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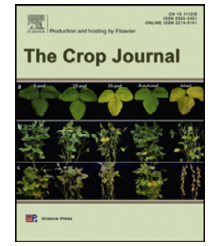

Relationship between plant canopy characteristics and photosynthetic productivity in diverse cultivars of cotton (*Gossypium hirsutum* L.)

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ABSTRACT

Genotype and plant type affect photosynthetic production by changing the canopy structure in crops. To analyze the mechanism of action of heterosis and plant type on canopy structure in cotton (*Gossypium hirsutum* L.), we had selected two cotton hybrids (Shiza 2, Xinluzao 43) and two conventional varieties (Xinluzao 13, Xinluzao 33) with different plant types in this experiment. We studied canopy characteristics and their correlation with photosynthesis in populations of different genotypes and plant types during yield formation in Xinjiang, China. Canopy characteristics including leaf area index (LAI), mean foliage tilt angle (MTA), canopy openness (DIFN), and chlorophyll relative content (SPAD). The results showed that LAI and SPAD peak values were higher and their peak values arrived later, and the adjustment capacity of MTA during the flowering and boll-forming stages was stronger in Xinluzao 43, with the normal-leaf, pagoda plant type, than these values in other varieties. DIFN of Xinluzao 43 remained between 0.09 and 0.12 during the flowering and boll-forming stages, but was lower than that in the other varieties during the boll-opening stage. Thus, these characteristics of Xinluzao 43 were helpful for optimizing the light environment and maximizing light interception, thereby increasing photosynthetic capability. The photosynthetic rate and photosynthetic area were thus affected by cotton genotype as changes in the adjustment range of MTA, increases in peak values of LAI and SPAD, and extension of the functional stage of leaves. Available photosynthetic area and canopy light environment were affected by cotton plant type as changes in MTA and DIFN. Heterosis expression and plant type development were coordinated during different growth stages, the key to optimizing the canopy structure and further increasing yield.

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1. Introduction

Optimizing crop canopy structure can improve canopy photosynthetic productivity and thereby crop yield potential [1–8]. The canopy structure of a crop is determined largely by the plant type. The plant type is the pattern of spatial arrangement and the combination of morphological and functional for all organs. The spatial arrangement associated with the yield, and the morphological and functional combination was involved in light-energy utilization in crops [9]. Plant type is important for the interception and use of solar energy and for increasing canopy photosynthetic productivity [10]. Plant type can effectively improve the canopy structure and can also affect canopy light distribution and light interception, increase light-energy absorption [11,12], and increase the yield of crops [13]. Solar energy utilization in the canopy is increased by coordination between heterosis utilization and plant-type modification [14–16].

Cotton has an indeterminate growth habit with a complex shape and living state of leaf, boll and branch [17]. The reproductive growth does not coincide with its apical dominance in cotton, and the reproductive organs are distributed within the cotton canopy, so that cotton plants have many reproductive growth centers distributed throughout the canopy. For this reason, research on its plant structure is more complex than that in gramineous crops [18]. To date, owing to the ecological environment in Xinjiang, China, the canopy photosynthetic capacity of cotton has been considerably increased by the use of heterosis, and its yield in China has markedly increased [6–8]. Thus, improving photosynthetic efficiency is one of the keys to future yield increases in crops [19–21]. It is a research hotspot that the plant type was optimized to improving yield in cotton [22]. Research on optimizing plant type has been focused on the effect of plant type on photosynthate transport [23] and the development [24] and spatial distribution [8] of the boll. However, there has been little research on the relationship between cotton plant type, photosynthetic capacity of the canopy, and yield. In the present study we investigated how heterosis and plant type affect the photosynthetic characteristics of the cotton canopy. We determined the canopy structure and photosynthetic production characteristics of cotton varieties with different genotypes and plant types. The function mechanism of heterosis and plant type on canopy structure was analyzed. The results of this study will provide a reference not only for breeding cultivar combinations with the obvious advantage on yield but also for improving agronomic practices.

2. Materials and methods

2.1. Cultivars and treatments

According to the division method for categorizing cotton plant type [25], four varieties are cultivated over a comparatively large area in the planting area of cotton in Xinjiang (Fig. 1). They include Shiza 2, a hybrid variety with an okra-leaf type and an inverted-cone plant type; Xinluzao 43, a hybrid variety with a normal leaf type and a tower plant type; Xinluzao 13, a conventional variety with large normal leaf type and compact plant type; and Xinluzao 33, a conventional variety with small normal leaf type, one-flower in each branch, and cylindrical plant type. A type was assigned to the large-leaf type if the leaf area was larger than that of Xinluzao 43 and otherwise to the small-leaf type.

The experiment was conducted at the agricultural experimental station of Shihezi University (45°19′ N, 86°03′ E), Xinjiang, China in 2009 and 2010. The soil was covered with plastic film (also called soil film), and then small holes were made in the film and seeds were sown by hand. The plastic film was 1 m in width and the distance between two films was 40 cm. Four rows were planted in each film, giving row spacings of 60, 20, 40, and 20 cm (Fig. 2). Each cotton variety had been three replicates, there were twelve plots that each plot had 60.0 m^2, the plots were randomly established, in this experiment for a total of twelve plots. The planting density was 165,000 plants ha^{-1} and the same cultivation techniques were used in both years. As basal fertilizer, 1500 kg ha^{-1} of organic fertilizer, and the fertilizers including 240 kg ha^{-1} of pure N and 75.3 kg ha^{-1} of P were mixed into the soil before sowing. Dimethyl piperidinium chloride was applied 6 times throughout the growth period with a cumulative dosage of 300 g ha^{-1} for regulating cotton plant growth. In 2009, sowing was performed on April 19 and seedlings emerged on April 26. In 2010, sowing was performed on April 24 and seedlings emerged on April 30. Drip irrigation was applied 12 times during the growth period for a total of 6000 m^3 ha^{-1} including 270 kg ha^{-1} of pure N until the end of August. Topping was performed during July 8–10. Other agronomic practices conformed to local practices for high-yield cotton production.

2.2. Canopy structural and photosynthetic measurements

Indicators of canopy structure including chlorophyll relative content (SPAD value), canopy apparent photosynthesis (CAP), light interception rate (LIR), and accumulation of photosynthate were measured at key stages of cotton growth and development, including peak squaring stage, peak flowering stage, initial boll setting stage, later boll setting stage, and boll opening stage.

2.2.1. Canopy structural measurements

Leaf area index (LAI), mean foliage tilt angle (MTA), and canopy openness (DIFN) were recorded with an LAI-2000 canopy meter (LI-COR, USA) following Malone et al. [26] for 4 replicates in different rows for each plot. First, the probe of the meter was placed at a set level over the canopy, and then the measuring button was pressed once after two alert sounds. Second, the probe was placed at the same level above the ground in a four different row, and then the button was pressed again, with four such readings were taken in different rows after two alert sounds, thrice measure were randomly selected in each plot.

2.2.2. Chlorophyll relative content (SPAD value)

SPAD was measured with a SPAD-502 Plus chlorophyll meter (Minolta, Japan), on a young and fully expanded functional cotton leaf, the fourth below the main stem terminal before plant topping and the second from the top after topping.