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Cultural intensity and planting density effects on aboveground biomass of 12-year-old loblolly pine trees in the Upper Coastal Plain and Piedmont of the southeastern United States

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ABSTRACT

We examined the effects of cultural intensity (operational and intensive), planting density (741, 1483, 2224, 2965, 3706 and 4448 trees ha^{-1}) and their interaction on aboveground biomass accumulation and allocation for 12-year-old loblolly pine (*Pinus taeda* L.) trees in the Upper Coastal Plain and Piedmont of the southeastern United States. Cultural intensity significantly affected accumulation of stem, bark, dead-branch and total aboveground biomass and biomass allocation in the dead-branch component. Accumulation of total aboveground biomass and each component biomass and biomass allocation to each component were significantly affected by planting density. The only significant culture × density interaction was for dead-branch biomass accumulation.

1. Introduction

Loblolly pine plantations in Georgia and Alabama comprise approximately 4 million hectares. With a total land area of approximately 21 million hectares, the Upper Coastal Plain and Piedmont of Georgia and Alabama are major regions where loblolly pine (*Pinus taeda* L.) plantation management has been carried out for more than four decades. Loblolly pine dominates well drained sites in the Coastal Plain and disturbed sites in the Piedmont (Hodler and Schretter, 1986).

Research on forest biomass production has been conducted over the past four decades to better understand timber production potential, ecosystem productivity, energy and nutrient flow, and forestland contribution to the global carbon cycle (Zeide, 1987; Waring and Running, 1998; Parresol, 1999). Particular interest has been directed towards carbon (C) stocks in forests because these ecosystems are the main terrestrial sinks for C (Murias et al., 2006). Recently, there has been a renewed interest in biomass research due to the need to predict forest C stocks and the potential amount of biomass available as a source of energy (Moore, 2010). It is important to quantify forest biomass to assess forest productivity and C sequestration because approximately 50% of the tree dry biomass is C (Losi et al., 2003).

The effects of fertilization and irrigation (Albaugh et al., 1998; King et al., 1999; Jokela and Martin, 2000), competition control (Colbert et al., 1990), planting density (Baldwin et al., 2000; Burkes et al., 2003; Ares and Brauer, 2005), and age (Larsen et al., 1976; Pehl et al., 1984; Van Lear and Kapeluck, 1995) on loblolly pine biomass accumulation and allocation have been extensively studied. The results show that biomass accumulation and allocation to different components of the tree are affected by resource availability and age. Overcoming resource deficiencies causes greater biomass allocation to aboveground components at the expense of roots (Linder, 1989; Albaugh et al., 1998; Coyle et al., 2008). In the humid southeastern United States, nutrition is often a more limiting factor for pine growth than moisture (Jokela et al., 2004), and fertilization, spacing, and competition control are key practices for managing site nutrition and improving biomass production. Accurate estimates of biomass accumulation and allocation to components are needed to better estimate potential yield for different products. While much research has focused on the cultural intensity or planting density effects on stem biomass accumulation (Quicke et al., 1999; Carlson et al., 2009; Zhao et al., 2011), relatively less is known about the effects of planting density, cultural intensity, and their interaction on biomass accumulation and allocation.

The present study examined the effects of different cultural regimes and planting densities on aboveground biomass accumulation and allocation in 12-year-old loblolly pine trees. The following two hypotheses were examined: (i) culture, density, and their interaction have significant effects on aboveground biomass accumulation of loblolly pine trees: (ii) culture, density, and their interaction have significant effects on the biomass allocation to aboveground components of loblolly pine trees.

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2. Materials and methods

2.1. Study description

This study was conducted on four installations of the loblolly pine culture/density study established by the Plantation Management Research Cooperative (PMRC) of the University of Georgia in 1998 (Fig. 1). Locations, soil types and rainfall information of these installations are presented in Table 1.

There were two levels of cultural intensity (operational and intensive) and six levels of planting densities within each level of cultural intensity (741, 1483, 2224, 2965, 3706, 4448 trees ha^{-1}) at each of the four locations. The details of intensive and operational treatments are presented in Table 2. At each installation there was a random assignment of cultural intensities to main plot, and within a cultural intensity level the planting densities were randomly assigned to subplots. This arrangement results in a split-plot design with one replication at each installation.

PMRC cooperators selected the genetic material to plant at each installation. First or second generation open-pollinated stock considered good quality at the time of plantation establishment was used. To ensure the targeted initial density, each planting spot was double-planted and reduced to a single surviving seedling after the first growing season. If both seedlings were healthy then one was randomly selected for removal. If one seedling was at risk of dying, it was removed. Measurement plot size ranged from 0.106 ha (for 741 trees ha^{-1}) to 0.040 ha (for 4448 trees ha^{-1}).

2.2. Field and laboratory work

All trees in each measurement plot were measured for diameter at breast height (DBH) during the dormant season at age 12 years. One hundred and ninety-two trees (4 trees/plot $\times$ 2 cultural intensities $\times$ 6 planting densities $\times$ 4 installations) were destructively sampled in February/March of 2010. Trees were selected based on their size classes (1 below average DBH tree, 1 average DBH tree, and 2 larger than average DBH trees in the dominant or co-dominant crown classes). Selected trees were cut 15 cm above ground line and the stem was marked at 0.60, 1.21, 2.43, 3.65, 6.10 and subsequently at 2.43 m intervals. The live crown was divided into three equal sections. Two live branches with foliage were randomly selected from each section, weighed individually and placed in paper bags for lab processing. All other live branches with foliage were weighed by crown section. Two dead branches were sampled from each tree, weighed and placed in paper bags for lab processing. All other dead branches were weighed for each

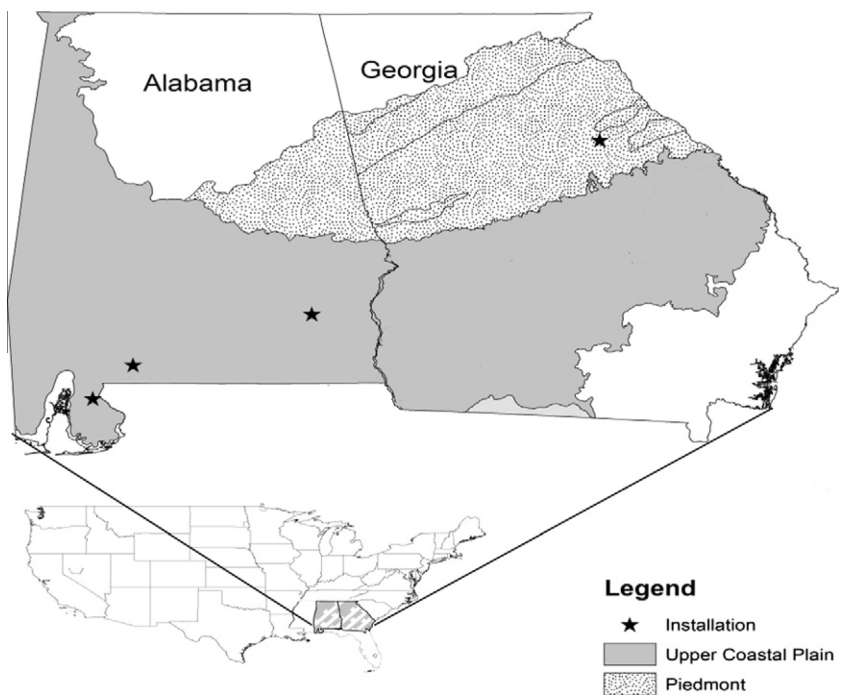

Fig. 1. Plantation Management Research Cooperative study sites sampled for loblolly pine biomass accumulation and allocation. Three installations were in the Upper Coastal Plain of Alabama and one installation was in the Piedmont of Georgia.

Table 1
Location (county, state), latitude/longitude, soil taxonomy, and average annual precipitation for four study installations.

Location	Latitude/longitude	Soil taxonomy[a]	Average annual precipitation[b]
Baldwin, Alabama	30.833/−87.686	Fine loamy, kaolinitic, thermic Plinthic Kandiudult	64
Escambia, Alabama	31.1954/−87.315	Fine loamy, kaolinitic, thermic Rhodic Kandiudult	58
Greene, Georgia	33.6235/−83.028	Coarse loamy, mixed, semi active, thermic Typic Dystudept	48[c]
Barbour, Alabama	31.7467/−85.674	Loamy, kaolinitic, thermic Grossarenic Kandiudult	54

[a] Soil information is based on NRCS general and detail soil map of 1963 and 1972 and NRCS SSURGO data.
[b] Average annual precipitation information is based on average annual rainfall map produced by Department of Geography, College of Arts and Sciences at the University of Alabama, average annual precipitation map of Georgia produced by PRISM group and Oregon Climate Service at Oregon State University and US weather data of average temperatures and rainfall in US cities available at coutrystudies.com.
[c] Greene County installation faced three years drought from 2006 and 2009.