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Capacity of biochar application and nitrogen fertilization to mitigate grass competition upon tree seedlings during stand regeneration

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ABSTRACT

Background and aims: This experiment examined early competition dynamics of a tree-grass intercropping system. We hypothesized that (1) the effects of competition would outweigh those of facilitation in this system and (2) soil amendment-induced fertility would alter competitive relationships between these species.
Methods: We intercropped loblolly pine and switchgrass seedlings at three rates of density-induced interspecific competition (high, low, and pine only) and amended soils with biochar (0, 5, and 20 Mg ha^{-1}) and nitrogen fertilizer (0 and 56 kg ha^{-1} N). We measured soil properties, foliar N concentrations, and plant productivity over two years.
Results: Soil temperatures decreased and total soil N increased in intercropping treatments relative to the pine only control treatment. Competition reduced soil moisture and inorganic N concentrations as well as tree productivity and switchgrass yields. Biochar amendments increased total soil C, C:N ratios, and soil moisture. Fertilization acidified soil pH and decreased total soil C and N pools. Switchgrass yields were increased and soil moisture was decreased with N fertilization.
Conclusions: The net effects of competition outweighed those of facilitation within this system. Competitive relationships amongst these species were altered by soil amendment-induced fertility. Favorable switchgrass responses to soil inorganic N suggests its competitive ability is increased on nitrogen-rich or fertilized sites.

1. Introduction

Understanding competitive relationships between trees and grasses is important in furthering our knowledge of community ecology within mixed-species ecosystems (Aerts, 1999). The simultaneous occurrence of facilitative and competitive interactions amongst species of differing growth forms makes quantifying these relationships difficult (Callaway et al., 1991; Callaway and Walker, 1997; Holmgren et al., 1997). Facilitation amongst trees and grasses may manifest as favorable changes in microclimate (Callaway, 1995), enhanced nutrient cycling (Nair et al., 1999; Palm, 1995; Rhoades, 1997), and increased soil moisture levels with shading (Rhoades, 1997). Unabated interspecific competition may negate facilitative effects between plant species as they develop and compete for similar resource pools. The net effects of facilitative and competitive interactions regulate species fitness, yield, co-existence, and long-term successional trends. One factor shown to affect competitive relationships between two or more species is soil fertility (Tilman, 1980; Grime, 1979); however, no definitive consensus regarding the effects of soil fertility upon plant-plant competitive dynamics has emerged (Craine, 2005; Fynn et al., 2005; Grace, 1991). Soil amendments which favorably mediate soil properties and increase fertility could alter competitive dynamics across a variety of ecosystems.

One tree-grass system which has received recent attention in the southeastern United States is an intercropping system incorporating switchgrass (*Panicum virgatum* L.) between rows of loblolly pine (*Pinus taeda* L.) (Albaugh et al., 2012, 2014; Blazier et al., 2012; Minnick et al., 2014; Susaeta et al., 2012). Annually harvested switchgrass is grown for bioenergy feedstock while loblolly

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pine trees are grown for sawtimber. Benefits of a loblolly pine-switchgrass intercropping system compared to switchgrass monoculture may include improved N-use efficiency (Minnick et al., 2014), greater productivity per land area (Krapfl et al., 2015), improved switchgrass establishment (Blazier et al., 2012), increased wildlife habitat (Loman et al., 2014; Marshall et al., 2012), and carbon sequestration (Blazier et al., 2015; Strickland et al., 2014). Loblolly pine-switchgrass intercropping may also improve income earning potential and product diversification (Susaeta et al., 2012). There is a large potential for interspecific competition to decrease productivity within this system but silvicultural practices can, to some extent, mitigate these effects (Krapfl et al., 2015). If the loblolly pine-switchgrass intercropping system proves to be economically viable, it is likely that additional input factors such as soil amendments may be considered, which may affect the competitive balance of this system.

We examined loblolly pine-switchgrass competition dynamics across an induced range of soil resource availabilities by using soil amendments. The first amendment, biomass-derived black carbon (biochar), is derived from the pyrolysis of plant-based materials. Additions of biochar to soils have been shown to favorably affect a suite of soil attributes, including pH and solubility of heavy metals (Major et al., 2010), nutrient cycling (Ding et al., 2010; Gundale and DeLuca, 2007; Lehmann et al., 2002; Steiner et al., 2008), cation exchange capacity (Liang et al., 2006), soil moisture and nutrient retention (Laird et al., 2010; Lehmann et al., 2003; Karhu et al., 2011; Krapfl et al., 2014; Tryon, 1948), soil structure (Busscher et al., 2010; Downie et al., 2009), and microbial diversity (Lehmann et al., 2011; Warnock et al., 2007). Inorganic N fertilization is common throughout the United States and is applied to a variety of cropping systems to alleviate deficiencies and sustain high yields. Inorganic fertilizers have also been associated with negative impacts such as groundwater contamination and eutrophication (Carpenter et al., 1998; Spalding and Exner, 1993), increased soil acidity (Bolan et al., 1991), and greenhouse gas emissions (Galloway et al., 2003). Studies applying both biochar and fertilizers have typically found synergistic effects of the combination compared to biochar or fertilization alone (Asai et al., 2009; Blackwell et al., 2010; Lehmann et al., 2002; Major et al., 2010; Schulz and Glaser, 2012; Steiner et al., 2007, 2008; Van Zwieten et al., 2010).

Despite the potential for soil amendments such as biochar and fertilizer to mediate the competitive interactions of grass with trees, the dynamics of such a system have rarely been addressed. We initiated a field-scale study investigating competitive relationships between switchgrass and loblolly pine across a gradient of soil resource availabilities. We focused on the influence of switchgrass on the early growth of loblolly pine and induced interspecific switchgrass competition on pine. Even though pine seedlings induce some competitive pressure on switchgrass, this effect is minor at this early stage of pine growth (1–2 years old in this study; see Krapfl et al., 2015). Therefore this study and the remainder of this manuscript is focused on the interspecific competition of switchgrass on pine, hereafter referred to as competition. To test the ability of soil resources to influence the competitive relations amongst the species we applied soil amendments at varying rates. Our first objective was to examine the effects of competition upon soil resources and productivity to evaluate the hypothesis that competition is a major driver of vegetation dynamics at the time of stand regeneration within the loblolly pine-switchgrass intercropping system. Additionally, we evaluated the effects of biochar and N fertilization upon vegetation dynamics to investigate the hypothesis that soil resource availability alters the ways in which trees interact with grass across a gradient of grass competition.

2. Materials and methods

2.1. Study establishment

A replicated (n = 6) field trial was established in 2012 in northeastern Mississippi, USA (33°23′N, 88°44′W). The site is located on the western edge of the Blackland Prairie physiographic region, which is characterized by clayey, calcareous soils; soils at the site have a pH of 7.3–15 cm depth and are of the Catalpa silty clay loam series (fine, smectic, thermic Fluvaquentic Hapludolls) (USDA Soil Survey Staff, 2013). The site had been maintained as mowed pasture for decades prior to study initiation and was disc plowed in spring of 2012 prior to treatment initiation. Treatments, arranged as a fully factorial split-plot design, included varying rates of competitive intensity (high competition (HIGH), low competition (LOW), and pine only (PINE)), biochar (0, 5, and 20 Mg ha^{-1}), and inorganic N fertilization (0 and 56 kg ha^{-1}). Competitive intensity and biochar treatments were main plot factors while fertilization was a sub-plot factor. Within each plot (2.4 m radius, 18 m^2, Fig. 1), biochar derived from southern pine (Reprieve Renewables, Soperton GA) was hand applied according to treatment on a dry weight basis and immediately incorporated into the soil with a tractor-mounted disc plow to 15 cm depth; selected physico-chemical properties of the biochar are provided in Table 1. Four days later, plots were fertilized (0 or 56 kg ha^{-1} of N as NH_4NO_3) and cultipacked. Weedy vegetation was subsequently controlled by applying a tank-mixture of glyphosate and atrazine with a boom sprayer at rates of 0.26 and 0.96 L ha^{-1}, respectively. One-year-old varietal loblolly pine seedlings were double-planted and switchgrass plugs (9.0 × 7.6 cm plugs) were single-planted in spring of 2012. Loblolly pine seedlings were planted at the plot center with eight radii of switchgrass plants emerging from the plot center composed of two switchgrass plugs per radii (Fig. 1). Competitive intensity was controlled by switchgrass planting density; HIGH competition plots had switchgrass planted at 0.6 m spacing from pines while switchgrass in LOW competition plots were planted at 1.2 m spacing from pines. One month later, switchgrass survival was evaluated and approximately 25% of the plugs were replanted to ensure complete stocking. Where both loblolly pine seedlings survived, one was cut at ground-level retaining the tallest seedling per plot following the year 1 growing season. Switchgrass plugs were propagated in a greenhouse setting prior to planting according to methodology provided in Krapfl et al. (2014). A second application of NH_4NO_3 (either 0 or 56 kg ha^{-1} of N) was applied in spring of year 2. No evidence of insect or disease damage was observed over the study period for either species.

2.2. Field sampling and laboratory procedures

Growing season volumetric water content (VWC) was sampled monthly in year 1 and bi-monthly in year 2 with a FieldScout TDR 300 soil moisture meter (Spectrum® Technologies Inc., Aurora IL) at 20 cm depth. Volumetric soil moisture values were corrected based upon a calibration equation developed by the manufacturer for site-specific adjustment (FieldScout® TDR 300 Soil Moisture Meter Product Manual). Regardless of treatment, soil moisture measurements were collected on the same two opposing sides of the central pine tree at 0.3 m distance from the tree and averaged. In year 2, soil temperature within each plot was evaluated in conjunction with soil moisture with a soil thermometer (12 cm depth) at 0.3 m from trees. Soil cores (0–15 cm depth) were collected with a soil push probe near the beginning (spring) and end (fall) of each growing season on the same two opposing sides of the central pine tree at 0.3 m distance and composited by plot. Soil cores were transported to the lab, air dried, passed through a soil grinder fitted