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Soil change and loblolly pine (*Pinus taeda*) seedling growth following site preparation tillage in the Upper Coastal Plain of the southeastern United States

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Abstract

To determine the relationship between changes in soil physical properties due to tillage and growth of loblolly pine (*Pinus taeda* L.) seedlings, we measured soil moisture and penetration resistance for a range of tillage treatments on two Upper Coastal Plain sites in Georgia and 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 + subsoil + bed (CSB). The effects of tillage on soil penetration resistance and volumetric water content were isolated from the potentially confounding effects of tillage on competition and soil fertility by completely eliminating all competing vegetation and by comparing tree response with and without periodic nutrient additions. At the site with a clay B-horizon at the surface, the tillage treatments increased relative height and relative diameter growth compared to the NT treatment during the first season, decreased soil penetration resistance, and decreased volumetric soil moisture (VWC). At the sandy site with a loamy sand topsoil averaging 15–40 cm in depth over a sandy clay loam B-horizon, bedding, subsoiling and the minimal tillage associated with machine planting increased seedling growth compared to the C treatment. Soil penetration resistance and VWC were greatest in the C treatment, intermediate in the NT treatment, and lowest in the treatments receiving bedding. Soil penetration resistance between 40 and 50 cm ($p = 0.03$, $r^2 = 0.40$) was negatively correlated with seedling relative diameter growth at the clay site. Soil penetration resistance between 10 and 40 cm ($p < 0.02$, $r^2 = 0.35$) was negatively correlated with seedling diameters at the sandy site. Overall, the positive effects of soil tillage on growth were relatively small (i.e., increases in height and diameter of about 20%). Most of the positive benefits of tillage on growth and soil physical properties were captured with less intensive treatments such as machine planting (sandy site) or the coulter only (clay site).

Keywords: *Pinus taeda*; Loblolly pine; Tillage; Bedding; Subsoiling; Upper Coastal Plain

1. Introduction

Mechanical site preparation is a common silvicultural treatment used in plantation forest management in all areas of the southeastern United States (Lantagne and Burger, 1987). Benefits of mechanical site preparation include improved drainage, improved micro-site environment (nutrients, aeration, temperature, and moisture) for root development, and reduced competition (Haines et al., 1975). Many upland sites of the Coastal Plain have thin topsoil above a restrictive subsoil that may inhibit seedling root growth and limit nutrient availability (McKee and Wilhite, 1986; Wheeler et al., 2002). Additionally, soil compaction caused by trafficking of heavy equipment is a problem on many of these sites. Between 25 and 50% of a site is

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trafficked during harvest (e.g., Hatchell et al., 1970; Aust et al., 1998). Upland sites of the Coastal Plain are particularly susceptible to compaction damage because harvesting can be conducted on these sites during wet periods when they are suspended in other locations (Miller et al., 2004).

On upland sites, tillage, such as bedding and subsoiling, have several potential mechanisms by which they increase seedling growth. The primary mechanism is to increase the easily rooted soil volume and allow the seedlings to more efficiently exploit existing soil resources (Will et al., 2002; Nadeau et al., 1998; Morris and Lowery, 1988; Wittwer et al., 1986). However, site preparation tillage also increases the concentrations of resources available to the tree through increased mineralization and decreased interspecific competition (Attiwill et al., 1985; Haines et al., 1975; Lantagne and Burger, 1987). Generally, the relative contributions of the potential mechanisms by which site preparation increases growth have not been quantified. Several recent studies of site preparation tillage on upland sites reported only small increases (Wheeler et al., 2002) or no increase (Schilling et al., 2004) in seedling growth when the benefits of tillage were isolated from the effects plant competition. Given the relatively high cost of upland soil tillage, which averages between \$92 and \$120 per acre when subsoiling is included (Smidt et al., 2005), its use may not be justified if some of the previously reported growth increases (e.g., Lantagne and Burger, 1987; McKee and Wilhite, 1988; McKeand et al., 2000) can be captured through other less expensive treatments such as fertilization or competition control.

If tillage increases seedling growth by improving soil physical properties irrespective of the other benefits, then upland tillage may be an important silvicultural tool. To appropriately use this tool, seedling growth responses need to be quantified across a range of soil physical properties related to the implementation of different tillage intensities. In particular, soil strength, or the capacity of soil to withstand stress without experiencing failure by rupture or fragmentation, can limit root growth and water movement (Daddow and Warrington, 1983; Carlson, 1986). In addition to the direct effects of soil moisture on seedling growth (Morris et al., 1993; Torreano and Morris, 1998; Gholz et al., 1990), soil moisture is inversely related to soil strength (Shaw et al., 1942) such that low soil moisture may limit root elongation and alter distribution patterns (Ludovici and Morris, 1997). Therefore, understanding the relationship between tillage mediated changes in soil strength and soil moisture in relation to seedling growth is necessary to evaluate the potential importance of mechanical tillage on upland sites.

The overall goal of this study was to determine the effects of different intensities of soil tillage (no-till, coulter-only, coulter + bedding, coulter + subsoiling, and coulter + bedding + subsoiling) on soil penetration resistance, a measure of soil strength, and soil moisture and to relate these changes to loblolly pine (*Pinus taeda* L.) seedling growth. The effects of tillage on soil physical properties were isolated from tillage effects that could be met by other silvicultural treatments by (1) eliminating competing vegetation on all plots to prevent confounding tillage effects of soil physical properties with tillage effects of competition control and (2) eliminating the effects associated with available nutrient concentrations by comparing the effects of tillage among fertilized trees that were not nutrient limited. As the effects of tillage vary with soil type, the potential range of tillage response on upland sites was determined on two contrasting sites. While these results are generally applicable to plantation forest systems, loblolly pine represents a particularly good model system. Loblolly pine is the most important economic species in the southeastern United States, composing the majority of the 13 million ha of pine plantations in that region (Fox et al., 2006). In addition, loblolly pine is known to respond well to changes in soil physical properties and resource availability (e.g., Fox et al., 2006; Will et al., 2006; Wheeler et al., 2002).

2. Methods

This study was established on two tracts of land, one owned by MeadWestvaco Corp. and the other by Rayonier Inc. Both tracts are located in the Upper Coastal Plain of Georgia. The clay site (MeadWestvaco) is located southeast of Cuthbert, GA (latitude 31°77′N, longitude −84°79′W) and has a Greenville soil series (Fine, kaolinitic, thermic Rhodic Kandiudult) that is highly eroded and compacted with a clay-rich B-horizon at the surface. Sand, silt, and clay percentages are 53, 14, 33 (0–10 cm), 36, 16, 48 (10–20 cm), 31, 16, 44 (20–50 cm), and 30, 39, 31 (50–100 cm). The sandy site (Rayonier) is located west of Lumpkin, GA (latitude 32°05′N, longitude −84°79′W) and has an Orangeburg soil series (fine-loamy, kaolinitic, thermic Typic Kandiudult) with a loamy sand topsoil averaging 15–40 cm in depth over a sandy clay loam B-horizon. Sand, silt, and clay percentages are 87, 7, 6 (0–10 cm), 84, 9, 8 (10–20 cm), 61, 9, 30 (20–50 cm), and 49, 27, 24 (50–100 cm). Existing loblolly pine plantations were operationally harvested from both sites in 2002. Five site preparation treatments were evaluated on each site, no-till (NT), coulter (C), coulter + bed (CB), coulter + subsoil (CS), and coulter + subsoil + bed (CSB). Three blocks of treatments were established at each site with tillage treatments randomly assigned to plots.

Prior to tillage treatments, October 2003, the clay site received an aerial herbicide treatment of 0.95 L Chopper™ (BASF Corporation, Research Triangle Park, NC; active ingredient Isopropylamine salt of Imazapyr 27.6%), 2.84 L Glypro Plus™ (Dow Agrosciences, Indianapolis, IN; active ingredient glyphosate 41.0%), and 0.59 L RedRiver 90 surfactant (Brewer International, Vero Beach, FL) in a total aqueous solution of 57 L ha^{-1}. The plots at the clay site were operationally hand-planted in February 2004 with a full-sib family Atlantic Coast loblolly pine family (same male and female parents, both originating on the Atlantic Coastal Plain). The rows were 3.7 m apart with seedlings planted at 1.8 m spacing along the rows. A broadcast herbaceous weed control treatment of 340 g ha^{-1} of Oustar™ (E.I. du Pont de Nemours and Company, Wilmington, DL; active ingredients hexazinone 63.2% and sulfometuron methyl 11.8%) was applied in 1.8 m bands along the rows in March of 2004. A second herbaceous weed control treatment consisting of 340 g ha^{-1} of Oustar™ was applied on 1.5-m bands in April 2004. To ensure uniform and complete weed control, hand spraying using glyphosate