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Influence of plant architecture on maize physiology and yield in the Heilonggang River valley

Shoubing Huang[a,1], *Yingbo Gao*[a,1], *Yebei Li*[a], *Lina Xu*[b], *Hongbin Tao*[a], *Pu Wang*[a,*]

[a]*College of Agronomy and Biotechnology, China Agricultural University, Beijing 100093, China*
[b]*College of Life Science and Technology, Henan institute of Science and Technology, Xinxiang 453003, China*

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ABSTRACT

The size and distribution of leaf area determine light interception in a crop canopy and influence overall photosynthesis and yield. Optimized plant architecture renders modern maize hybrids (*Zea mays* L.) more productive, owing to their tolerance of high plant densities. To determine physiological and yield response to maize plant architecture, a field experiment was conducted in 2010 and 2011. With the modern maize hybrid ZD958, three plant architectures, namely triangle, diamond and original plants, were included at two plant densities, 60,000 and 90,000 plants ha^{-1}. Triangle and diamond plants were derived from the original plant by spraying the chemical regulator Jindele (active ingredients, ethephon, and cycocel) at different vegetative stages. To assess the effects of plant architecture, a light interception model was developed. Plant height, ear height, leaf size, and leaf orientation of the two regulated plant architectures were significantly reduced or altered compared with those of the original plants. On average across both plant densities and years, the original plants showed higher yield than the triangle and diamond plants, probably because of larger leaf area. The two-year mean grain yield of the original and diamond plants were almost the same at 90,000 plants ha^{-1} (8714 vs. 8798 kg ha^{-1}). The yield increase (up to 5%) of the diamonds plant at high plant densities was a result of increased kernel number per ear, which was likely a consequence of improved plant architecture in the top and middle canopy layers. The optimized light distribution within the canopy can delay leaf senescence, especially for triangle plants. The fraction of incident radiation simulated by the interception model successfully reflected plant architecture traits. Integration of canopy openness is expected to increase the simulation accuracy of the present model. Maize plant architecture with increased tolerance of high densities is probably dependent on the smaller but flatter leaves around the ear.

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* *Corresponding author.*
E-mail address: wangpu@cau.edu.cn (P. Wang).
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[1] Authors contributed equally to this article.

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1. Introduction

Canopy architecture is an important factor determining yield of many crops as a result of interplant competition for light distribution and absorption, particularly in a dense population [1]. Canopy functions (e.g. photosynthesis) improve as leaf area index (LAI) increases until LAI reaches approximately 4 for many maize (*Zea mays*. L.) hybrids, but decrease with further LAI increase [2,3]. Correspondingly, grain yield of maize first increases and then decreases with increasing plant densities. Modern maize hybrids, which have erect leaves above the ear and flat leaves below the ear, can tolerate high plant densities, thus yielding better [4–6]. These cultivars have been widely accepted because of higher yields, but yields are lower than expected in some regions where solar radiation is limited, particularly during critical periods such as the silking or grain-filling periods. Reduced solar radiation can slow elongation of internodes [7], reduce leaf photosynthesis, and result in poor kernel setting in maize [8]. In the Heilonggang River valley (in the northern part of the North China Plain), almost all modern maize hybrids used in the past decade have not produced the expected grain yield under any favorable conditions that researchers or farmers could provide [9]. The suppressed yield in this area is assumed to result from insufficient photosynthetically active radiation (PAR) because of cloudy and drizzly weather conditions during silking and grain filling [10–12]. Canopy architecture could determine how PAR is intercepted and consequently influence canopy photosynthesis and grain yield [13–15]. Thus, optimizing plant architecture could be a method for increasing maize yield in this region.

Photosynthate for maize yield is produced largely by five or six leaves near and above the ear [16–18], but these leaves are largely shaded at high plant densities, resulting in reduced productivity. Liu et al. [18] found that removal of the two uppermost leaves was an effective way to increase maize yield at high densities as a result of increased kernel number per ear and increased ear number per unit area [18]. Kernel setting and kernel growth in maize are associated with light interception during the flowering period [19] and with assimilate production and translocation during the grain filling period (source–sink relationships). Both processes interact with ear position on the plant and are affected by position of leaves relative to the ear [17,20]. With this relationship in mind, it would be possible to achieve a further increase in grain yield for modern maize hybrids if plant architecture could be improved.

As described above, evaluation of plant architecture depends strongly on morphological and physiological parameters such as leaf area, angle and orientation, photosynthesis, and yield formation. It is difficult or impossible to collect robust field measurements of so many parameters, because of the costs of time and labor. Light projection models [21–23] and canopy architectural models [23] have been used in the evaluation of maize plant architecture. However, these models require even more parameters to assure simulation accuracy. It is desirable to develop a simple practice-oriented model that needs fewer parameters, based on a combination of subcomponents of the above models that are related to light interception or light distribution in the crop canopy.

The objectives of this study were accordingly to (i) evaluate physiological and yield responses of summer-planted maize to changes in plant architecture, and to (ii) develop a practice-oriented light interception model for the evaluation of maize plant architecture.

2. Materials and methods

2.1. Experimental site and design

The field experiment was conducted in 2010 and 2011 at Wuqiao Experimental Station (37°41′02″N, 116°37′23″E) of China Agricultural University, located in the Heilonggang River valley in the east of the North China Plain. In this region, soils are loams with pH of approximately 8.0. Soil at 0–20 cm depth contains 11.5 mg kg^{-1} organic matter, 1.1 mg kg^{-1} total nitrogen, 45.2 mg kg^{-1} available phosphorus, and 187.3 mg kg^{-1} available potassium. Mean annual precipitation and temperature are 560 mm and 14.0 °C, respectively. Weather variables during the 2010 and 2011 maize growing seasons are shown in Fig. 1.

The experiment was arranged in a split-plot design with plant density as the main factor and plant architecture as the second factor. Maize hybrid ZD958, which has been widely adopted in the region in the past decade, was used. Two plant densities were applied: 60,000 and 90,000 plants ha^{-1}. Regulated plant architectures (triangle and diamond) were obtained by spraying the chemical regulator "Jindele" (with active ingredients ethephon and cycocel; EC). Triangle plants were obtained by spraying 0.15 L ha^{-1} EC at the 6- and 8-leaf stages and diamond plants were obtained by spraying 0.225 L ha^{-1} EC at the 6-leaf and 0.15 L ha^{-1} EC at the 12-leaf stage. The original plants received the same amounts of H_2O. The plot size was 6 m × 10 m with a row spacing of 0.6 m, and each treatment had three replicates.

2.2. Field management

Maize seeds were manually sown into the standing stubble of winter wheat without tillage. The sowing and harvesting dates were June 24 and October 6, respectively, in both years. At sowing, 60 kg N ha^{-1}, 105 kg P_2O_5 ha^{-1}, 120 kg K_2O ha^{-1}, and 15.0 kg $ZnSO_4$ ha^{-1} were applied, and an additional extra 120 kg N ha^{-1} was applied at the 6-leaf stage. Irrigation (approximately 75 mm ha^{-1}) was applied immediately after sowing to achieve uniform emergence. Optimal management was used to control weeds, insects and diseases during the entire maize growing period.

2.3. Plant sampling and management

2.3.1. Leaf area index and leaf orientation value (LOV)

At silking stage and 25 days after silking in each plot, three plants were selected randomly in each plot to determine green leaf area (GLA). GLA was calculated as Σ (leaf length × maximum leaf width) × 0.75. Leaves with half yellow area were considered as senesced.

Leaf angles (LA) from the vertical of 10 randomly selected plants in each plot were measured with a clinometer at