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Influence of variable organic matter retention on nutrient availability in a 10-year-old loblolly pine plantation

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ABSTRACT

The effects of varying forest floor and slash retention at time of regeneration were evaluated 10 years after the establishment of a loblolly pine plantation near Millport, Alabama. Treatments included removing, leaving unaltered, or doubling the forest floor and slash material. Forest floor and litterfall mass and nutrient concentrations, available soil N, foliar nutrient concentrations and stand yield were all impacted by the treatments. Forest floor mass and nutrient contents in the doubled treatment were significantly greater than the other two treatments. The doubled treatment accumulated 25, 45 and 350% more forest floor mass and 56, 56, and 310% more N than the control treatment in the Oi, Oe, and Oa layers, respectively. The other nutrients followed similar patterns. Potentially mineralized NO_3^--N in the mineral soil was also significantly higher in the doubled treatment. The positive effect of doubling the forest floor on soil N availability was reflected in greater foliage production, 30% more litterfall and 25% more stand yield for this treatment. This study shows that increasing the forest floor retention has resulted in increased nutrient availability and improved tree growth.

1. Introduction

Intensively managed pine plantations provide an efficient way to produce the wood and fiber required to satisfy the demands of our growing society (Sedjo, 2001). The productivity of these plantations strongly depends on the ability of the soils to provide essential nutrients. However, productivity of most loblolly pine plantations in the southeast USA is limited by low soil nutrient availability (Fox et al., 2007). To overcome these limitations, fertilizer application has become common practice to increase leaf area and stemwood production (Albaugh et al., 2007). With the resulting greater leaf area, litterfall is increased, and a larger forest floor typically accumulates since increases in litterfall are not matched by similar increases in forest floor decomposition and nutrient release (Gurlevik et al., 2003). Nitrogen (N) accumulations contained in the forest floor of 100, 300, and up to 700 kg-N ha^{-1} have been reported for loblolly pine plantations in the southeast US at ages 15 years (Switzer and Nelson, 1972), 22 years (Tew et al., 1986), and 34 years (Markewitz et al., 1998), respectively. Similarly, forest floor N and phosphorus (P) accumulations were reported to be 1.7–3.2 and 1–1.7 times greater than the above-ground biomass N and P contents, respectively (Tew et al., 1986; Markewitz et al., 1998). Increases of forest floor mass and N content due to fertilization in the range of 200% and 400%, respectively are not uncommon in very responsive sites of the Southeast US (Rojas, 2005). Nutrient accumulation in the forest floor, at levels comparable or greater than those occurring in the above-ground biomass highlight the importance of the forest floor as a source or sink of nutrients (Piatek and Allen, 2001) for current and subsequent rotations.

Nutrient cycling studies have shown that the forest floor mineralizes (Switzer and Nelson, 1972; Jorgensen et al., 1980; Covington, 1981), as well as retains nutrients through immobilization (Vitousek and Matson, 1985; Piatek and Allen, 2001), making the forest floor both a sink and a source of nutrients depending on the nutrient, tissue type (e.g. branches, foliage), and time since deposition. Climatic factors such as temperature and moisture have explained most of the differences in decomposition (Carey et al., 1982; Cortina and Vallejo, 1994) especially in recently deposited material (McHale et al., 1998; Rustad and Fernandez, 1998) at the regional level. However, at the local level, litter quality (Berg et al., 1993; De Santo et al., 1993; Piatek and Allen, 2001), lignin content (Berg, 1986; Scott and Binkley, 1997; Sariyildiz and Anderson, 2003), and the type of colonizing fungal species during microbial succession (Cox et al., 2001) have been associated with differences in decomposition rates. Based on these factors, the amount and quality of forest floor in a stand are expected to influence its decomposition and nutrient dynamics, thus the nutritional status of the stand as a whole.

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Forest floor removal was common with past site preparation practices in loblolly pine plantations such as shearing, piling, and burning, and was found to have either no impact (Vitousek and Matson, 1985; Fox et al., 1986; Li et al., 2003) or negatively influence (Burger and Pritchett, 1984) nutrient availability. Currently, more widely used practices include strip shearing, bedding, and hardwood control with herbicides, all of which retain the forest floor on site. However, little information is available concerning the effects of forest floor retention on nutrient availability and productivity in loblolly pine plantations. Unfortunately in many residue management studies, the inclusion of tillage (bedding or disking) in several but not all treatment combinations confounds the interpretation of organic matter removal and/or retention. Furthermore, few reported studies (Smith et al., 2000; Mendham et al., 2003; Tutua et al., 2008 for plantations of *Pinus radiata*, *Eucalyptus globulus*, and *Pinus elliotti* × *Pinus caribaea* hybrid, respectively) and none in loblolly pine have included treatments with organic matter additions above levels originally on the site, a condition which would more closely mimic forest floor accumulations obtained with current fertilization practices.

We hypothesized that on nutrient-poor sites supporting loblolly pine, the retention of organic matter could have positive effects on growth and productivity if nutrients retained on site contribute to nutrient levels in the soil. Specific objectives of our study were to assess the effects of varying organic matter retention treatments imposed at time of regeneration on: forest floor and litterfall mass, nutrient concentrations and contents, available N in the mineral soil, foliar nutrition and stand yield 10 years after treatment imposition.

2. Materials and methods

2.1. Site and study description

The study site was located in the Upper Coastal Plain physiographic province in Lamar County near the town of Millport, Alabama (33°32′22.87″N, 88°7′7.53″W). Mean annual temperature (1971–2000) is 15.9 °C with mean monthly temperatures ranging from 4.6 °C in January to 26.3 °C in July. Mean annual precipitation is 1,398 mm with a fairly uniform distribution throughout the year. September is the driest month with 85 mm, and January is the wettest month with 157 mm (NOAA, 2003). The soils are deep, well-drained Ruston soil series (fine-loamy, siliceous, semiactive, thermic Typic Paleudults). The A horizon is sandy loam with an average depth of 23 cm over a clay loam Bt horizon.

The study was established in 1994 by Weyerhaeuser Co. after harvesting a 34-year-old loblolly pine plantation (site index of 17 m at age 25). Twelve 0.16 ha plots were established in a randomized complete block design with 3 treatments and 4 blocks. Blocking was done against the slope to account for possible site differences. The three treatments imposed after harvest and immediately before planting the current rotation included removed treatment, doubled treatment and control. In the removed treatment, all forest floor, understory, and slash material, comprised mostly of small branches, were removed using rakes and tarps. In the doubled treatment, all the material coming from the removed treatment plots was uniformly applied to the plots. On average, 118.2 Mg ha^{-1} of dry matter where displaced from the removed treatments to the doubled treatments of which, 72%, 9%, and 19% were forest floor, understory, and pine slash respectively. In the control treatment, the understory was cut and left on site along with the forest floor and the slash material. Loblolly pine seedlings were planted at 4.3 m × 3 m spacing in each 121-tree plot (11 × 11 trees) and only the inner 49 trees (7 × 7 trees) were considered for measurement purposes, leaving the trees in the treated perimeter as buffers.

2.2. Forest floor sampling and analysis

Ten years after treatment imposition, the forest floor was collected from five randomly located points per plot using a 30.5 cm diameter round sampler. The forest floor layer was cut until the mineral soil was reached. For each sampling location, the forest floor was separated in the field into three layers, Oi, Oe, and Oa (Guthrie and Witty, 1982). These correspond to the litter (L), fermentation (F), and humus (H) classification of forest floor layers, respectively (Kendrick, 1959). Samples were bulked by layer, providing three forest floor samples per plot.

Forest floor samples were oven dried at 70 °C to a constant mass. The lost-on-ignition method (Nelson and Sommers, 1996) was used to determine the ash-free weight of the Oi, Oe, and Oa layers and to correct for any mineral soil fraction that might have been collected along with the forest floor. Based on the area of the forest floor sampler, these mass estimates were scaled to a per hectare basis.

Oven dry samples of the Oi, Oe, and Oa layers were ground to pass through a 1 mm mesh sieve and analyzed for N and carbon (C) concentration using the CHN elemental analyzer (CE Instruments-NC 2100, CE Elatech Inc., Lakewood, NJ). Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), sulfur (S), boron (B), copper (Cu), and zinc (Zn) concentrations were determined by digesting 0.8 g of ground, oven-dry material with nitric acid (Zarcinas et al., 1987) followed by analysis using an inductively coupled plasma atomic emission spectrometer (IPS-AES, Varian ICP, Liberty Series 2, Varian analytical instruments, Walnut Creek, CA).

2.3. Mineral soil sampling and analysis

A-horizon samples were collected immediately after the forest floor collections using the same 5 randomly located points per plot. The thickness of the A-horizon was measured in each sampling point to obtain a plot average. The samples were composited by plot in the field, put in plastic bags and transported in coolers with ice to the laboratory where they were immediately sieved through 2 mm mesh to remove the coarser fraction. No coarse fraction was detected in this fine-loamy textured soil. These samples were then stored in the fridge at 4 °C until further analysis. Three bulk density samples were also collected from the A-horizon in each plot using the core method (Grossman and Reinsch, 2002). Soil variables were scaled to a per hectare basis using the depth of the A-horizon and the bulk density of the soil.

A 28-day aerobic incubation was used as an index of potential net N mineralization in the mineral soil (Hart et al., 1994b). Five 10-g sub samples of each mineral soil sample were weighed and prepared for this incubation; one was used for moisture content determinations, two were used for the N extraction values at time zero, and the two remaining samples were left to incubate at field moisture content and 25 °C for 28 days. Changes in the moisture content of the incubated samples were monitored every other day and deionized water was added when the moisture contents in the samples dropped by more than 5% below their initial levels. Soil samples, at time zero, were extracted in 35 ml of 2 M KCl by shaking at high speed for one hour and centrifuging for 15 min at 4000 rpm. The centrifuged solution was filtered using Fisherbrand G8 glass fiber filters and the filtered solutions were analyzed for inorganic N with a Lachat Autoanalyzer (Quick-Chem 8000, Zellweger Analytics, Inc., Milwaukee, WI). After 28 days, the same extraction procedure was used for the incubated samples. Potential N net mineralization was calculated by subtracting the time zero averaged values of NO_3^--N and NH_4^+-N from the incubated average values.