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Research paper

Effect of intercropping hybrid poplar and switchgrass on biomass yield, forage quality, and land use efficiency for bioenergy production

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ABSTRACT

Land use efficiency can be maximized if an intercropping system is utilized to produce switchgrass (*Panicum virgatum* L.) biomass within the alleys between hybrid poplar trees (*Populus* spp.). Information is limited on switchgrass production and intercropping system in the Pacific Northwest of U.S. The objectives of this study were to evaluate the effects of hybrid poplar trees on switchgrass yield and forage quality and to determine the land use efficiency in an intercropping system under irrigation. Three cultivars of switchgrass ('Kanlow', 'Blackwell', and 'Trailblazer') were planted in the alleys between hybrid poplar trees (Clones: OP367 and PC4) at the Greenwood Resources, Boardman, OR in 2011. Switchgrass growth was negatively influenced by hybrid poplar trees with mean leaf area index, tiller density, and switchgrass dry matter (DM) yield in the monoculture and intercropped plots equal to 4.9 and 1.7, 383 and 69 tillers m^{-2}, and 15 and 4 Mg ha^{-1}, respectively, in the third year of this study. The 3-year cumulative switchgrass monoculture, switchgrass intercropping, and tree yield was 47.7, 21.5, and 58.5 Mg ha^{-1}. As a result, cumulative land equivalent ratio during the three years of the study was 1.45 in intercropped compared to 1.0 in monoculture plots. This indicates that 45% more land would be required in monoculture system to produce the same amount of DM produced in the intercropping system. This study revealed that, despite the reduced switchgrass growth under hybrid poplar trees, intercropping hybrid poplar and switchgrass can improve land use efficiency for biomass production.

1. Introduction

Switchgrass (*Panicum virgatum* L.) is a model herbaceous species selected for second generation biofuel feedstock due to its high yielding capacity [1], low greenhouse gas emissions [2], greater net energy than oil-seeds [3], high water use efficiency [4], and high C sequestration ability [5]. Research highlighting switchgrass as viable feedstock for the production of cellulosic ethanol has been concentrated in the eastern U.S. [6]. Among southeastern states (NC, TN, VA, and WV), an average dry matter (DM) yield of 14.2 Mg ha^{-1} yr^{-1} was reported in seven year-old stands grown under dryland conditions [7]. Although the majority of switchgrass studies have been conducted east of the Rocky Mountains, switchgrass DM yields observed in western states are comparable or greater when grown under irrigation [1,5,8]. A study established in 2004 in southeastern WA near the Colombia River showed the cultivar Kanlow produced DM yield of 3.3, 21.0, and 22.6 Mg ha^{-1} during first, second, and third year of establishment, respectively [5] and maintained mean DM yield of 26.7 Mg ha^{-1} yr^{-1} for fourth to sixth year [1]. A study reported DM yields ranging between 13.0 and 27.1 Mg ha^{-1} yr^{-1} across four locations in CA, and showed a high capability for switchgrass feed stock production [8]. As many U.S. states concentrate on producing important cash crops (e.g., cotton, corn, soybean, and wheat), it is wise to diversify the feedstock production regions, reducing pressure of feedstock production across the

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There are concerns that using limited land resources for biofuel feedstock production may reduce resources for food and fiber. Alley cropping is the practice of intercropping plants in open areas between woody species. Intercropping of trees and crops improves N cycling [9], C sequestration [10], activity of soil microorganisms, and wildlife [11]. It reduces ground water contamination [12,13] and has early economic returns [14,15]. Incorporating alley cropping could substantially improve biomass production and land use efficiency. Hybrid poplar (*Populus* spp.) is a fast growing bioenergy woody species used for cogeneration of heat, electricity, and liquid fuel [16,17]. At some locations, hybrid poplar can produce up to 22 Mg ha^{-1} yr^{-1} of above ground biomass [18] and is often harvested in 10 years or less for timber production. Among other woody species, such as willow (*Salix* spp.) and eucalyptus (*Eucalyptus* spp.), investigated for biofuel production by the Department of Energy, hybrid poplar contains high cellulose (40%) and low lignin (22%), which make liquid fuels conversion easier [19].

Although intercropping two perennial crops is beneficial for many reasons, it also increases management difficulties. Generally, establishment of small-seeded warm-season grass is difficult because of high amounts of dormant seeds [20] and weak seedling vigor [21,22]. Shading may contribute to establishment failure by slowing plant growth [23,24] and decreasing biomass yield [25] especially in C_4 species with a higher light saturation point than C_3 grasses [26]. Switchgrass intercropped with loblolly pine (*Pinus taeda* L.) showed no shading effect on the second year after planting in eastern NC [27]. In view of the light efficiency of *P. taeda* plantations, a shading effect is anticipated to develop over time as suggested by the authors. Yield reduction associated with shading effect has been observed in warm-season grasses intercropped with tree species in other studies [28,29]. The yield reduction was correlated with the relative position of the grass to trees [30]. Given the well documented yield reduction of warm-season grasses in intercropping system, it is critical to assess overall productivity per unit land area. Land equivalent ratio (LER) is utilized to measure the degree of land use efficiency in intercropping [31,32]. A LER value greater than 1.0 indicates total biomass produced within a given intercropped area is greater than the biomass produced in a monoculture practice where by definition LEA equal to 1.0.

Despite the ongoing challenges of alley cropping, limited information is available on establishment and management of two leading biofuel crops, hybrid poplar and switchgrass, in an intercropping system in Pacific Northwest. A large quantity of feedstock can contribute to future energy demand in this region. Intercropping two leading bioenergy species, switchgrass and hybrid poplar, might increase biomass production per unit land area. The objectives of this study were to evaluate the effect of hybrid poplar trees on switchgrass DM yield and biomass quality and to determine a land use efficiency of the intercropping system in Pacific Northwest under irrigation.

2. Materials and methods

2.1. Climate

The 20-years (1998–2017) average daily temperature and annual precipitation at the study site were 11.2 °C and 204 mm, respectively (Fig. 1a and b). Average annual temperature and precipitation during the growing season (April to October) were 17.2 °C and 93 mm, respectively (Fig. 1a and b). Average daily temperature peaked in July and August during the study years. Annual precipitation in 2012 was 114 mm higher than the 20-years average. For more detail on monthly maximum, monthly average, monthly minimum temperatures, and soil temperatures, see Ref. [33].

2.2. Field preparation and experimental design

The poplar-switchgrass intercropping study was established in a field on the GreenWood Resources Inc., Boardman Tree Farm, Boardman, OR (45°46″, 119°32″ W; elevation 192 m; Frost Free Days 162; climatic data in Fig. 1) in 2011 on Quincy soil series (mixed, Mesic Xeric Torripsamments). The previous use of the site was continuous hybrid poplar plantation under the operation by Boardman Tree Farm. The field experiment was designed as a randomized complete block design with four experimental blocks. We tested three levels of each factor. The three deployment patterns were: 1) intercropping with *Populus* × *generosa* ‘OP367’, 2) intercropping with *P.* × *Canadensis* ‘PC4’, and 3) no poplar intercrop as a control. The three switchgrass cultivars, 1) Kanlow [34], 2) Blackwell [35], and 3) Trailblazer [36], were assigned to the subplots. Switchgrass monoculture plots were established at the same location under the same site conditions and management, adjacent to the switchgrass-hybrid poplar intercropped plots. The switchgrass monoculture plots allowed comparison of switchgrass production between intercropped plots and monoculture plots. Table 1 shows the analysis of variance that was used in analyzing the quantitative response data. Field plots comprise an area occupied by 30 poplar trees with north-south orientation configured 5 rows × 6 trees within rows. Tree spacing was 6 m between rows and 3 m between trees within rows. There was a single grass/poplar buffer bordering each plot; so, that the total plot dimension including the buffer was 5 rows × 12 trees (60 trees per plot). Each plot occupied 792 m^2. Each poplar varietal block containing four replicates was 6336 m^2. The total area occupied

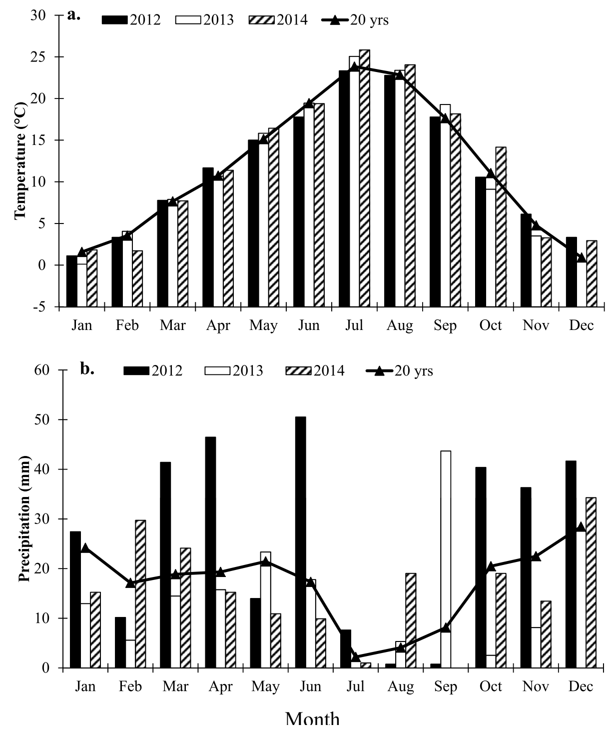

Fig. 1. Monthly temperature (a.) and precipitation (b.) along 2012 to 2014 at Boardman, OR.

Table 1
Analysis of Variance (ANOVA).

Source of Variation	DF
Block	3
Deployment Pattern	2
Whole Plot Error	6
Switchgrass Cultivar	2
Deployment × Cultivar interaction	4
Experimental Error	18
Total	35