RELATIONSHIP BETWEEN TILLAGE INTENSITY AND INITIAL GROWTH OF LOBLOLLY PINE SEEDLINGS

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Abstract—To determine the relationship between changes in soil attributes associated with differing tillage intensities and growth of loblolly pine seedlings, we measured soil moisture, nitrogen (N) availability, and soil strength across a range of tillage treatments on an Orangeburg soil series near Cuthbert, GA (four replications). We then correlated these measurements to the growth of individual seedlings. The five tillage treatments were: no-till (NT), coulter only (C), coulter + subsoil (CS), coulter + bed (CB), and coulter + bed + subsoil (CSB). Adjacent to 3 trees per plot (60 trees total), soil moisture was measured every 2 weeks using TDR, soil N availability was measured monthly by KCl extractions, and soil strength was measured 2 times during the year using a cone penetrometer beginning in May, 2003. In December of 2003, the 60 trees were excavated to determine tree biomass. Average soil moisture in the upper 60 cm decreased from 28 percent in the NT treatment to 22 percent in the CB and CSB treatments. Nitrate concentrations increased by 33 percent in the bedded treatments (CB and CSB) compared to the NT, C, and CS treatments. From 0 to 200 mm, bedding decreased the average soil strength by 46 percent compared to the other treatments. Subsoiling decreased soil strength at depths > 200 mm. Tillage positively affected relative height growth ($p = 0.0005$), and all the tillage treatments increased relative height growth compared to the NT treatment. Soil strength between 0 and 100 mm ($P=0.002$, $r^2=0.41$) was positively correlated with seedling relative height growth. Soil moisture from 0 to 300 mm ($P=0.0016$, $r^2=0.44$) was negatively correlated with seedling relative height growth. In contrast, N availability was not correlated to seedling growth. These results indicate tillage increases rootability by decreasing soil strength and increasing porosity, and that these changes are associated with increased seedling growth.

INTRODUCTION

Intensive site preparation has become a standard practice for the establishment of pine plantations (Outcalt 1983). Mechanical site preparation methods, such as bedding and subsoiling, can improve water status and structure of many soils, and facilitate planting (Berry 1979). The beneficial effects of bedding or subsoiling can be attributed to improved drainage, improved microsite environment (nutrients, aeration, temperature, and moisture) for root development, increased moisture availability, and reduced competition (Haines and others 1975). Operations that increase the ability of a seedling to exploit the existing resources in the soil or increase the quantities of the resources in the soil will increase seedling growth (Wheeler and others 2002).

However, the high cost of mechanical site preparation techniques and inconsistent results have caused many forest managers to reconsider the benefits of these practices. Lower-cost treatments such as fertilization and herbicide application may reduce the need for tillage if the positive effects of tillage are largely due to increased resource availability. However, if the positive effects of soil tillage are related to changes in soil physical properties and the ability of roots to exploit the soil volume, then tillage is useful to increase seedling growth. The goals of this study were to (1) quantify the effects of soil tillage on soil strength (SS), soil moisture, and soil nitrogen (N) availability and (2) determine the relationship between tillage-mediated changes in soil attributes and growth of loblolly pine seedlings. Different levels of soil tillage (coulter only, bedding, subsoiling, and bedding and subsoiling combined) were employed to generate a range of responses and to determine the minimum amount of tillage necessary to obtain the desired changes in soil attributes.

PROCEDURES

This study was established on a tract of land owed by MeadWestvaco, located in the Upper Coastal Plain of southwest Georgia. The site has an Orangeburg (Typic Kandiudult) soil type with 1 to 6 inches of sandy loam topsoil over a clay loam B-horizon. Five treatments were evaluated, no-till (NT), coulter (C), coulter + bed (CB), coulter + subsoil (CS), and coulter + subsoil + bed (CSB). Prior to tillage treatments, all plots received an aerial herbicide treatment of 6 quarts of Accord SP and 1 ounce of Escort in a total aqueous solution of 15 gallons per acre on July 3, 2002. The plots were operationally hand-planted on January 7, 2003, with a first-generation open-pollinated Atlantic Coast loblolly pine family. The rows were 12 feet apart, and the seedlings were planted at a 6-foot spacing along the rows. A broadcast herbaceous weed control treatment of 12 ounces per acre of Oustar® was aerially applied on March 8, 2003, at 10 gallons per acre. To ensure uniform and complete weed control, mop-up spraying using glyphosate was done throughout the year to control herbaceous and woody competition.

The randomized complete block design consisted of four blocks each containing five randomly placed treatment plots. The plots are 7 rows wide with 30 trees per row (0.37 acre). Tillage treatments were implemented on November 17, 2002, using a Savannah Forestry Equipment, LLC model 420 two-disk heavy-duty subsoil plow pulled by a Caterpillar D-7R tractor. This plow consists of a linear arrangement of a 1.2 m coulter wheel, followed by a 7.5-cm-wide subsoil shank and then 2 80-cm-diameter opposed notched disk blades. The plow creates a continuous bed up to 50 cm in height, 1.7 m wide, and subsoils at a depth up to 60 cm. To install the non-bedded tillage treatments, the disks were elevated to avoid

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soil contact. To install the non-subsoiled tillage treatments, the subsoil shank was removed from the plow. The no-till treatments were hand-planted at the same spacing as the tillage treatments.

Before the first growing season (2003), 3 trees of differing size were chosen in each plot (60 trees total) to be observed all year and intensively measured. Seedling height and ground line diameter were measured at regular intervals. Near each of 60 trees, exchangeable N in the form of ammonium and nitrate, volumetric soil moisture, and SS were periodically measured. We measured KCl-extractable ammonium and nitrate concentration once per month (Mulvaney 1996). Soil moisture was measured via time domain reflectometry from 0 to 300 and 0 to 600 mm every 2 weeks from early April until September and monthly from September until December. SS was measured with a Rimik CP 20 Cone Penetrometer in May and August. Nine insertions were made to a depth of 600 mm and recorded in 25 mm increments in an area of 1 m^2 around each tree. At the end of the first growing season, all 60 measurement trees were excavated to measure stem, foliar, and root biomass.

We tested the effects of tillage type on SS, soil moisture, and N availability with analysis of variance (ANOVA), using a split plot analysis when appropriate, i.e., when soil depth (SS) and date (soil moisture) were included in the analysis. We then tested the relationship between the tillage-mediated differences in these soil attributes on seedling relative height growth (absolute height growth/initial height) using linear regression. The responses of the three seedlings per plot were averaged before analyses as the plot served as the experimental unit.

RESULTS

Soil Strength

SS changed with soil depth (depth effect $P < 0.0001$). In the NT plots, SS increased between 100 to 200 mm and then decreased at deeper depths, probably reflecting a root restrictive layer in the soil profile across the site (fig.1). Overall, the tillage treatments reduced SS (tillage effect $P < 0.0001$), but depth to which the different tillage treatments was effective depended on tillage type (tillage x depth interaction $P < 0.0001$). The bedding treatments (CB and CSB) were reduced in average SS from 1,411 kPa in the NT treatment to 463 kPa in the beds between 0 and 100 mm. At greater soil depths, the subsoil treatments became more effective at reducing SS. Between 500 to 600 mm, the CSB treatment was most effective, with an average SS of 922 kPa compared to 1,462 kPa of the NT. The C treatment was less effective than the more intensive tillage treatments at reducing SS, but this treatment reduced SS at all depths compared to the NT treatment. The results for August, 2003, were similar to May with tillage treatment, depth, and tillage x depth significant ($P < 0.0001$).

Soil Moisture

Volumetric soil moisture varied throughout the growing season with generally reduced moisture in summer due to lower precipitation and greater evapotranspiration (date effect $P < 0.0001$) (fig. 2). Between 0 to 600 mm, the volumetric moisture content of the soils in the NT treatment was consistently higher than in the tillage treatments, with the bedded (CB and CSB) treatments having the lowest moisture content (tillage effect $P = 0.0002$). Tillage effects were generally consistent throughout the year (date x tillage treatment, $P = 0.11$). Average volumetric soil moisture content ranged from 28 percent in the NT treatment to 22 percent in the CSB treatment (fig. 2). Moisture content from 0 to 300 mm was similar to 0 to 600 mm with treatment and date significant, but there was a date x tillage interaction ($P < 0.0001$) probably due to less consistent moisture contents of the tillage treatments resulting from greater variation in periodic wetting and drying.

Soil Nitrogen Concentration

Tillage treatment ($P = 0.006$) and date ($P < 0.0001$) significantly affected soil Nitrate N concentration (fig. 3). Average nitrate N levels throughout the year ranged from a high of 3.2 µg/g in the CB treatment to 1.8 µg/g in the CS treatment. The higher nitrate N levels in the bedded treatments was most likely due to increased organic matter and top soil that are localized around the seedlings and a soil surface that was more rapidly warmed (Morris and Lowery 1988). Higher

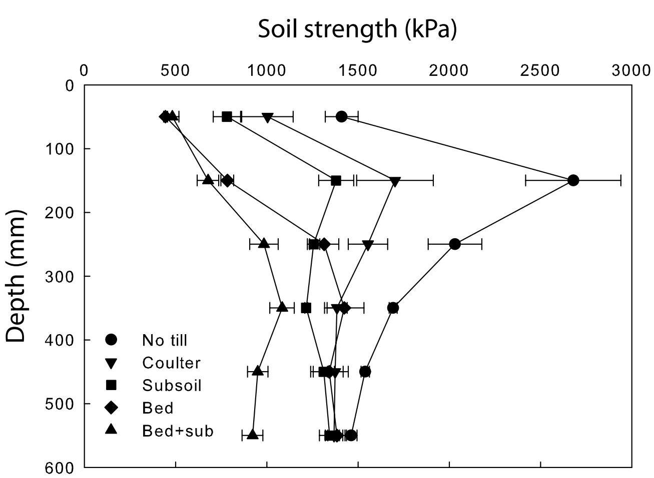

Figure 1—The response of soil strength to soil depth and tillage treatment for a 1-year-old loblolly pine stand in southwest Georgia measured in May, 2003.

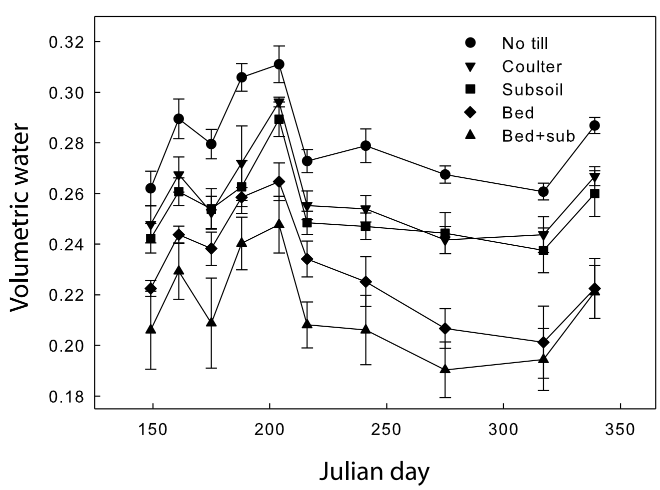

Figure 2—Average volumetric water content from 0 to 600 mm of the tillage treatments for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

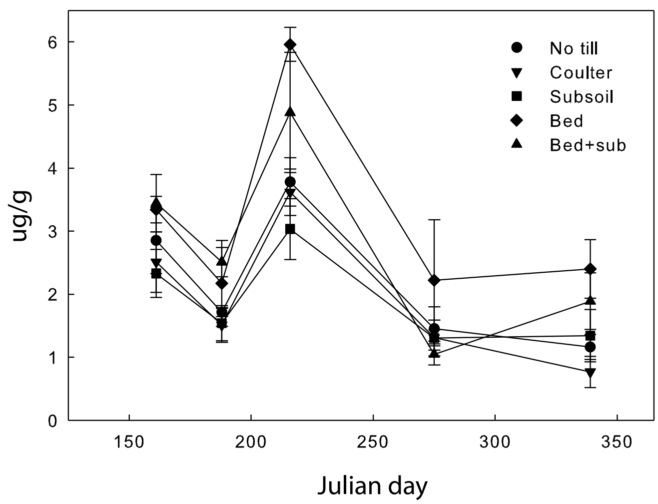

Figure 3—Nitrate concentration of the tillage treatments for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

nitrate levels in mid-summer were expected because of higher temperatures. Tillage treatments did not significantly affect ammonium N concentration (P = 0.60).

Seedling Growth

Seedling height after the first growing season was correlated to seedling biomass. Across tillage treatments, a positive relationship existed between seedling height and root biomass ($P < 0.0001$ and $r^2 = 0.46$) and seedling height and stem biomass ($P < 0.0001$ and $r^2 = 0.60$). The regression equations are height = 46.089+0.3851* (root biomass) and height = 43.139 + 0.6495* (stem biomass) where height is seedling height in cm and biomass is in grams. During the 2003 growing season, the seedlings in the tilled treatments grew taller than the seedlings in the NT treatment resulting in a significant date x treatment interaction ($P < 0.0001$) (fig. 4). Seedling height increased from 22.5 to 52.3 cm in the NT treatment and from 19.1 to 69.5 cm on the CSB treatment. Planting depth differences caused a difference in initial heights between treatments of up to 6 cm. Because of the differences among the initial heights of seedlings within treatments (from 16 cm in the CB treatment to 23 cm in the NT) and due to the small differences in initial heights between tillage treatments, we used relative height growth (seedling height growth/initial height) as our estimate of seedling response. Relative height growth increased as a result of tillage (P = 0.0005) (NT = 1.4; C = 2.9; CS = 3.1; CB = 3.5; CSB = 2.9).

Relative height growth increased as SS decreased in the upper portion of the soil profile (0 to 400 mm). From 400 to 600 mm, the relationship between SS and relative height growth was not significant. As SS in the 0 to 100 mm zone decreased from 1,900 to 500 kPa, relative height growth increased from 1.6 to 3.5 with 41 percent of the variation in relative height predicted by SS (fig. 5). This relationship was also significant ($P < 0.05$) from 100 to 200 mm ($r^2 = 0.37$), 200 to 300 mm ($r^2 = 0.31$), and 300 to 400 mm ($r^2 = 0.22$). When average volumetric water content between 0 to 300 mm decreased from 29 percent to 19 percent, relative height growth increased from 1.6 to 3.5 (P = 0.002, $r^2 = 0.44$) (fig. 6). The relationship at 0 to 600 mm was not as strong (P = 0.01, $r^2 = 0.29$). Nitrate N, both ammonium (P = 0.72) and nitrate (P = 0.26) (fig. 7), were not significantly related to relative height growth.

DISCUSSION

The purpose of soil tillage in forest site preparation is to improve soil physical attributes and to facilitate seedling establishment and growth. The data in this study indicate a positive correlation between SS and seedling growth. This positive correlation was most likely due to improved soil physical conditions that enabled roots to better capture and exploit soil resources (Will and others 2002). Subsoiling was successful at reducing SS at depths > 400 mm, but as other studies have shown, adding subsoiling to other tillage treatments did not increase growth (Wheeler and others 2002). The reason decreased SS deeper in the soil profile did not increase growth is most likely due to concentration of roots near the surface soil (Nambiar and Sands 1993).

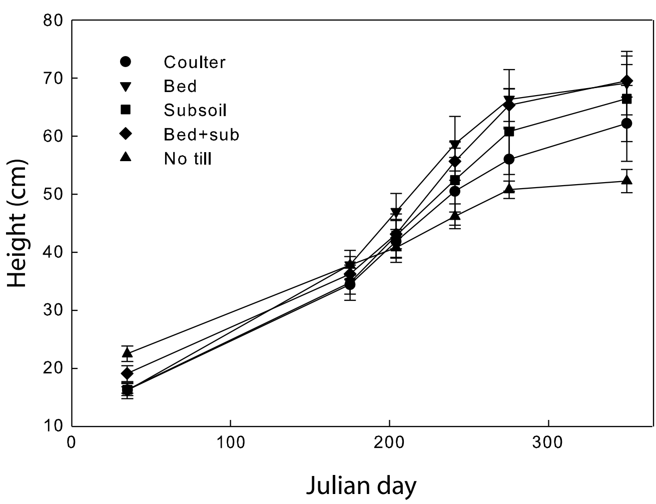

Figure 4—Height growth of loblolly pine seedlings by tillage treatment for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

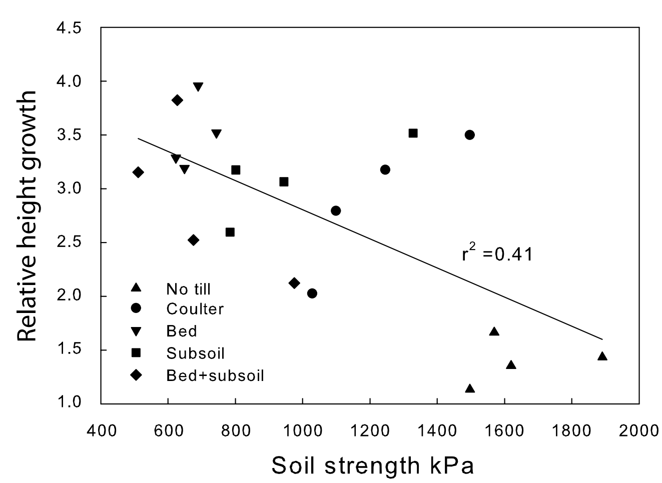

Figure 5—Regression of soil strength from 0 to 100 mm as related to relative height growth for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

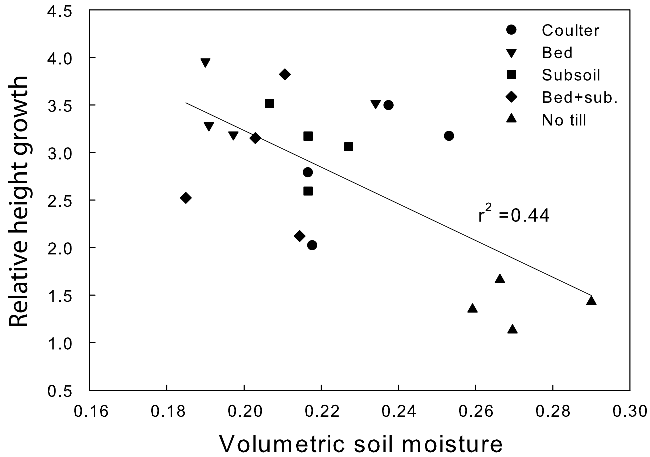

Figure 6—Regression of average soil moisture from 0 to 300 mm as related to relative height growth for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

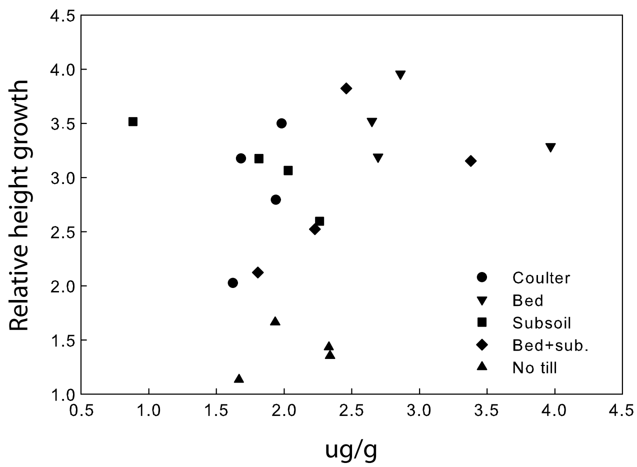

Figure 7—Regression of nitrate N levels of individual tillage treatments as related to relative height growth for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

As volumetric water content decreased, relative height growth increased. The decrease in volumetric water content in the tilled treatments did not necessarily translate into less available water for the seedlings; the amount of soil water available to plants is a function of rooting volume as well as water infiltration and retention characteristics of the soil (Morris and Lowery 1988). The decrease in volumetric water content in this study was most likely caused by an increase in large voids in the soil and increased macro-porosity created by the tillage treatments (Harrison and others 1994). Increased macro-porosity probably allowed the roots to more fully utilize the site, and this may have translated into improved relative height growth (Shiver and Fortson 1979, Will and others 2002).

Although tillage increased Nitrate N, this increase did not relate to increased relative height growth. Increased levels of N in the soil may not always be necessary to improve early seedling growth. Morris and Lowery (1988) stated that increased N mineralization may not be important in young stands because over 100 pounds per acre of N may be mineralized in the first 2 years after site preparation while pine seedlings accumulate only 3 to 5 pounds per acre when planted at normal densities. These increased levels of nitrate N may be useful to the trees when they grow larger and the site becomes more fully exploited. Also, in this case weed control eliminated any vegetation competing for available N that could be expected to have an adverse effect on seedling growth (Burger and Pritchett 1988).

The results obtained in this study indicate that tillage treatments decreased SS, decreased volumetric soil moisture, and increased N availability. The change in SS resulting from tillage is probably the most meaningful predictor of seedling response to tillage intensity. In areas with high SS, particularly in the upper portion of the soil profile, tillage will increase seedling growth. On this soil, adding subsoiling to bedding did not cause any additional benefit, and minimal tillage, i.e., the coulter only, provided almost as much benefit as the more intensive treatments. The effects of tillage will probably provide an additive benefit to weed control since we found a tillage response in the absence of competing vegetation.

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