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Effect of late planting and shading on cotton yield and fiber quality formation

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ABSTRACT

Due to the competition of temperature and light resources during the growing season of double cropping system (cotton-rapeseed or cotton-wheat), cotton is generally late-germinating and late-maturing and has to suffer from the two factors of declining temperature and low light especially in the late growth stage. In this study, late planting (LP) and shading were used to fit the two-factor interaction stress, and to investigate their effects on lint yield and fiber quality formation. Two cotton cultivars, Kemian 1 and Sumian 15, were grown in the field in 2010 and 2011 at three planting dates with three shading levels. Among the three yield components, boll weight and boll number were the most sensitive indices to cool temperature and low light, respectively. The two-factor interaction of cool temperature and low light had a significantly effect on boll weight and lint percentage. Fiber length under shading increased throughout the extended duration of fiber elongation ($T(Len)$) in the normal planting date of 25-April ($NPD_{25\text{-April}}$), and by the decline of maximum fiber elongation rate ($V(Len)_{max}$) in the late planting dates (LPD). Fiber strength was reduced under the two-factor interaction of $NPD_{25\text{-April}}$ and shading due to the decrease of the duration and the mean strengthen rate of fiber strength growth periods. With further temperature decreasing, shading reduced strength mainly due to lower cellulose content and fiber biomass. In addition, compared to Sumian 15, Kemian 1 had higher $V(Len)_{max}$ and longer $T(Mic)$ (data not shown) under the two-factor interaction of LP and shading, leading to longer fiber length and smaller decline of micronaire, and also had a lower decline in strength because of the smaller decline of fiber cellulose content and biomass. Therefore, cotton cultivar of Kemian 1 with a higher $V(Len)_{max}$, longer $T(Mic)$ and a less decline in cellulose content and biomass were more tolerant to the two-factor interaction.

1. Introduction

Cotton-rapeseed or cotton-wheat double cropping systems are popular in the Yangtze River Valley and Yellow River Valley of China (Dai and Dong, 2014). Due to the competition of temperature and light resources during the growing season of double cropping system, cotton is generally late-germinating and late-maturing and has to suffer from the two-factor interaction of declining temperature and low light especially in the late growth stage (Chen et al., 2014a,b). As an important economic crop, the highly variable properties of cotton fiber are associated with the quality of the yarn and machining efficiency (Bradow et al., 1997). However, cotton boll development and fiber quality were restricted partly because of cool temperature and low light in many cotton growing areas (Shu et al., 2009; Yeates et al., 2010).

Abbreviations: BO, boll opened day; *Cel* (*Bio*, *Len*, *Str* or *Mic*), cotton fiber cellulose (biomass, length, strength or micronaire); *CRLR*, crop relative light rate; CV(%), coefficient of variance; DPA, days post anthesis; LP, late planting; LPD, late planting dates; PAR_0, photosynthetic active radiation measured at the position about 0.2 m above the canopy; NPD, normal planting date; *T*, the duration of the fiber cellulose rapid-accumulation (biomass rapid-accumulation or rapid-elongation) period; T_{RG} (T_{SG}), the duration of the rapid (steady) growth periods of fiber strength; V_{max}, maximum fiber cellulose accumulation rate (maximum biomass accumulation rate or maximum elongation rate); V_{RG} (V_{SG}), the mean strengthen rate of rapid (steady) growth period of fiber strength; ↑Δ% or ↓Δ%, increasing amplitude or decreasing amplitude.

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To more realistically reflect the effect of cool temperature on cotton growth and development, planting date studies have been used instead of controlled environment chamber studies (Zheng et al., 2012; Liu et al., 2013). Planting date for cotton is one of the principal determinants of lint yield and fiber quality potential. A number of studies indicated that late planting (LP) usually resulted in reduced lint yield with low boll weight due to delayed maturity and carbohydrate deficiency (Arshad et al., 2007; Gwathmey and Clement, 2010). The response of fiber quality to planting date had not come to an agreement because plant density, fertilization, weather events and cultivars adaptation can all influence fiber quality (Liakatas et al., 1998). Compared with normal-planted cotton, late-planted cotton had fiber with greater elongation and lower micronaire, while fiber length and strength decreased, remained unchanged, or increased in the late-planted cotton or under cool temperature (Shu et al., 2008; Wrather et al., 2008; Cao et al., 2011; Liu et al., 2015).

During the flowering and boll formation period, field-grown cotton suffered from low light conditions. Researchers have mainly used shading to analyze the effect of low light on cotton yield and fiber quality formation. Shading decreased net photosynthetic rate and enzyme activities that participate in the Calvin cycle in cotton leaf (Zhao and Oosterhuis, 1998; Pettigrew, 2001), reduced the assimilate supply, and decreased lint yield and fiber quality consequently. Boll number was the most sensitive yield component to shading (Zhao and Oosterhuis, 2000; Lv et al., 2013). Boll weight was also decreased through reducing carpel growth, fiber biomass maximum increase rate and fiber final biomass (Dusserre et al., 2002). However, the response of fiber quality to shading didn't have come to an agreement because of timing and duration of shading (Zhao and Oosterhuis, 1996). Cotton had fiber with lower strength and micronaire, while fiber length decreased or increased under shading conditions (Zhao and Oosterhuis, 2000; Wang et al., 2006; Lv et al., 2013).

Previous studies were conducted using only a single factor of cool temperature (late planting) or low light (shading). However, cool temperature and low light often appear together during the flowering and boll formation period of field-grown cotton in the Yangtze River Valley. Little is known about assessing the two-factor interaction of cool temperature plus low light on cotton yield and fiber quality formation. Therefore, late planting (LP) and shading were used to fit the combined situation which cotton generally suffers from in the cotton-rapeseed or cotton-wheat double cropping systems. The objectives of this study were (1) to determine the impact of declining temperature and low light (formed by LP and shading) on lint yield and fiber quality formation; (2) to elucidate their relationships with fiber biomass and cellulose; (3) to identify the difference of temperature-tolerate cultivar and temperature-sensitive cultivar in lint yield and fiber quality formation. These results should provide a theoretical basis for cotton cultivation techniques of fine fiber quality to adapt climatic changes.

2. Materials and methods

2.1. Experimental design

Cotton cultivars were different sensitive to cool temperature (Martin and Haigler, 2004). Based on the variance of fiber strength, 14 diverse cultivars, widely grown in the Yangtze River Valley in China, were studied with different flowering dates (Wang et al., 2008, 2009). Therefore, Kemian 1 (cool temperature-tolerate) and Sumian 15 (cool temperature-sensitive) were selected in this study. Furthermore, it was found that Sumian 15 was more sensitive than Kemian 1 in cellulose synthesis and leaf sucrose metabolism under cool temperature due to late planting (Shu et al., 2009; Liu et al., 2013).

Field experiments were conducted at Pailou experimental station of Nanjing Agricultural University at Nanjing (32°02′N, 118°50′E), China, in the Yangtze River Valley in 2010 and 2011. The soil at the experimental site was clay, mixed, thermic, Typic Udalfs, Alfisols with 18 and 16 g kg^{-1} organic matter, 1.1 and 1.0 g kg^{-1} total N, 64 and 50 mg kg^{-1} mineral N (NH_4^+-N and NO_3^--N), 18 and 17 mg kg^{-1} Olsen P, and 102 and 96 mg kg^{-1} exchangeable K (NH_4OAc-K) contained in 20 cm depth of the soil profile before sowing cotton of two years, respectively.

In the field, different environmental conditions during the fiber developing period were provided by planting cotton on different dates, 25-April, 25-May and 10-June in 2010 and 2011. Planting date of 25-April ($NPD_{25\text{-April}}$) is comparatively appropriate to grow cotton in the Yangtze River Valley, and 25-May and 10-June are belong to late planting dates ($LPD_{25\text{-May}}$ and $LPD_{10\text{-June}}$). Cotton was sown in a nursery bed, and seedlings with three true leaves were transplanted to field at 80 cm × 25 cm spacing.

When approximately 50% of flowers in the first fruiting node of the 6–7th fruiting branches of plants in each planting date bloomed, three shading treatments were imposed for the plots of each planting date, including an non-shaded control (*CRLR* (crop relative light rate) 100%), mild shading (*CRLR* 80%), severe shading (*CRLR* 60%) achieved with different shading cloth which reduced the incident light by 20% and 40%, respectively. Shade cloths were removed after cotton bolls in the first fruiting node of the twelfth fruiting branches opened. Experiments were arranged as a randomized complete block design in the field with three replications. Each plot was 6 m wide and 11 m long, and the shade cloth over each plot was 12 m long, 7 m wide and 2 m above the plot. Furrow-irrigation was applied as needed during both seasons. Conventional insect and weed control methods were utilized as needed.

2.2. Sampling and processing

White flowers from the first or the second fruiting node positions on the 6–7th fruiting branches were tagged and labeled with small plastic tags on the same day to ensure that the tagged flowers were of equivalent metabolic and developmental ages. The labeled bolls were collected at 09:00–10:00 at 5 days post anthesis (DPA), and then over every 7 days from 10 DPA until boll opening (BO). The bolls of 5 DPA were only used for measuring fiber length, and fibers of the other bolls were hand-ginned and allowed to dry at ambient room temperature as described previously (Zhao et al., 2012). The dried fibers were preserved to determine biomass, cellulose content and fiber quality. To obtain fiber-quality measurements, the immature fibers were treated as mature fibers and equilibrated under the same humidity and temperature conditions (Zhao et al., 2012).

2.3. Measurements of cellulose content and fiber quality

Fibers were digested in an acetic–nitric reagent, and then cellulose contents were measured with anthrone (Updegraff, 1969).

Cotton fiber length (*Len*, mm) of the harvested bolls was measured using the water washing method (Thaker et al., 1989) within 30 DPA, and using a Y-146 cotton fiber photodometer (Taicang Electron Apparatus Co., Ltd., Suzhou, China) after 30 DPA. Fiber strength (*Str*, cN tex^{-1}) and micronaire of the immature bolls were measured by a KX-154 fiber bundle tensile tester (Kang-xin Optoelectronics Co., Ltd., Shanghai, China) and a Y145C Airometer (Ningbo Textile Instrument Factory, Ningbo, China), respectively. Cotton fiber strength and micronaire of the mature bolls were determined by Uster HVI 1000 Classing (Uster Technologies AG, Uster, Switzerland).