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Research paper

Switchgrass growth and morphological changes under established pine-grass agroforestry systems in the lower coastal plain of North Carolina, United States

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ABSTRACT

Switchgrass (*Panicum virgatum* L.) intercropped with Loblolly pine (*Pinus taeda* L.) has been proposed as a potential biomass feedstock for biofuel production in the southeastern United States. This study investigated effects of treatments (intercropping *vs.* grass only) on biomass increment processes and morphological properties of switchgrass at two experimental plots (Lenoir1) located in the coastal plain of North Carolina. We also evaluated effects of trimming lower tree branches of pine trees on switchgrass growth at another watershed-scale site (Carteret7) in the same region. Results showed that biomass yield of intercropped switchgrass was reduced by adjacent trees and negatively affected by relative position of grass to trees at the 6th year after planting at Lenoir1. Relative grass-to-tree position was also found to be a significant ($p < 0.001$) factor affecting grass growth at Carteret7 site with tree age of 5 years old, which is irrespective to the trimming practice. Trimming lower tree branches did not significantly ($p = 0.57$) improve biomass yield of switchgrass at Carteret7. We also observed intercropped switchgrass typically had higher specific leaf area and grew taller compared to grass-only plots. Stem-to-leaf ratios of switchgrass were significantly ($p = 0.02$) affected by trees at Lenoir1, but not by trimming lower branches in Carteret7 and relative position of grass to trees at both study sites. Findings from this study are important for evaluating the viability of producing biofuel feedstocks using this proposed intercropping system in the southeastern United States.

1. Introduction

Sustainable biofuel production will ultimately play a key role for ensuring global energy security [1]. Currently, bioenergy feedstock comes primarily from agricultural crops such as maize and sorghum, influencing food and feed supply and eventually limiting expansion of grain-based ethanol production [2]. More and more interests were diverted to dedicated perennial grasses such as switchgrass (*Panicum virgatum* L.) grown on marginal lands as an alternative to biomass originating from agricultural crops [2–4]. In the southeastern United States, intercropping switchgrass between rows of loblolly pine (*Pinus taeda* L) trees in plantations has been proposed as a potential source of cellulosic biomass [5–7]. The vast area of pine plantations in this region (1580000 km^2 in 2010) and favorable environmental conditions provides a potential future for this novel cultivation system [7,8]. Understanding impacts of pine trees on switchgrass growth will be of critical importance for assessing long-term viability and sustainability of the system.

Although intercropping of pine trees and switchgrass for biomass production is relatively new, it shares many similarities with traditional agroforestry systems in terms of above- and belowground interactions between or among species [9–11]. Aboveground interspecies interactions typically involve microclimate modifications and light competition [10]. The latter is the main focus of many studies in agroforestry because it generally poses negative effects on crop productivity [11]. Significant decline in yield has been found for many understory species, such as wheat [12], soybean [13], and warm season grasses [5,14]. Availability of light for crops underneath trees can be affected by many

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factors such as tree age, tree density, canopy size, row orientation, and time of year [10,11]. Shading effects on crop growth are also subject to many other factors including soil type, site fertility status, climate condition, species, and management practices [10]. Different site-specific conditions may explain findings of past studies that found no impacts of shading on growth of understory species [15–17]. For instance, a study conducted in southeastern U.S. showed that yield of herbaceous vegetation was not affected by pine tree spacing ≥4.9 m [18]. Belowground competition for soil water and various nutrients is another factor affecting vegetation growth [9,10,19,20]. A number of studies have found that plant growth could be negatively affected due to competition for soil water [15,21–23]. Studies reporting crop yield decline caused by competition for nutrients are limited [24,25] because most agroforestry systems are fertilized at conventional agronomic levels [10]. Belowground interactions are affected by several biotic and abiotic factors such as soil resources availability, root characteristics, climatic conditions, and phenology [9,10].

Similar to these findings from traditional agroforestry systems, switchgrass growth could be negatively affected by adjacent trees in pine-switchgrass systems. Moreover, it is generally acknowledged that C4 species are theoretically more susceptible to shading conditions than C3 species [10,26,27]. Thus, tree shading effects on growth and productivity of switchgrass need to be thoroughly investigated to develop proper management practices to maximize biomass productivity within intercropping. Several studies have reported yield decline of switchgrass [28–30] and other crop-pasture species [31,32] under intercropping systems. Two recent studies in a pine-switchgrass intercropping land demonstrated that switchgrass yield [6] and gas (H_2O and CO_2) exchange rates of switchgrass [33] were not affected by intercropping versus grass-only treatments during the initial stage of the system. However, tree roots and canopy could negatively affect switchgrass growth and yield as the trees establish and mature. For example, an alley cropping study conducted in the midwestern United States showed that maize yield in rows adjacent to black walnut (*Juglans nigra* L.) or red oak (*Quercus rubra* L.) declined by more than 50% during the 10 years after establishment [15]. A plot scale study found that pine age (stage) is one factor that affects switchgrass growth in an agroforestry system in Louisiana, United States [5]. To infer potential impacts of tree shading on switchgrass growth, a greenhouse study [48] investigated switchgrass growth under artificial shade and found that tiller number, height, gas exchange rates, and biomass production were significantly reduced with increasing shade. In addition, they extrapolated their findings to actual pine-switchgrass plantation by measuring photosynthetic available radiation (PAR) levels between pine rows in a range of loblolly pine stands across southeastern U.S. They concluded that switchgrass biomass would be significantly reduced once leaf area index (LAI) of pine trees reaches 1.95 to 2.25, which will typically occur at a stand age of 6–7 years. Further field experimental studies are necessary to verify findings from greenhouse and field observations [34–36].

The objectives of this study were to experimentally: 1) investigate effect of pine trees on switchgrass growth in established pine-switchgrass intercropping systems; and 2) evaluate effects of trimming lower tree branches on improving biomass productivity by reducing tree shade. We hypothesized that: 1) switchgrass growth will be negatively affected by pine trees as trees grow larger; 2) trimming lower branches could effectively increase biomass yield of switchgrass and extend the longevity of biomass production in the intercropping system.

2. Materials and methods

2.1. Study sites and treatments

We conducted field measurements at two sites (Lenoir1 and Carteret7) on the North Carolina Lower Coastal Plain, southeastern United States (Fig. 1A and Fig. 1B). Lenoir1 (Fig. 1C) and Carteret7 (Fig. 1D) are located in Lenoir (35°15′ N, 77°27′ W) and Carteret (34°48′ N, 76°42′ W) counties of North Carolina, respectively. The sites were composed of loblolly pine plantations owned and managed by Weyerhaeuser for saw timber production. Both sites were established to investigate sustainability and productivity of loblolly pine-switchgrass intercropping to produce wood fiber and biofuel feedstock.

Lenoir1 was poorly drained with soils classified as either Pantego (fine, loamy siliceous, semiactive, thermic, Umbric Paleaquults) or Rains (fine, loamy, siliceous, semiactive, thermic Typic Paleaquults). Parallel open ditches spaced approximately 100 m at a depth of 1.0–1.2 m were installed in the early 1970s to improve trafficability and provide desirable soil water conditions for tree growth. Long-term mean annual precipitation was 1252 mm and long-term mean annual temperature was 16.5 °C [6]. Multiple treatments were established at the site based on a randomized complete block design [6]. Treatments were established three months after clearcut harvesting of a full rotation (34-year old) loblolly pine stand in September 2008. After site preparation, loblolly pine seedling trees were planted during winter of 2008 at about 1100 stems ha^{-1} on bedded rows spaced 6 m apart. Orientation of tree rows was from northeast to southwest (Fig. 1C). Although several treatments were established at Lenoir1, in this study, we compared switchgrass growth under switchgrass only (SWITCH) treatment and intercropping with pine trees (PSWITCH) in two replicated plots with an area of approximately 0.8 ha. Switchgrass (Alamo cultivar) was machine-seeded using a modified corn planter at 6 cm deep in June 2009 with 9 kg pure live seed per ha in rows spaced 0.38 m apart. Intercropped switchgrass was planted in 3-m wide alleys with edges approximately 1.5 m away from rows of pine trees. Switchgrass plots were sprayed with 2,4-D and a post-emergent herbicide (Basagran) in May 2010 to facilitate switchgrass establishment. Both treatments were fertilized annually after planting except in 2011. Measured LAI using AccuPAR LP-80 (Decagon Devices, Inc.) of pine trees was about 3.1 $m^2\ m^{-2}$ in June 2014 and the tree height was about 6.8 m (unpublished data). Detailed descriptions of the study site, experimental design, and treatments can be found in other studies [6,8,37].

Carteret7 was flat (less than 0.1% slope) and had hydric soil (Deloss fine sandy loam, Fine-loamy, mixed, semiactive, Thermic Typic Umbraquults). It was drained by four, 1.2-m deep parallel lateral ditches dug at 100 m spacing. Long-term mean annual precipitation and Penman-Monteith grass-reference evapotranspiration were 1517 mm and 1010 mm, respectively [39]. Detailed description of the study site and timeline of management practices implemented on it prior to switchgrass production can be found elsewhere [39–43]. Although several treatments were established at Carteret 7, only PSWITCH was included here to evaluate the effect of trimming lower tree branches on switchgrass growth. Intercropping treatments were established after clearcutting a 35-year old loblolly pine stand (about 25 ha) in spring of 2009. After standard site preparation, pine seedlings were planted in January 2010 at a density of 1087 trees ha^{-1}. Tree rows were oriented from east to west (Fig. 1D). Switchgrass (Alamo cultivar) was initially planted during August 2011 and replanted on April 2012 using the same planter as used at Lenoir1. Planting density was slightly higher (12.4 kg ha^{-1}) and row spacing was narrower (0.25 m) than at Lenoir1. In February 2012, switchgrass was replanted due to low