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# Shade tolerance plays an important role in biomass production of different poplar genotypes in a high-density plantation

Ningning Wang [a,b,1], Qinjun Huang [c,1], Jingru Sun [a,b], Suli Yan [a,b], Changjun Ding [c], Xindi Mei [a,b], Dan Li [c], Xianjun Zeng [c], Xiaohua Su [c,*,2], Yingbai Shen [a,b,*,2]

[a] College of Biological Sciences and Technology, Beijing Forestry University, Beijing 100083, China
[b] National Engineering Laboratory for Tree Breeding, Beijing Forestry University, Beijing 100083, China
[c] State Key Laboratory of Tree Genetics and Breeding, Research Institute of Forestry, Chinese Academy of Forestry, Beijing 100091, China

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ABSTRACT

Poplar (*Populus* sp.) canopy provides considerable shading in high-density plantations, imposing adverse impacts on crown characteristics relating to biomass production, such as leaf area index (LAI) and photosynthesis. However, it is yet unclear how the LAI, photosynthesis, and biomass production of poplars would respond to shading. In this study, the shading responses were investigated in three poplar genotypes with contrasting biomass performance in a high-density plantation (1667 $ha^{-1}$) established six years prior to the study. A three dimensional laser scanner and a portable photosynthesis system were used to measure the canopy structure and photosynthetic parameters. Principal component analysis (PCA) and the partial least squares method (PLS) were used to determine the importance of measured variables to LAI and biomass. Among all the factors studied, LAI was one of the most related factors to biomass. The genotype with greater shade tolerance ability had higher LAI. Moreover, the high biomass genotype showed a low light compensation point (LCP) and respiration rate ($R_d$) accompanied with a high ratio of photosynthesis to respiration ($A_{max}/R_d$) and a high maximum photosynthetic rate ($A_{max}$). This characteristic was more distinct in the middle (M) and lower (L) crown layers than in the upper (U) crown layer. Therefore, high LAI, $A_{max}$ and $A_{max}/R_d$ accompanied by low LSP and $R_d$ are the key traits in obtain a high biomass genotype. Thus, improving shade tolerance in leaves of the middle and lower canopy layer to obtain a high LAI and biomass production can be an effective breeding method.



## 1. Introduction

Poplars (*Populus* sp.) are a renewable source of biomass energy and wood fiber products because of their fast growth and high production traits (Dickmann and Keathley, 1996; Tuskan, 1998; Broeckx et al., 2012). A better understanding on factors that influence biomass production is required to maximize the productivity of high-density poplar plantations. However, high-density plantations create a shading environment in their canopy, which adversely affects biomass production (Claveau et al., 2005). Thus, it is imperative to identify and quantify the shade tolerance of leaves contributing to canopy leaf area as well as biomass in order to aid the selection and breeding of poplar hybrids.

Light interception area, photosynthetic rate and crown structure are strongly affected by light environment (Cannell et al., 1988; Ishii et al., 2012; Li et al., 2012). Light interception and $CO_2$ assimilation affected by leaf area index (LAI) and photosynthesis, which are indispensable for biomass production (Barigah et al., 1994; Posada et al., 2009). Significant genotypic variability in crown architecture and photosynthesis has been reported within the genus poplar (Isebrands et al., 1988; Ceulemans et al., 1990; Wu and Stettler, 1996, 1998). Past researches on poplars have been mostly concerned on understanding and enhancing photosynthetic activity and light interception through optimization of canopy structure–distribution and origination of branches and leaves. Branch diameter and branch length are the most important determinants of wood production and leaf area index (LAI) (Rae et al., 2004; Broeckx et al., 2012). There are clear evidence that canopy leaf area and LAI of poplars are strongly affected by sylleptic branches, which are a type of branches that grow out of the lateral buds during the same growing season (Scarascia-Mugnozza et al., 1999; Rae et al., 2004; Benomar et al., 2012; Verlinden et al.,

* Corresponding authors. Tel.: +86 1062889627; fax: +86 1062872015 (X. Su). Address: No. 35, Qinghua East Road, Haidian District, Beijing 100083, PR China. Tel.: +86 1062336563; fax: +86 1062336013 (Y. Shen).

*E-mail addresses:* suxh@caf.ac.cn (X. Su), ybshen@bjfu.edu.cn (Y. Shen).

[1] These authors contributed equally to this work.
[2] These authors contributed equally to this work.

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2013). Foliage aggregation may lead to lower light interception efficiency in stands with greater total leaf area (Cannell et al., 1988; Dickmann et al., 1990; Niinemets et al., 2004; Sinoquet et al., 2005). The leaf petiole and leaf inclination have important effects on foliage aggregation and light interception (Bunn et al., 2004; Niinemets et al., 2004; Rae et al., 2004; Chmura and Tjoelker, 2008). Leaf area and nitrogen distribution affect light interception and biomass of high-density plantations (Wu, 1993; Weith and Nordh, 2005; Weih and Rönnberg-Wästjung, 2007). High photosynthetic rate per unit leaf area and high ratio of photosynthesis to dark respiration of poplars are important traits of a high biomass ideotypes (Donald, 1968; Dickmann et al., 1990; Dickmann and Keathley, 1996). Isebrands et al. (1988) and Nelson (1988) showed that whole-tree photosynthesis integrated over the growing season was related to a superior growth with crowns composed of electrophile leaves that have a greater photosynthetic potential. However, these studies mainly focused on the morphology of two- or three-year-old crowns and trees with leaves that optimize light interception. The aboveground light environment is a key factor in biomass accumulation in high-density tree plantations, which have high biomass and serve as resources for biofuel and papermaking. Claveau et al. (2005) showed that biomass distribution traits varied with size and that most traits showed a significant interaction with both size and light. However, leaf responses to light have drawn little attention despite their importance for photosynthesis as well as biomass production in high-density plantations (Dickmann et al., 1990). Moreover, it is not certain if the traits of leaf response to light have direct and strong relations with biomass (Dickmann et al., 1990). This knowledge is necessary for breeders to choose and evaluate hybrids for high-density plantations and bio-energy production.

In the present study, the variations in crown leaf area and crown photosynthesis were examined in relation to biomass among three poplar genotypes grown in a high-density experimental plantation. All measurements were made during the sixth growing season following establishment. The general objective was to gain a better insight into the relations between traits of leaf response to light and biomass production. Such information would help in the selection of genotypes required for bio-energy plantations and interspecific hybridization. Firstly, we hypothesized that the poplar genotypes with different crown leaf area and LAI would have alternative growth strategies in high-density plantation. This hypothesis was addressed by determining the factors governing LAI and biomass production. Secondly, we hypothesized that genotypes differing in physiological characteristics of leaves in response to light would have different canopy leaf area and biomass accumulation. This was tested by studying the relationship between shade tolerance of leaves, LAI and tree biomass.

## 2. Material and methods

### 2.1. The genotypes

Three clonal genotypes of poplars were used in this study, namely genotypes 6, 14, and 171. The genotype 6 was produced by the hybridization of the maternal *P. deltoides* from Romania and the paternal *P. nigra* 'Vereecken' from the Netherlands. Genotype 14 has the same paternal as the genotype 6, and its maternal is a hybrid offspring of *P. deltoides* Bartr. cv. 'Shanhaiguanensis' from China and *P. deltoides* Bartr. cl. 'Harvard' (I-63/51) from Italy. The cross of genotypes 6 and 14 was made in 2002. The cross producing genotype 171 (*P. deltoides* cl.'55/65' × *P. deltoides* cl.'2KEN8') × (*P. nigra* 'Brummen' × *P. nigra* 'Piccarolo') was made in 2003.

### 2.2. The field trials and site description

The study started in the spring of 2007, at a site in Linghai in the southern part of Jinzhou, Liaoning province (41°17′ N, 121°36′ E), with an elevation of 17 m above sea level. Before the experimental plantation was established, the site was a farmland used for planting maize. Subject to a temperate monsoon climate, this area has a high temperature difference (30 °C). The long-term mean annual temperature of the area is 8–9 °C and the mean annual precipitation is 540–640 mm. The regional soil is a type of black loam with naturally good drainage.

The experimental plantation consisted of totally 22 clonal poplar hybrids (genotypes) in a randomized block design. The purpose of the plantation was to screen for high biomass clones from the 22 hybrids. One year roots without stems were planted for 3 m in rows and with 2 m between adjacent individuals within each row. There were three blocks in the plantation serving as biological replicates. The three replicate blocks were arranged in a line from north to south. Each block contained 11 single rows orienting from north to south, with the northern block containing 57 lines and the middle and southern blocks containing 43 lines. The plantation was established as a combination of monoclonal plots from one year old clonal plantlets. Within the plantation, trees of the genotype 6 were laid out in six rows and five lines, the genotype 14 in four rows and four lines, and the genotype 171 in three rows and four lines in the northern block; whereas in the middle and the southern blocks, trees of the clone 6 were distributed in six rows and four lines, the genotype 14 in four rows and four lines, and the genotype 171 in three rows and four lines.

Measurements were made on trees distributed in the middle of the clonal plots to avoid the possible edge effects.

### 2.3. Measurements

#### 2.3.1. Biomass production and canopy dimensions

Fifteen trees were chosen within each genotype and used for measurements of the stem biomass production and crown dimensions. On each of the monoclonal plots in each block, five trees in the middle of the plots were selected from the plot center, and the biomass data for the 5 trees were averaged to represent the biomass per plant (BP) of the block. Stem diameter was assessed as the main tree characteristic for woody biomass production. Diameter at breast height (1.3 m, DBH) were measured at the end of the growing season in 2012. DBH was measured to the nearest 0.1 cm with a DBH measuring caliper.

The tree height and crown width were measured from a 3D points cloud file. The points cloud files were scanned by a three dimensional laser scanner (Faro Laser Scanner Focus 3D; focus 3D 120, FARO technologies, Germany). The software accompanying the scanner, SCENE (5.0, FARO technologies, Germany), was used to combine the scanned points into a 3D image. Thereafter, both Geomagic studio (2012, 3D system, USA) and Geomagic Spark (3D system, USA) were used to measure the distance between two points. Several studies have used the laser scanner to achieve effective results (Sinoquet et al., 1997; Teobaldelli et al., 2008; Gaëtan et al., 2012). The tree height and crown width were measured by Geomagic studio (2012, 3D system, USA). Tree height is defined as the distance from a point at the ground level to the tip of the tree. The crown width was calculated as the average of projected crown diameter. Crown depth is the distance from the basal branch to the tip of the tree, calculated by subtracting the height from ground level to the lower live branches from tree height.

The stem, branches and leaves constitute aboveground biomass. Previous studies have shown that stem diameter and tree height are closely related to the biomass of a tree (Barigah et al., 1994;