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Establishment phase productivity of loblolly pine and switchgrass when grown across a gradient of cultural treatment and site productivity

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ABSTRACT

A three-year field study was established to evaluate the production potential of an intercropping system of loblolly pine (*Pinus taeda* L.) and switchgrass (*Panicum virgatum* L.) in the southeastern United States. Tree-grass competitive interactions are expected to negatively affect overall productivity within this system, but a better understanding of these relationships will aid in developing cultural practices to mitigate competitive effects. We hypothesized that interspecific competitive interactions would decrease the productivity of both species within this system. We also hypothesized that productivity declines, due to interspecific competition, could be mitigated through management. We established loblolly pine and switchgrass intercropping systems at varying rates of competitive intensity initiated by cultural practices (pine only, switchgrass only, pine planted directly into switchgrass, pine planted into a 1.2 m vegetation removal zone, and pine planted into a 2.4 m vegetation removal zone) at two sites in northeastern Mississippi. Over the study duration, we observed decreased production in loblolly pine due to switchgrass competition. However, the establishment of 1.2 or 2.4 m vegetation removal zones surrounding pine seedlings allowed for tree growth equal to or greater than the pine only control at both sites. Likewise, intercropped switchgrass production was equal to or greater than the switchgrass only treatment by year 3 due to an apparent edge effect occurring at the tree-grass interface. Our results demonstrate that cultural practices intended to reduce interspecific competition were effective in mitigating productivity declines of intercropped loblolly pine while preserving or increasing switchgrass productivity. The dual-species productivity gains observed in this study advocate the loblolly pine-switchgrass intercropping system as a possible alternative to switchgrass monoculture. This study only examined production dynamics during the initial three growing years of this system and further research is needed to elucidate productivity patterns throughout the rotation.

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1. Introduction

Environmental and economic concern regarding fossil fuel consumption has generated interest in the production of renewable fuels derived from plant-based sources. Corn (*Zea mays* L.) is currently the most utilized crop in the United States for biofuel production (Keshwani and Cheng, 2009; Parrish et al., 2008; U.S. Dept. of Energy, 2011). Debate regarding the usage of food crops and agricultural lands for bioenergy has refocused the production of plant-based bioenergy feedstocks to lands less suitable for traditional food crops (Gutierrez and Ponti, 2009; Heaton et al., 2008; Keshwani and Cheng, 2009). Switchgrass (*Panicum virgatum* L.) is a species well-suited to production on these lands and has been identified as a model bioenergy feedstock due to its perennial nature, adaptability to a variety of sites, and high biomass potential as well as concern regarding the utilization of lands suitable for row-crop production for bioenergy cropping (McLaughlin and Kszos, 2005; Mitchell et al., 2008; Sanderson et al., 2006). Despite this potential, there is economic risk and landowner uncertainty associated with producing a crop dedicated to a relatively new biofuel market (Blazier, 2009; Susaeta et al., 2012).

One alternative to monoculture production of switchgrass on marginal lands is an intercropping system in which switchgrass is grown between rows of widely spaced trees. Such a system could diversify income earning potential and provide multiple revenue streams by combining short-term income from an annually

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harvested bioenergy crop with long-term revenues derived from a tree crop (Susaeta et al., 2012; Workman and Nair, 2002). Intercropping systems can optimize the spatial and temporal availability of soil and environmental resources and increase productivity of one or both species compared to monoculture (Jose et al., 2004).

Among the most promising tree species for intercropping with switchgrass in the southeastern United States is loblolly pine (*Pinus taeda* L.). This species is particularly well-suited to intercropping due to its established market value, wide adaptability to a variety of sites, and high production potential (Baker and Langdon, 1990; Blazier, 2009; Schultz, 1999). Loblolly pine is primarily managed for high-value sawtimber and pulpwood with yields exceeding 5 m^3 ha^{-1} yr^{-1} with intensive management (Fox et al., 2007). Potential bioenergy markets have also raised interest in managing loblolly pine plantations for bioenergy feedstock and an intercropping system presents additional opportunities for utilizing tree residues from thinning and harvest operations (Scott and Tiarks, 2008). Little information to date is available regarding minimum sizes of vegetation removal needed to overcome interspecific competition among trees and herbaceous bioenergy species, such as switchgrass, but a broader body of literature addressing tree growth responses to suppression of weedy herbaceous species is well established (Antony et al., 2011; Borders et al., 2004; Jokela et al., 2010; Miller et al., 1991, 2006). From an economic and environmental perspective, it is imperative to perform competition control across the smallest area possible which achieves the desired growth response. Loblolly pine has been intercropped in silvopasture with perennial grasses (Burner, 2003; Burner and Brauer, 2003; Burner and MacKown, 2005; Clason, 1995, 1999), with cotton (Zamora et al., 2009) as well as with switchgrass (Albaugh et al., 2012; Blazier et al., 2012; Haile et al., 2016) and has consistently experienced growth reductions due to competition. In this study, our objective was to quantify loblolly pine, switchgrass, and intercropping productivity across a gradient of competitive intensities. Our first hypothesis was that interspecific competitive interactions would decrease the productivity of both species within this system. We also hypothesized that productivity declines, due to interspecific competition, could be mitigated through cultural treatments.

2. Materials and methods

2.1. Site descriptions

Intercropping systems of loblolly pine and switchgrass were established at two sites in northeastern Mississippi. The first site, Pontotoc Ridge-Flatwoods Branch Experiment Station (Pontotoc), is located 12 km south of Pontotoc, MS (34°07′N, 88°59′W). Soils at Pontotoc (pH 6.5) include the Atwood (fine-silty, mixed, semiactive, thermic Typic Paleudalfs) and Cascilla (fine-silty, mixed, active, thermic Fluventic Dystrudepts) silt loam series and parent material is a mixture of loess and silty alluvium deposits (USDA Soil Survey Staff, 2013). The second site, John W. Starr Memorial Forest (Starr), is located approximately 26 km southwest of Starkville, MS (33°16′N, 88°53′W). Soils at Starr (pH 4.9) include the Ora (fine-loamy, siliceous, semiactive, thermic Typic Fragiudults) and Savannah (fine-loamy, siliceous, semiactive, thermic Typic Fragiudults) fine sandy loam series and parent material is of loamy marine and alluvial origin (USDA Soil Survey Staff, 2013). The sites vary in agricultural suitability, with Pontotoc being relatively well suited to traditional food crop production and Starr being better suited to rangeland or forest use. Climate in the study region is characterized by hot, humid summers and mild, wet winters. Mean annual temperatures (°C) for the region were 16.6, 17.4 and 15.6 and total annual precipitation rates (cm) were 135.7, 126.3 and 134.4 in years 1, 2 and 3, respectively (NOAA, 2017). Pontotoc was managed for multiple uses, including pasture, vegetable production, and wildlife food plot in the years leading to study initiation. Starr had been maintained as a mowed pasture in the decades leading to study initiation.

2.2. Site preparation

Site preparation at both sites began in 2010. At Pontotoc, broadcast herbicide applications of glyphosate and 2,4-D were applied in May at rates of 2.3 and 0.9 L ha^{-1}, respectively. Two weeks later, 'Alamo' switchgrass seed was drill seeded and cultipacked at 5 kg ha^{-1} pure live seed. Competing vegetation was controlled one month later by applying a tank mixture of nicosulfuron and metsulfuron methyl herbicides at rates of 0.6 and 0.2 kg ha^{-1}. Poor switchgrass germination was observed in July and the site was reseeded with Alamo switchgrass at 7 kg ha^{-1} pure live seed to ensure adequate stocking in subsequent growing seasons. At Starr, site preparation began with a prescribed burn in late March and a 1 Mg ha^{-1} lime application in April. Two weeks later, Starr was drill seeded with Alamo switchgrass at a rate of 5 kg ha^{-1} pure live seed.

After switchgrass seeding and prior to tree planting, north-south oriented rows spaced 9 m apart were ripped to 40 cm depth. Loblolly pine seedlings of a single varietal were hand planted in March 2011 at 1.5 m spacing within rows (ca. 740 trees ha^{-1}). Throughout the duration of the study, seedlings recruiting from adjacent lands were excluded from both sites.

2.3. Experimental design

At each site, a randomized complete block design consisting of eight blocks and five competition treatments was established in 2011 (year 1 of the study; Fig. 1). Each plot consisted of a single, central row of trees and the 4.5 m area on either side of the tree row. At Pontotoc, 12 trees were included in each plot (9 m × 18 m plots) and at Starr, 10 trees were included within each plot (9 m × 15 m plots). Competition treatments, initiated in the first growing season of the study and maintained throughout the three years of this study, were:

1. Switchgrass only (SG): No trees planted and switchgrass grown throughout the entire treatment plot.
2. Pine only (PINE): A central row of loblolly pines were planted and all other vegetation (both woody and herbaceous) was removed from the plot. Vegetation removal was carried out as needed over the course of the growing seasons with shielded, directed sprays of 2% glyphosate herbicide (Cornerstone® Plus) as well as with mechanical weeding.
3. Pine in switchgrass (P + SG): Loblolly pine seedlings were planted directly into established switchgrass and no vegetation removal was performed.
4. 1.2 m zone (1.2): Loblolly pine seedlings were planted into a 1.2 m (0.6 m on either side of the pine rows) vegetation removal zone. All vegetation within this zone was removed as described in the PINE treatment.
5. 2.4 m zone (2.4): Loblolly pine seedlings were planted into a 2.4 m (1.2 m on either side of the pine rows) vegetation removal zone. All vegetation within the zone was removed as described for the PINE treatment.

2.4. Field sampling and laboratory analyses

Loblolly pine productivity was assessed annually by measuring tree heights (ht) in the dormant seasons following growing seasons 1, 2, and 3. Diameters at breast height (1.3 m, dbh) were assessed in December of year 3. A tree volume index for year 3 was

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