growing season than did the C,B area, which contained more N than the S-D area (Table 11). The S,R,D area contained 7.6 kg/ha of N stored in pine tissue. The C,B area had 4.7 kg/ha and the S-D area only 2.8 kg/ha.

The NCONT of planted pines on all treatment areas increased from the second to the third growing seasons (Table 15).

Forest Floor

The S-D area had the largest forest floor biomass of the

Table 15. Changes in planted pine biomass and N content (NCONT) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)	NCONT (kg/ha)
S,R,D	2	244 b	2.4 b
	3	929 a	7.6 a
C,B	2	100 b	0.9 b
	3	660 a	4.7 a
S-D	2	83 b	1.0 b
	3	326 a	2.8 a

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

three treatment areas during the second growing season with 16,922 kg/ha (Table 16). The C,B and S,R,D treatment areas had forest floor biomass values of 5,222 kg/ha and 3,822 kg/ha, respectively.

During the third growing season the trend was the same (Table 16). The S-D area still had greater forest floor biomass, with 39,597 kg/ha, than either the C,B or S,R,D areas with 14,579 kg/ha or 10,345 kg/ha, respectively.

The S,R,D and C,B areas both showed increases in forest floor biomass from the second to the third growing seasons (Table 17). The increase in biomass of the S-D area forest floor was only significant at alpha=0.10.

The NCONC of forest floor materials during the second growing season is presented in Table 16. NCONC was greater for the S-D area than for the C,B area. The S,R,D area NCONC was intermediate with respect to the other two areas and was different from neither.

Third growing season NCONC values did not differ for the two disked treatment areas, and were both greater than for the C,B area (Table 16). The S-D treatment area had a forest floor NCONC of 9,219 mg/kg. The S,R,D area NCONC was quite similar, being 8,899 mg/kg, while the C,B area NCONC was only 6,652 mg/kg.

The forest floor NCONC values for both of the disked treatment areas showed increases from the second to the third growing seasons (Table 17). No change in forest floor

Table 16. Forest floor biomass, N concentration (NCONC) and N content (NCONT) during the second and third growing seasons of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)		NCONC (mg/kg)		NCONT (kg/ha)	
S,R,D	2	3,822	b	6,583	ab	18.6	b
C,B	2	5,222	b	5,948	b	31.6	b
S-D	2	16,922	a	7,703	a	113.8	a
S,R,D	3	10,345	b	8,899	a	79.8	b
C,B	3	14,579	b	6,652	b	51.9	b
S-D	3	39,597	a	9,219	a	296.8	a

Comparisons are made only within columns, by growing season. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

Table 17. Changes in forest floor biomass, N concentration (NCONC) and N content (NCONT) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)		NCONC (mg/kg)		NCONT (kg/ha)	
S,R,D	2	3,822	b	6,583	b	18.6	b
	3	10,345	a	8,899	a	79.8	a
C,B	2	5,222	b	5,948	a	31.6	a(b)
	3	14,579	a	6,652	a	51.9	a(a)
S-D	2	16,922	a(b)	7,703	b	113.8	b
	3	39,597	a(a)	9,219	a	296.8	a

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test. Significance levels in parentheses are for tests conducted at alpha=0.10.

NCONC was found on the C,B area over the same period.

During the second growing season NCONT of the forest floor was greater for the S-D area than for the other areas (Table 16). The S-D area contained 113.8 kg/ha N while the C,B area contained only 31.6 kg/ha and the S,R,D area just 18.6 kg/ha.

During the third growing season, the S-D area NCONT was again greatest, with 296.8 kg N/ha (Table 16). The S,R,D area, with 79.8 kg N/ha, and the C,B area with only 51.9 kg N/ha did not differ.

The forest floor NCONT of the S-D and S,R,D treatment areas increased from the second to the third growing season (Table 17). An increase in NCONT on the C,B area could also be shown when the alpha level was raised to 0.10.

Total Soil Nitrogen

Organic Residue: There was no difference in the amount of organic residue in soil among treatment areas, during the second growing season (Table 18). The three areas averaged 5,799 kg/ha of dead roots or surface materials which had been incorporated into soil during site preparation.

No differences were found among organic residue biomass values of any of the treatment areas, during the third growing season (Table 18).

Table 18. Soil organic residue biomass, N concentration (NCONC) and N content (NCONT) during the second and third growing seasons of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)	NCONC (mg/kg)	NCONT (kg/ha)
S,R,D	2	5,012 a	8,038 a	37.2 a
C,B	2	6,675 a	6,161 b	24.4 a
S-D	2	5,710 a	8,065 a	45.8 a
S,R,D	3	4,481 a	8,167 a	29.5 a
C,B	3	7,397 a	5,830 b	29.6 a
S-D	3	4,683 a	8,479 a	35.6 a

Comparisons are made only within columns, by growing season. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

There were no changes in organic residue biomass on any of the three treatment areas from the second to the third growing seasons (Table 19).

The organic residue on the C,B site had the lowest NCONC of all three treatment areas during both the second and third growing seasons (Table 18). During both growing seasons the disked treatment areas had very similar organic residue NCONC values. During the second growing season the S-D area had an NCONC of 8,065 mg N/kg, while the S,R,D area had a value of 8,038 mg N/kg and the C,B area organic residue NCONC was only 6,161 mg N/kg. The NCONC values for the third growing season were 8,479, 8,167, and 5,830 mg N/kg, for the S-D, S,R,D and C,B areas, respectively. The low NCONC values found on the C,B area are probably related to the presence of charcoal in former root channels and incorporated debris.

No differences were present for any of the three areas in the NCONC of organic residue, between the second and third growing seasons (Table 19).

No differences were found among treatment areas, with regard to NCONT of organic residue, in either of the second or third growing seasons (Table 18). Total N content of organic residue averaged 35.8 kg N/ha during the second growing season and 31.6 kg N/ha during the third growing season.

There were no differences in the NCONT values for soil

Table 19. Changes in soil organic residue biomass, N concentration (NCONC) and N content (NCONT) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Biomass (kg/ha)	NCONC (mg/kg)	NCONT (kg/ha)
S,R,D	2	5,012 a	8,038 a	37.2 a
	3	4,481 a	8,167 a	29.5 a
C,B	2	6,675 a	6,161 a	24.4 a
	3	7,397 a	5,830 a	29.6 a
S-D	2	5,710 a	8,065 a	45.8 a
	3	4,683 a	8,479 a	35.6 a

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

organic residue of any of the three areas, from the second to the third growing seasons (Table 19).

Fine Soil Organic Matter: During the second growing season after site preparation the CON area had the highest soil NCONC values of the four areas with 1,228 mg N/kg (Table 20). There was no difference between the CON area and the S-D area which had a soil NCONC of 1,096 mg N/kg or between the S-D area and the S,R,D area, which had a NCONC of 959 mg N/kg. The CON value was greater than either the S,R,D or the C,B area, and the C,B soil NCONC was the lowest of all with a value of only 700 mg N/kg.

During the third growing season the S-D treatment area had the highest soil NCONC, with a value of 1,666 mg N/kg (Table 20). All other treatment areas, including the CON, were significantly lower and did not differ from each other.

The soil NCONC values for the C,B and S-D sites increased from the second to the third growing season (Table 21). The soil NCONC of the S,R,D and CON areas did not change over this period.

The soil NCONT during the second growing season followed much the same pattern as the NCONC values, except that differences were slightly more distinct (Table 20). The CON area had the largest amount of total N in the surface 15 cm of mineral soil, followed by the S-D area and the S,R,D area which were not different, and the C,B site, with 2,157.0,

Table 20. Mineral soil N concentration (NCONC) and N content (NCONT) during the second and third growing seasons of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	NCONC (mg/kg)	NCONT (kg/ha)
S,R,D	2	959 b	1,616.4 b
C,B	2	700 c	1,180.9 c
S-D	2	1,096 ab	1,696.9 b
CON	2	1,228 a	2,157.0 a
S,R,D	3	1,167 b	1,966.0 ab
C,B	3	1,227 b	2,069.1 ab
S-D	3	1,666 a	2,580.0 a
CON	3	896 b	1,572.9 b

Comparisons are made only within columns, by growing season. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

Table 21. Changes in mineral soil N concentration (NCONC) and N content (NCONT) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	NCONC (mg/kg)	NCONT (kg/ha)
S,R,D	2	959 a	1,616.4 a
	3	1,167 a	1,966.0 a
C,B	2	700 b	1,180.9 b
	3	1,227 a	2,069.1 a
S-D	2	1,096 b	1,696.9 b
	3	1,666 a	2,580.0 a
CON	2	1,228 a	2,157.0 a
	3	896 a	1,572.9 a

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

1,696.9, 1,616.4, and 1,180.9 kg N/ha, respectively.

During the third growing season the differences between treatment areas were not as clear (Table 20). The S-D area had a higher NCONT than did the CON site but was not different from the other treated areas.

The NCONT of the S-D, and C,B area surface soils increased from the second to the third growing seasons (Table 21). The NCONT of the S,R,D and CON areas did not change over this period.

Mineral Soil and Organic Residue: The upper 15 cm of mineral soil with all of its incorporated organic residue contained different amounts of N among treatment areas, in the second growing season (Table 22). The S-D area had the most soil N with 1,742.7 kg N/ha. This was greater than the NCONT of the S,R,D area, with 1,653.6 kg N/ha, which in turn was greater than that of the C,B area, which was only 1,205.3 kg N/ha.

During the third growing season the NCONT of the C,B area soil increased enough that there was no longer a significant difference between the S,R,D or the C,B areas (Table 22). Both soils still had lower NCONT values than the S-D treatment area. The fine organic matter of the soil contributed more N to the sum of the soil and organic residue NCONTs than did the organic residue. It is therefore not surprising that all changes in the total soil

Table 22. Total system N content (NCONT) during the second and third growing seasons (1984 and 1985) of three loblolly pine plantations on the Virginia Piedmont.

System Component	Treatment Area	NCONT 1984 (kg/ha)	NCONT 1985 (kg/ha)
Native Vegetation	S,R,D	46.9 b	60.9 ab(b)
	C,B	32.4 b	40.0 b(b)
	S-D	78.3 a	82.2 a(a)
Planted Pines	S,R,D	2.4 a	7.6 a
	C,B	0.9 b	4.7 b
	S-D	1.0 b	2.8 c
Forest Floor	S,R,D	18.6 b	79.8 b
	C,B	31.6 b	51.9 b
	S-D	113.8 a	296.8 a
Soil and Organic Residue	S,R,D	1,653.6 b	1,995.5 b
	C,B	1,205.3 c	2,098.7 b
	S-D	1,742.7 a	2,615.6 a
Total	S,R,D	1,721.5 b	2,143.8 b
	C,B	1,270.2 c	2,195.3 b
	S-D	1,935.8 a	2,997.4 a

Comparisons are made only within columns, by system component. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test. Significance levels in parentheses are for tests conducted at alpha=0.10.

NCONT are exactly parallel to those occurring in the fine soil organic matter alone (Table 21).

Total System Nitrogen

The total amount of N in the entire above-ground system and the upper 15 cm of mineral soil is presented in Table 22, along with a summation of the individual component totals. For both the second and third growing seasons the S-D area had the greatest total N. During the second growing season the S,R,D area contained more total N than did the C,B area, but this difference was no longer present during the third season.

Both the C,B and S-D areas increased total system N from the second to the third growing seasons, while the S,R,D area did not (Table 23).

Available Soil Nitrogen

Mineral Nitrogen: There was no difference, by treatment area, in the amount of $CaCl_2$-extractable mineral N found in surface soils during the second growing season (Table 24). The average value for all four areas was 16.9 kg N/ha.

During the third growing season the CON area still

Table 23. Changes in total system N content (NCONT) from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	NCONT (kg/ha)
S,R,D	2	1,721.5 a
	3	2,143.8 a
C,B	2	1,270.2 b
	3	2,195.3 a
S-D	2	1,935.8 b
	3	2,997.4 a

Comparisons are made only within columns, by growing season. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

Table 24. Mineral N, potentially mineralizable N and potentially available soil N during the second and third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Mineral N (kg/ha)	Potentially Mineralizable N (kg/ha)	Potentially Available N (kg/ha)
S,R,D	2	16.4 a	118 ab	134 ab
C,B	2	14.0 a	85 b	99 b
S-D	2	20.8 a	148 a	168 a
CON	2	16.4 a	138 a	154 a
S,R,D	3	1.9 b	142 a	144 a
C,B	3	1.1 b	107 b	108 b
S-D	3	2.3 b	154 a	157 a
CON	3	11.2 a	95 b	107 b

Comparisons are made only within columns, by growing season. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

contained 11.2 kg mineral N/ha, but amounts of mineral N had dropped to between 1.1 and 2.3 kg N/ha for the treated areas (Table 24).

The amount of mineral N decreased in all treated areas, between the second and third growing season (Table 25). Decreases in mineral N were 763, 1,173 and 804% for the S,R,D, C,B and S-D areas, respectively. The CON area did not change over this period.

Potentially Mineralizable Nitrogen: Potentially mineralizable N, N_o, was higher for the S-D and CON areas during the second growing season than for the C,B area (Table 24). The mineralization potential of the S,R,D area was not different from any of the other areas.

During the third growing season N_o was highest for the disked treatment areas, and lowest for the C,B and CON areas (Table 24).

No changes in N_o, from the second to the third growing seasons, were found on any of the four areas (Table 25).

Potentially Available Nitrogen: Potentially available N is the sum of mineral N present in soils at the start of the incubation period and the N_o value. The response of potentially available N to both treatment area and time can be seen to parallel those for N mineralization potential (Tables 24, 25). This should be expected since N_o makes up

Table 25. Changes in the levels of mineral N, potentially mineralizable N and potentially available N from the second to the third growing season of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Growing Season	Mineral N (kg/ha)	Potentially Mineralizable N (kg/ha)	Potentially Available N (kg/ha)
S,R,D	2	16.4 a	118 a	134 a
	3	1.9 b	142 a	144 a
C,B	2	14.0 a	85 a	99 a
	3	1.1 b	107 a	108 a
S-D	2	20.8 a	148 a	168 a
	3	2.3 b	154 a	157 a
CON	2	16.4 a	138 a	154 a
	3	11.2 a	95 a	107 a

Comparisons are made only within columns, by treatment area. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test.

the greatest proportion of potentially available N.

Pine Growth

Trees per Hectare: More planted pines per unit area were present on the S,R,D area than on the S-D area through the third growing season (Table 26). The C,B area was intermediate between the other two areas with respect to the number of trees present. At the end of the third growing season the S,R,D, C,B and S-D areas had 1,420, 1,277 and 1,038 trees/ha, respectively. Using an alpha level of 0.10, the C,B area did not differ from the S,R,D area, but had more trees/ha than the S-D area, after the first growing season. The greater number of pines present on the intensely prepared areas was due primarily to more thorough slash removal by site preparation treatment and the resulting increase in accessable planting area on these sites.

Height: No differences in mean pine height were found among any of the treatment areas during the first three growing seasons (Table 26).

Root Collar Diameter: No root collar diameter differences were found among treatment areas during the first three

Table 26. Pine growth for the first three growing seasons of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Stand Age (years)	Trees/ha	Height (cm)	Root Collar Diameter (cm)	Volume Index (cm^3)
S,R,D	1	1,453 a	35.0 a	0.74 a(a)	24 a
C,B	1	1,297 ab	32.1 a	0.63 a(b)	16 a
S-D	1	1,100 b	35.5 a	0.65 a(ab)	18 a
S,R,D	2	1,443 a(a)	94.8 a	1.98 a	500 a
C,B	2	1,285 ab(a)	88.8 a	1.89 a	423 a
S-D	2	1,075 b(b)	92.7 a	1.66 a	387 a
S,R,D	3	1,420 a(a)	190.4 a	3.78 a	3,394 a
C,B	3	1,277 ab(a)	179.1 a	3.69 a	2,990 a
S-D	3	1,038 b(b)	177.5 a	3.23 a	2,617 a

Comparisons are made only within columns, by stand age. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test. Significance levels in parentheses are for tests conducted at alpha=0.10;

growing seasons (Table 26). Using alpha=0.10 the S,R,D area had a greater mean root collar diameter during the first growing season than did the C,B area.

Volume Index: No volume index differences were found among treatment areas for any of the first three growing seasons (Table 26).

Pine Nutrition

Cations: Potassium concentrations in pine foliage ranged from 4,267 to 4,717 mg K/kg after the second growing season, with no significant differences among treatment areas (Table 27). By the end of the third growing season, foliar K concentrations were greatest for the C,B area, with 7,717, 6,590, and 6,067 mg K/kg for the C,B, S,R,D and S-D areas, respectively (Table 27).

Calcium concentrations were the same among treatment areas after the second growing season (Table 27). By the end of the third growing season the Ca concentration in pine foliage was highest for the S,R,D area with 1,855 mg Ca/kg, followed by the S-D and C,B areas with 1,567 and 1,550 mg Ca/kg, respectively. The S-D area did not differ from the other two areas. When alpha was increased to 0.10 the S,R,D area had the highest foliar Ca concentration after the third

Table 27. Foliar nutrient status of pine leaves collected at the end of the second and third growing seasons of three loblolly pine plantations on the Virginia Piedmont.

Treatment Area	Stand Age (years)	N	P	K	Ca	Mg
		(mg/kg)				
S,R,D	2	16,336 a	1,201 b (b)	4,527 a	1,936 a	727 a
C,B	2	14,567 b	1,295 ab(b)	4,717 a	1,983 a	750 a
S-D	2	15,683 a	1,403 a (a)	4,267 a	1,933 a	717 a
S,R,D	3	15,418 a	1,317 a	6,590 b	1,855 a (a)	718 a
C,B	3	14,967 a	1,415 a	7,717 a	1,550 b (b)	700 a
S-D	3	15,417 a	1,376 a	6,067 b	1,567 ab(b)	667 a

Comparisons are made only within columns, by stand age. Means followed by the same letter are not significantly different at the alpha=0.05 level by Duncan's Multiple Range Test. Significance levels in parentheses are for tests conducted at alpha=0.10;

growing season.

Magnesium concentrations were relatively constant ranging from 667-750 mg Mg/kg (Table 27). No differences were found in foliar Mg among treatment areas, after the second or third growing seasons.

Phosphorus: Phosphorus concentrations were highest for the S-D area following the second growing season (Table 27). The C,B area was not different than the S-D or the S,R,D areas but the S-D foliar P levels were greater than those of the S,R,D area. When an alpha level of 0.10 was employed the S-D area had the highest second-year foliar P concentration of the three treatment areas. After the third growing season differences among pine foliar P concentrations were no longer present.

Nitrogen: After the second growing season the pine foliar N concentrations were highest for the disked treatment areas (Table 27). The C,B area had the lowest N concentration in pine foliage. After the third growing season there were no significant differences among treatment areas, with respect to foliar N, and all concentrations ranged between 14,967 and 15,418 mg N/kg.

DISCUSSION

Native Vegetation

Competition and Control: Competition with native vegetation has been shown to reduce growth of loblolly pine seedlings (Bacon, 1986; Knowe et al., 1985; Lantagne, 1984; Nelson et al., 1981; Stransky, 1981; and Stransky and Wilson, 1964). Generally, reductions in seedling growth associated with competition are attributed to moisture stress (Moehring and Ralston, 1967; and Tuttle et al., 1985).

Many researchers have reported better control of native vegetation with more intensive site preparation practices (Stransky, 1981; Haywood et al., 1981; DeWit and Terry, 1983; Lantagne, 1984; and Baker et al., 1974). In this study, as well, it was found that the more intensively prepared areas, the S,R,D, and C,B areas, had lower total native vegetation biomass than did the S-D area, after both the second and third growing seasons (Tables 4 and 5). Since the S,R,D and C,B areas had fewer hardwood stems to begin with (Table 1), the lower levels of native vegetation during the second and third growing seasons cannot be attributed to treatment alone.

The amount of native vegetation in loblolly pine plantations peaks near the third or fourth growing season and then declines on most sites until it comprises only a minor component of the system at stand age 10-15 years (Baker et al., 1974; Cox and Van Lear, 1985; Larsen et al., 1976; Switzer and Nelson, 1972; and Wells and Jorgensen, 1975). On these study sites the biomass of native vegetation increased from the second to the third growing season on only the S,R,D area. The other areas showed no change, indicating that a leveling off of native vegetation biomass accumulation was occurring on these sites (Table 9).

Site Stabilization: Successional species play an important role in site stabilization and nutrient retention on disturbed sites. They quickly occupy the site and rapidly accrue large amounts of mineral nitrogen which might otherwise be lost from the system (Boring et al., 1979; Marks and Bormann, 1972; Vitousek et al., 1979; and Waide and Swank, 1976).

Rapid site occupancy by successional species was noted for all three plantations in this study. The least intensively prepared area was occupied the fastest, and had the most mineral N retained at both measurement times. The highest native vegetation NCONC occurred on the disked areas (Tables 4 and 5). Similar results have been reported by House et al., (1984), and Kennedy, (1984). The combination of higher NCONC and more biomass resulted in greater NCONT levels on the S-D area.

Total N in native vegetation for the sites in this study ranged from 32.4 to 82.2 kg N/ha (Tables 4 and 5) which is in agreement with values reported in the literature, of 28 to 75 kg N/ha. All native vegetation biomass, NCONC, and NCONT values reported in this study are consistent with those reported by others (Allison, 1965; Bacon, 1986; Baker et al., 1974; Cox and Van Lear, 1985; Haywood et al., 1981; Kennedy, 1984; Larsen et al., 1976; Lockaby and Adams, 1986; and Switzer and Nelson, 1972).

Planted Pines

Site Occupancy and Nitrogen Accumulation: Planted pines generally do not make up a significant portion of site biomass, or contain significant amounts of N, relative to other system components, before the fourth or fifth growing season (Cox and Van Lear, 1985; Smith et al., 1971). After this point however, the pines take control of the site and become a major biomass component and N sink (Baker et al., 1974; Ku and Burton, 1973; Larsen et al., 1976; Nemeth, 1972; Switzer and Nelson, 1972; Switzer and Nelson, 1974; Van Lear et al., 1984; Wells and Jorgensen, 1975; and Wheeler, 1972).

The data in this study show rapidly accelerating pine biomass and N accumulation through the third growing season, but actual levels of pine biomass and total N are still small relative to other organic components of these plantation systems (Table 15). Nitrogen concentrations of pine foliage on the study areas ranged from 12,492 mg N/kg in third-year C,B tissue to 15,638 mg N/kg in second-year S,R,D area foliage (Tables 10 and 11). Foliar NCONC values reported in the literature vary widely, ranging from 8,500 to 18,100 mg N/kg (Cox and Van Lear, 1985; Metz and Wells, 1965; Pehl, 1983; Pope, 1979; Ralston and Prince, 1965; Van Lear et al., 1984; Wells, 1965; and Wilhite and McKee, 1985).

Biomass and NCONT values reported in this study are also consistent with other reported values for young loblolly pine plantations (Baker et al., 1974; Cox and Van Lear, 1985; DeBell et al., 1984; Haines and Davey, 1979; and Switzer and Nelson, 1972). Pine root biomass was reported to be near 34 kg/ha by DeBell et al. (1984) for a 2-year-old plantation, while Haines and Davey (1979) found pine root biomass values of near 15 and 19 kg/ha for one and 2-year-old plantations, respectively. The values reported in this study are between 12 and 43 kg/ha for the second growing season (Table 10). Pine leaf biomass was reported to be near 37 kg/ha in a 2-year-old stand (Haines and Davey, 1979), and 275 kg/ha in a 3-year-old stand reported by Baker et al. (1974). Pine leaf biomass in this study ranged from 42 to 115 kg/ha in the second growing season and from 131 to

387 kg/ha in the third growing season (Tables 10 and 11). Biomass of pine stem and branches has been reported to be near 41 kg/ha in the second growing season, and 275 kg/ha after the third growing season (Haines and Davey, 1979; and Baker et al., 1974). The values reported in this study are 29 to 86 kg/ha during the second growing season, and 143 to 393 kg/ha during the third growing season (Tables 10 and 11).

Forest Floor

Dynamics After Disturbance: Pre-harvest and post-site preparation levels of forest floor biomass and NCONT were presented in Table 3 from data compiled by Fox (1984). Prior to harvest the S-D area had biomass and NCONT values which were quite similar to those of the CON area. The C,B area had higher biomass and NCONT levels and the S,R,D area had the highest of all.

After site preparation the S,R,D area showed a substantial reduction in both biomass and NCONT (Table 2), presumably due in large part to raking losses. As of the second growing season both biomass, and N levels were even lower, but were on the upswing again during the third growing season (Table 17).

The biomass, and NCONT of the forest floor on the C,B area rose slightly after site preparation due to the deposition of ash and unburned logging debris. Much of this ash was lost by the second growing season when forest floor biomass, and NCONT were only 30% of post-site preparation levels. But on this area too, a recovery was noted during the third growing season (Table 17).

The S-D area showed a large increase in forest floor debris and N following site preparation. Levels had declined by the second growing season, presumably due to rapid decomposition of high quality organic substrate following treatment. Levels of both biomass and NCONT still surpassed pre-harvest levels during the second growing season and increased again substantially during the third growing season (Table 17).

Most information in the literature on forest floor development is not segregated by site preparation treatment, and generally is for mid to late-rotation age stands. The values for 11 to 32 year-old loblolly pine stands in the Southeast range from 10,830 to 35,111 kg/ha for total biomass, and 55-416 kg N/ha for NCONT (Jorgensen et al., 1975; Jorgensen et al., 1980; Larsen et al., 1976; Metz et al., 1970; Pope, 1979; Switzer and Nelson, 1972; Van Lear and Goebel, 1976; and Wells and Jorgensen, 1975). Forest floor NCONT in five and 10-year-old stands was reported to be 15 and 75 kg N/ha, respectively, by Switzer and Nelson (1972). The values reported in this study are considerably higher, with only the C,B area being below their 10-year level during the third growing season (Table 16). This may be due to the fact that much of the litter and forest floor material in the third growing season originated from hardwood or herbaceous species, which typically produce larger amounts of high N-concentration biomass, than do pines (Fisher and Stone, 1969; and Wells et al., 1972).

Initially, in disturbed forest stands, the forest floor accrues biomass and nutrients and does not play a major role in plant nutrition. Jorgensen et al. (1980) found that only 34% of N assimilated annually in the above-ground biomass of an 11-year-old loblolly pine stand originated in the forest floor, as compared to 86% in a 32-year-old stand. This illustrates the importance of the forest floor to long-term N nutrition, and points out the importance of the soil as an interim source of plant available N after major disturbance.

Soil Nitrogen

Total Nitrogen: Soil N concentrations reported in this study were higher than those generally reported in the literature. Commonly reported values range from 450-978 mg N/kg soil (Fox, 1984; Haines and Haines, 1979; Metz et al., 1970; and Wells, 1965). Soil NCONC values for this study ranged from 700-1666 mg N/kg (Table 20). Values of total soil N calculated for these study areas are consistent with those reported by others (Haines and Haines, 1979; Jorgensen et al., 1975; Larsen et al., 1976; Metz et al., 1970; Switzer et al., 1968; Tuttle et al., 1985; Vitousek and Matson, 1985; Wells, 1965; and Wells and Jorgensen, 1977).

Nitrogen Availability: Vitousek and Matson (1985) reported that initial N availability levels were associated with the degree of N loss experienced during harvest and site preparation. They found higher levels of available N in soils on chop and burn sites than for those on shear, rake, disk sites during the second growing season. Levels of both KCl extractable, and mineralizable N had declined substantially by the fifth growing season. Morris and Pritchett (1982 and 1983) reported initially high levels of available N after harvest and site preparation, and reduced amounts of potentially mineralizable N by the second growing season. They found that even where N losses had occurred during site preparation, N availability increased, due to more optimal conditions for mineralization of material that was left behind.

For the sites examined in this study, $CaCl_2$-extractable N declined on all treated areas from the second to the third growing seasons. Comparable, but not statistically significant, increases were noted in potentially mineralizable N levels over the same period. Levels of potentially mineralizable N remained elevated over pre-harvest levels, as of the third growing season (Table 25).

Pine Growth and Nutrition

Pine Growth: Height, root collar diameter, and volume estimates for young loblolly pine, in the literature, span a wide variety of pine genotypes, stand establishment practices, soil types, and climatic conditions, and are therefore extremely variable. Tree growth values presented for all treatment areas in this study are consistent with values reported by others for young stands (Stransky, 1981; Knowe et al., 1985; Nelson et al., 1981; Schmidtling, 1973; Powers and Rowan, 1983; Nelson et al., 1970; DeWit and Terry, 1983; Metz and Wells, 1965; Smith et al., 1963; Stafford et al., 1985; Haines and Haines, 1979; and Haines and Davey, 1979). No treatment differences were noted in this study, after the first three growing seasons, with respect to pine height, root collar diameter, or volume index (Table 26). However, the S,R,D area had the greatest pine stem biomass during both the second and third growing seasons (Tables 10 and 11).

Pine Nutrition: Foliar concentrations of N, P, K, Ca, and

Mg for this study (Table 27) are comparable or slightly higher than the average values reported in the literature (Jorgensen et al., 1975; Pehl, 1983; Stafford et al., 1985; Switzer et al., 1968; Van Lear and Goebel, 1976; and Wells, 1965). Even the lowest concentrations found in this study are well above the ranges of critical concentrations for loblolly pine (Switzer and Nelson, 1972) or for slash pine or radiata pine (Pritchett, 1979). It is therefore unlikely that nutritional deficiencies existed on any of the study areas during the second or third growing season.

SUMMARY AND CONCLUSIONS

Significant amounts of site N were removed from the S,R,D and C,B areas during site preparation. No organic material or N was removed from the S-D site during site preparation. For this reason, it can be stated conclusively that the S-D treatment is a more N-conservative treatment than either of the other two treatments. The S-D treatment area had higher amounts of N in native vegetation, forest floor, and soil in the third growing season than did either of the other treatment areas. The S-D area also had the highest levels of potentially available N during the third growing season. The overall N status of the S-D area was clearly superior to the other areas, yet pine foliage N concentrations were high for all areas and no evidence existed to suggest existing or impending nutrient deficiencies on any site. Pine growth was acceptable on all sites but was best on the intensively prepared S,R,D and C,B areas (Table 11).

The data presented in this study, as well as that from numerous others, suggests that intensive site preparation results in better initial growth of loblolly pine. This is primarily due to more efficient competition control and the improved soil moisture status that results. But what is not clear is whether or not this initial growth advantage will be maintained for the entire rotation, and if so, whether it will have been worth the expense of added establishment cost and wasted nutrient capital which also result from intensive site preparation.

It is logical that, on sites with adequate N reserves, some N can be lost during stand establishment with no apparent detrimental effect, and it is likely that this occurred on these sites. But it is also logical that such trends cannot continue forever. Even the best sites have finite supplies of topsoil and nutrients and will be depleted, and become less productive, under repeated use of wasteful management practices.

LITERATURE CITED

Adams, J.A. 1978. Long-term aspects of nutrient loss from forest soils and ecosystems. N. Z. J. For. 23:10-20.

Allison, F.E. 1965. Decomposition of wood and bark sawdusts in soil, nitrogen requirements, and effects on plants. USDA Ag. Res. Serv. Tech. Bul. No. 1332. 57 pp.

Arbour, S.J., and A.W. Ezell. 1981. Effect of mechanical site preparation treatments on height growth of loblolly pine in East Texas sandy soils. pp. 96-99. In J.P. Barnett (ed.) Proc. Fir. Bien. S. Silv. Res. Conf., Atlanta, Ga. USDA For. Serv. Gen. Tech. Rep. SO-34.

Bacon, C.G. 1986. Interspecific competition in young loblolly pine plantations on the Virginia Piedmont. Ph.D. Dissertation, Virginia Tech, Blacksburg. 103 pp.

Baker, J.B., G.L. Switzer, and L.E. Nelson. 1974. Biomass production and nitrogen recovery after fertilization of young loblolly pines. Soil Sci. Soc. Am. Proc. 38:958-961.

Ballard, R. 1978. Effect of slash and soil removal on the productivity of second rotation radiata pine on a pumice soil. N. Z. J. For. Sci. 8:248-258.

Balmer, W.E., and N.G. Little. 1978. Site preparation methods. pp. 60-64. In T. Tippin (ed.) Proceedings: A Symposium on Principles of Maintaining Productivety on Prepared Sites. March 21-22, 1978. Starkville, Miss. USDA For. Serv. and Miss. State Univ.

Bengtson, G.W. 1981. Nutrient conservation in forestry: a perspective. S. J. Appl. For. 5:50-59.

Boring, L.R., Monk, C.D., and W.T. Swank. 1979. The role of successional species in nutrient conservation on a clearcut Appalachian watershed. p. 392 (abstract). In Proc. Impact of Intensive Harvesting on Forest Nutrient Cycling. Aug. 13-16, 1979. Syracuse, N.Y.

Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen-Total. pp. 595-624. In A.L. Page, R.H. Miller, and D.R. Keeney (eds.) Methods of Soil Analysis. Part 2 - Chemical and Microbiological Properties. Sec. Ed. Am. Soc. Agron., Madison, Wis.

Burger, J.A., and R.A. Kluender. 1982. Site preparation-Piedmont. pp. 58-74. In R.C. Kellison and S.A. Gingrich (eds.) Symposium on the Loblolly Pine Ecosystem (East Region). Dec. 8-10, 1982. Raleigh, N.C. USDA For. Serv. and N.C. State Univ.

Burger, J.A., and W.L. Pritchett. 1984. Effects of clearfelling and site preparation on nitrogen mineralization in a southern pine stand. Soil Sci. Soc. Am. J. 48:1432-1437.

Burns, E.B. 1977. Prescribed burning for site preparation. pp. 4-5. In H.L. Williston (ed.) Proceedings Site Preparation Workshop (West). April 27-28, 1977. Alexandria, La. USDA For. Serv.

Campbell, C.A., D.W. Stewart, W. Nicholaichuk, and V.O. Biederbeck. 1974. Effect of growing season soil temperature, moisture, and NH_4-N on soil nitrogen. Can. J. Soil Sci. 54:403-412.

Cassman, K.G., and D.N. Munns. 1980. Nitrogen mineralization as affected by soil moisture, temperature, and depth. Soil Sci. Soc. Am. J. 44:1233-1237.

Coile, T.S., and F.X. Schumacher. 1953. Relation of soil properties to site index of loblolly and shortleaf pines in the Piedmont region of the Carolinas, Georgia, and Alabama. J. For. 51:739-744.

Covington, W.W., and S.S. Sackett. 1986. Effect of periodic burning on soil nitrogen concentrations in ponderosa pine. Soil Sci. Soc. Am. J. 50:452-457.

Cox, S.K., and D.H. Van Lear. 1985. Biomass and nutrient accretion on Piedmont sites following clearcutting and natural regeneration of loblolly pine. pp. 501-506. In E. Shoulders (ed.) Proc. Third Bien. S. Silv. Res. Conf., Atlanta, Ga., USDA For. Serv. Gen. Tech. Rep. SO-54.

Daniel, T.W., J.A. Helms, and F.S. Baker. 1979. Principles of Silviculture. Sec. Ed. McGraw-Hill Book Co. 500 pp.

DeBell, D.S., D.D. Hook, W.H. McKee Jr., and J.L. Askew. 1984. Growth and physiology of loblolly pine roots under various water table level and phosphorus treatments. For. Sci. 30:705-714.

DeBell, D.S., and C.W. Ralston. 1970. Release of nitrogen by burning light forest fuels. Soil Sci. Soc. Am. Proc. 34:936-938.

DeWit, J.N., and T.A. Terry. 1983. Site preparation effects on early loblolly pine growth, hardwood competition and soil physical properties. pp. 40-47. In E.P. Jones, Jr. (ed.) Proc. Sec. Bien. S. Silv. Res. Conf., Atlanta, Ga. USDA For. Serv. Gen. Tech. Rep. SE-24.

Fisher, R.F., and E.L. Stone. 1969. Increased availability of nitrogen and phosphorus in the root zone of conifers. Soil Sci. Soc. Am. Proc. 33:955-961.

Flinn, D.W., P. Hopmans, P.W. Farrell, and J.M. James. 1979. Nutient loss from the burning of Pinus radiata logging residue. Aust. For. Res. 9:17-23.

Flinn, D.W., R.O. Squire, and P.W. Farrell. 1980. The role of organic matter in the maintenance of site productivity on sandy soils. N. Z. J. For. 25:229-236.

Fogg, D.N., and N.T. Wilkinson. 1958. The colorometric determination of phosphorus. Analyst 83:406-414.

Fox, T.R. 1984. The impact of harvesting and site preparation on nutrient dynamics, soil erosion and stream water quality in the Virginia Piedmont. M.S. Thesis, Virginia Tech, Blacksburg. 296 pp.

Glass, G.G., Jr. 1976. The effects from rootraking on an upland Piedmont loblolly pine (Pinus taeda L.) site. Tech. Rep. No. 56. N.C. State Forest Fertilization Cooperative. N.C. State Univ. 44 pp.

Grier, C.C. 1975. Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Can. J. For. Res. 5:599-607.

Haines, S.G., and C.B. Davey. 1979. Biomass response of loblolly pine to selected cultural treatments. Soil Sci. Soc. Am. J. 43:1034-1038.

Haines, L.W., and S.G. Haines. 1979. Fertilization increases growth of loblolly pine and ground cover vegetation on a Cecil soil. For. Sci. 25:169-174.

Haines, L.W., Sr., T.E. Maki, and S.G. Sanderford. 1975. The effect of mechanical site preparation treatments on soil productivity and tree (Pinus taeda L. and P. elliottii Engelm. var elliottii) growth. pp. 379-395. In B. Bernier and C.H. Winget (eds.) Forest Soils and Forest Land Management: Proc. Fourth N. Amer. For. Soils Conf., Quebec, Canada.

Harwood, C.E., and W.D. Jackson. 1975. Atmospheric losses of four plant nutrients during a forest fire. Aust. For. 38:92-99.

Haywood, J.D., R.E. Thill, and J.D. Burton. 1981. Intensive site preparation affects loblolly pine growth on upland sites. pp. 224-231. In Forest Regeneration. Proc. Am. Soc. Ag. Engr. Symp. on Engineering Systems for Forest Regeneration. Mar., 1981.

Hewlett, J.D., and R. Doss. 1984. Forests, floods, and erosion: a watershed experiment in the southeastern Piedmont. For. Sci. 30:424-434.

Hewlett, J.D., and W.L. Nutter. 1969. An Outline of Forest Hydrology. Univ. Ga. Press. Athens, Ga. 137 pp.

House, G.J., B.R. Stinner, D.A. Crossley, Jr., E.P. Odum, and G.W. Langdale. 1984. Nitrogen cycling in conventional and no-tillage agroecosystems in the Southern Piedmont. J. Soil Water Cons. 39:194-200.

Jorgensen, J.R., C.G. Wells, and L.J. Metz. 1980. Nutrient changes in decomposing loblolly pine forest floor. Soil Sci. Soc. Am. J. 44:1307-1314.

Jorgensen, J.R., C.G. Wells, and L.J. Metz. 1975. The nutrient cycle: key to continuous forest production. J. For. 73:400-403.

Keeves, A. 1966. Some evidence of loss of productivity with successive rotations of Pinus radiata in the southeast of South Australia. Aust. For. 30:51-63.

Kennedy, H.E., Jr. 1984. Hardwood growth and foliar nutrient concentrations best in clean cultivation treatments. For. Ecol. Mgmt. 8:117-126.

Klemmedson, J.O., A.M. Schultz, H. Jenny, and H.H. Biswell. 1962. Effects of prescribed burning of forest litter on total soil nitrogen. Soil Sci. Soc. Am. Proc. 26:200-202.

Knight, H. 1966. Loss of nitrogen from the forest floor by burning. For. Chron. 42:149-152.

Knowe, S.A., L.R. Nelson, D.H. Gjerstad, B.R. Zutter, G.R. Glover, P.J. Minogue, and J.H. Dukes, Jr. 1985. Four-year growth and development of planted loblolly pine on sites with competition control. S. J. Appl.

For. 9:11-15.

Kodama, A.E., and D.H. Van Lear. 1980. Prescribed burning and nutrient cycling relationships in young loblolly pine plantations. South. J. Appl. For. 4:118-121.

Ku, T.T., and J.D. Burton. 1973. Dry matter and minerals in loblolly pine plantations on four Arkansas soils. Ark. Acad. Sci. Proc. 27:21-23.

Lantagne, D.O. 1984. An evaluation of site preparation methods for the regeneration of loblolly pine in the South Carolina and Georgia Piedmont. Ph.D. Dissertation, Virginia Tech, Blacksburg. 197 pp.

Larsen, H.S., M.C. Carter, J.W. Gooding, and D.M. Hyink. 1976. Biomass and nitrogen distribution in four 13-year-old loblolly pine plantations in the Hilly Coastal Plain of Alabama. Can. J. For. Res. 6:187-194.

Lewis, W.W., Jr. 1974. Effects of fire on nutrient movement in a South Carolina pine forest. Ecology 55:1120-1127.

Lockaby, B.G., and J.C. Adams. 1986. Dry weight and nutrient content of fuelwood biomass from loblolly pine stands in North Louisiana. For. Sci. 32:3-9.

Marks, P.L., and F.H. Bormann. 1972. Revegetation following forest cutting: mechanisms for return to steady-state nutrient cycling. Science 176:914-915.

McGee, C.E. 1976. Maximum soil temperatures on clearcut forest land in western North Carolina. U.S. For. Serv. Res. Note SE-237. 7 pp.

Metz, L.J., and C.G. Wells. 1965. Weight and nutrient content of the aboveground parts of some loblolly pines. U.S. For. Serv. Res. Pap. SE-17. 20 pp.

Metz, L.J., C.G. Wells, and P.P. Kormanik. 1970. Comparing the forest floor and surface soil beneath four pine species in the Virginia Piedmont. USDA For. Serv. Res. Pap. SE-55. 8 pp.

Miller, H.G. 1983. Maintenance and improvement of forest productivity: an overview. pp. 280-285. In R. Ballard and S.P. Gessel (eds.) I.U.F.R.O. Symp. For. Site Cont. Prod., Aug. 22-28, 1982., Seattle, Wash.

Moehring, D.M., and C.W. Ralston. 1967. Diameter growth of loblolly pine related to available soil moisture and rate of soil moisture loss. Soil Sci. Soc. Am. Proc. 31:560-562.

Morris, L.A., and W.L. Pritchett. 1983. Effects of site preparation on Pinus elliottii-P. palustris flatwoods forest soil properties. pp. 243-251. In R. Ballard and S.P. Gessel (eds.) I.U.F.R.O. Symp. For. Site Cont. Prod., Aug. 22-28, 1982., Seattle, Wash.

Morris, L.A., and W.L. Pritchett. 1982. Nutrient storage and availability in two managed pine flatwoods forests. pp. 17-26. In S. Coleman, A. Mace, and B. Swindel (eds.) Impacts of Intensive Forest Management Practices Symp. Proc., Mar. 9-10, 1982., Gainesville, Fla.

Morris, L.A., W.L. Pritchett, and B.F. Swindel. 1983. Displacement of nutrients into windrows during site preparation of a flatwood forest. Soil Sci. Soc. Am. J. 47:591-594.

Neary, D.G., L.A. Morris, and B.F. Swindel. 1984. Site preparation and nutrient management in southern pine forests. pp. 121-144. In E.L. Stone (ed.) Forest Soils & Treatment Impacts. Proc. Six. N. Amer. For. Soil Conf. June, 1983. Knoxville, Tenn.

Nelson, L.E., G.L. Switzer, and W.H. Smith. 1970. Dry matter and nutrient accumulation in young loblolly pine (Pinus taeda L.). pp. 261-274. In C.T. Youngberg and C.B. Davey (eds.) Tree Growth and Forest Soils. Proc. Third N. Amer. For. Soils Conf., Oregon State Univ. Press. Corvallis, Ore.

Nelson, L.R., R.C. Pedersen, L.A. Autry, S. Dudley, and J.D. Walstad. 1981. Impacts of herbaceous weeds in young loblolly pine plantations. S. J. Appl. For. 5:153-158.

Nemeth, J.C. 1972. Dry matter production and site factors in young loblolly (Pinus taeda L.) and slash pine (Pinus elliottii Engelm.) plantations. Ph.D. Dissertation, N.C. State Univ., Raleigh.

Nutter, W.L., and J.E. Douglass. 1978. Consequences of harvesting and site preparation in the Piedmont. pp. 65-72. In T. Tippin (ed.) Proceedings: A Symposium on Principles of Maintaining Productivity on Prepared Sites. Mar. 21-22, 1978., Starkville, Miss.

Pehl, C.E. 1983. Site preparation influences on young loblolly pine plantations in East Texas. S. J. Appl. For. 7:140-145.

Pehl, C.E., and R.L. Bailey. 1983. Performance to age ten of a loblolly pine plantation on an intensively prepared site in the Georgia Piedmont. For. Sci. 29:96-102.

Pope, P.E. 1979. The effect of genotype on biomass and nutrient content in 11-year-old loblolly pine plantations. Can. J. For. Res. 9:224-230.

Powers, H.R., Jr., and S.J. Rowan. 1983. Influence of fertilization and ectomycorrhizae on loblolly pine growth and susceptibility to fusiform rust. S. J. Appl. For. 7:101-103.

Powers, R.F. 1984. Estimating soil nitrogen availability through soil and foliar analysis. pp. 353-379. In E. L. Stone (ed.) Forest Soils and Treatment Impacts. Proc. Six. N. Amer. For. Soils Conf., June 19-23, 1983., Knoxville, Tenn.

Pritchett, W.L. 1979. Properties and Management of Forest Soils. John Wiley & Sons., New York. 500 pp.

Pritchett, W.L., and C.G. Wells. 1978. Harvesting and site preparation increase nutrient mobilization. pp. 98-110. In T. Tippin (ed.) Proceedings: A Symposium on Principles of Maintaining Productivity on Prepared Sites. Mar. 21-22, 1978. Starkville, Miss. USDA For. Serv. and Miss. State Univ.

Pritchett, W.L., and L.A. Morris. 1982. Implications of intensive forest management for long-term productivity of Pinus elliottii flatwoods. pp. 27-34. In S.S. Coleman, A.C. Mace, Jr., and B.F. Swindel (eds.) Impacts of Intensive Forest Management Practices Symposium Proceedings. Univ. Fla.

Ralston, C.W., and A.B. Prince. 1965. Accumulation of dry matter and nutrients by pine and hardwood forests in the Lower Piedmont of North Carolina. pp. 77-94. In C.T. Youngberg (ed.) Forest-Soil Relationships in North America, Proc. Second N. Amer. For. Soils Conf., Oregon State Univ. Press, Corvallis, Ore.

Schmidtling, R.C. 1984. Early intensive culture affects long-term growth of loblolly pine trees. For. Sci. 30:491-498.

Schmidtling, R.C. 1973. Intensive culture increases growth without affecting wood quality of young southern pines. Can. J. For. Res. 3:565-573.

Schultz, R.P. 1975. Intensive culture of southern pines: maximum yields on short rotations. Iowa State Journal of Research. 49:325-337.

Smith, W.H., L.E. Nelson, and G.L. Switzer. 1971. Development of the shoot system of young loblolly pine. II. Dry matter and nitrogen accumulation. For. Sci. 17:55-62.

Smith, W.H., L.E. Nelson, and G.L. Switzer. 1963. The characterization of dry matter and nitrogen accumulation by loblolly pine (Pinus taeda L.) on poor sites. Soil Sci. Soc. Am. Proc. 27:465-468.

Squire, R.O. 1983. Review of second rotation silviculture of P. radiata plantations in southern Australia: establishment practice and expectations. pp. 130-137. In R. Ballard and S.P. Gessel (eds.) I.U.F.R.O. Symp. For. Site Cont. Prod., Aug. 22-28, 1982., Seattle, Wash.

Stafford, C.W., J.L. Torbert, and J.A. Burger. 1984. An evaluation of site preparation methods for loblolly pine regeneration on the Piedmont. pp. 57-60. In E. Shoulders (ed.) Proceedings of the Third Biennial Southern Silvicultural Research Conference. Nov. 7-8, 1984. Atlanta, Ga.

Stanford, G., and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stone, E.L., and G.M. Will. 1965. Nitrogen deficiency of second generation radiata pine in New Zealand. pp. 117-139. In C.T. Youngberg (ed.) Forest-Soil Relationships in North America, Proc. Second N. Amer. For. Soils Conf., Oregon State Univ. Press, Corvallis, Ore.

Stransky, J.J. 1981. Site preparation effects on soil bulk density and pine seedling growth. S. J. Appl. For. 5:176-180.

Stransky, J.J., J.H. Roese, and K.G. Watterston. 1985. Soil properties and pine growth affected by site preparation after clearcutting. S. J. Appl. For. 9:40-43.

Stransky, J.J., and D.R. Wilson. 1964. Terminal elongation of loblolly and shortleaf pine seedlings under soil moisture stress. Soil Sci. Soc. Am. Proc. 28:439-440.

Swindel, B.F., L.F. Conde, and J.S. Smith. 1986. Windrowing affects early growth of slash pine. S. J. Appl. For. 10:81-84.

Switzer, G.L., and L.E. Nelson. 1974. Maintenance of productivity under short rotations. pp.365-390. In FAO-I.U.F.R.O. Int. Symp. For. Fert., Dec. 3-7,1973., Paris.

Switzer, G.L., and L.E. Nelson. 1972. Nutrient accumulation and cycling in loblolly pine (*Pinus taeda* L.) plantation ecosystems: the first twenty years. Soil Sci. Soc. Am. Proc. 36:143-147.

Switzer, G.L., L.E. Nelson, and W.H. Smith. 1966. The characterization of dry matter and nitrogen accumulation by loblolly pine (*Pinus taeda* L.). Soil Sci. Soc. Am. Proc. 30:114-119.

Switzer, G.L., L.E. Nelson, and W.H. Smith. 1968. The mineral cycle in forest stands. pp. 1-9. In Forest Fertilization...theory and practice. Tenn. Val. Auth., Muscle Shoals, Ala.

Trousdell, K.B. 1970. Disking and prescribed burning: sixth-year residual effects on loblolly pine and competing vegetation. USDA For. Serv. Res. Note SE-133. 6 pp.

Tuttle, C.L., M.S. Golden, and R.S. Meldahl. 1985. Surface soil removal and herbicide treatment: Effects on soil properties and loblolly pine early growth. Soil Sci. Soc. Am. J. 49:1558-1562.

Van Lear, D.H., and N.B. Goebel. 1976. Leaf fall and forest floor characteristics in loblolly pine plantations in the South Carolina Piedmont. Soil Sci. Soc. Am. J. 40:116-119.

Van Lear, D.H., W.T. Swank, J.E. Douglass, and J.B. Waide. 1983. Forest management practices and the nutrient status of a loblolly pine plantation. pp. 252-258. In R. Ballard and S.P. Gessel (eds.) I.U.F.R.O. Symp. For. Site Cont. Prod., Aug. 22-28, 1982., Seattle, Wash.

Van Lear, D.H., J.B. Waide, and M.J. Teuke. 1984. Biomass and nutrient content of a 41-year-old loblolly pine (*Pinus taeda* L.) plantation on a poor site in South Carolina. For. Sci. 30:395-404.

Vitousek, P.M., H.L. Allen, and P.A. Matson. 1983. Impacts of management practices on soil nitrogen status. pp.

25-39. *In* E.L. Ellwood and E.W. Ross (eds.) Maintaining Forest Site Productivity. Proc. First Reg. Tech. Conf. Jan. 27-28, 1983. Myrtle Beach, S.C. Soc. Am. For.

Vitousek, P.M., J.R. Gosz, C.C. Grier, J.M. Melillo, W.A. Reiners, and R.L. Todd. 1979. Nitrate losses from disturbed ecosystems. Sci. 204:469-474.

Vitousek, P.M., and P.A. Matson. 1985. Intensive harvesting and site preparation decrease soil nitrogen availability in young plantations. S. J. Appl. For. 9:120-125.

Waide, J.B., and W.T. Swank. 1976. Nutrient recycling and the stability of ecosystems: implications for forest management in the southern U.S.. Soc. Am. For. Proc. 1975:404-424.

Wells, C.G. 1971. Effects of prescribed burning on soil chemical properties and nutrient availability. pp. 86-97., *In* Prescribed Burning Symp. Proc., Apr. 14-16, 1971., Charleston, S.C.

Wells, C.G. 1983. Impact of management practices on nutrient cycling and losses. pp. 40-51. *In* E.L. Ellwood and E.W. Ross (eds.) Maintaining Forest Site Productivity. Proc. First Reg. Tech. Conf. Jan. 27-28, 1983. Myrtle Beach, S.C. Soc. Am. For.

Wells, C.G. 1965. Nutrient relationships between soils and needles of loblolly pine (*Pinus taeda*). Soil Sci. Soc. Am. Proc. 29:621-624.

Wells, C.G., and J.R. Jorgensen. 1975. Nutrient cycling in loblolly pine plantations. pp. 137-158. *In* B. Bernier and C.H. Winget (eds.) Forest Soils and Forest Land Management: Proc. Fourth N. Amer. For. Soils Conf., Quebec, Canada.

Wells, C.G., and J.R. Jorgensen. 1977. Nutrient cycling in loblolly pine-silvicultural implications. pp. 89-93. TAPPI Joint Forest Biology/Wood Chemistry Conf., June 20-22, 1977., Madison, Wis.

Wells, C.G., and L.J. Metz. 1963. Variation in nutrient content of loblolly pine needles with season, age, soil, and position on the crown. Soil Sci. Soc. Am. Proc. 27:90-93.

Wells, C.G., and L.A. Morris. 1982. Maintenance and improvement of soil productivity. pp. 306-318. *In* R.C. Kellison and S. Gingrich (eds.) Symposium on the

Loblolly Pine Ecosystem (East Region). Dec. 8-10, 1982. Raleigh, N.C. USDA For. Serv. and N.C. State Univ.

Wells, C.G., D. Whigham, and H. Lieth. 1972. Investigation of mineral nutrient cycling in upland Piedmont forest. J. Elisha Mitchell Scient. Soc. 88:66-78.

Wheeler, G.L. 1972. The effects of fluorine on the cycling of calcium, magnesium, and potassium in pine plantations of eastern North Carolina. Ph.D. Dissertation, N.C. State Univ., Raleigh.

Whyte, A.G. 1973. Productivity of first and second crops of Pinus radiata on the Moutere gravel soils of Nelson. N. Z. J. For. 18:87-103.

Wilhite, L.P., and W.H. McKee, Jr. 1985. Site preparation and phosphorus application alter early growth of loblolly pine. S. J. Appl. For. 9:103-109.

Wollum, A.G. II, and C.B. Davey. 1975. Nitrogen accumulation, transformation, and transport in forest soils. pp. 67-106. In B. Bernier and C.H. Winget (eds.) Forest Soils and Forest Land Management: Proc. Fourth N. Amer. For. Soils Conf., Quebec, Canada.

York, M., and E. Buckner. 1983. Prescribed fire for hardwood control and fuel reduction in pine plantations of the Cumberland Plateau. pp. 74-78. In E.P. Jones, Jr. (ed.) Proc. Sec. Bien. S. Silv. Res. Conf., Atlanta, Ga., USDA For. Serv. Gen. Tech. Rep. SE-24.

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