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Manipulation of dry matter accumulation and partitioning with plant density in relation to yield stability of cotton under intensive management

Jianlong Dai, Weijiang Li, Wei Tang, Dongmei Zhang, Zhenhuai Li, Hequan Lu, A. Egrinya Eneji*, Hezhong Dong*

Cotton Research Center, Shandong Academy of Agricultural Sciences, Shandong Key Lab for Cotton Culture and Physiology, 202 Gongye Beilu, Jinan 250100, Shandong, China

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) yield under extensive field management across a certain range of plant population densities can be stabilized by manipulating the number of bolls and boll weight, but little is known of similar yield stability under intensive management and how the yield stability is achieved by dry matter accumulation and partitioning under various plant densities. A field experiment was conducted to study the effects of plant density (1.5, 3.3, 5.1, 6.9, 8.7 and 10.5 plants m^{-2}) on dry matter accumulation and partitioning in relation to cotton yield. The seedcotton and lint yields at 1.5 plants m^{-2} were significantly lower than those at other plant densities, but there was little difference in either seedcotton or lint yield among plant densities ranging from 3.3 to 10.5 plants m^{-2}. Plant biomass increased gradually with increasing plant density. The ratio of dry weight of fruiting forms to plant biomass (DWFF/PB) at 135 days after sowing (DAS) at 1.5 plants m^{-2} exceeded those under 5.1 plants m^{-2} by 12.3%, 6.9 plants m^{-2} by 12.7%, 8.7 plants m^{-2} by 20.5% and 10.5 plants m^{-2} by 21.8%. Also, the harvest index at 1.5 plants m^{-2} exceeded those at 5.1, 6.9, 8.7 and 10.5 plants m^{-2} densities by 16.2, 16.2, 34.3, 38.7%, respectively. Seedcotton yield was positively correlated with total biomass at extremely low plant density (1.5 plants m^{-2}), but was better correlated with DWFF/PB at higher densities (5.1–10.5 plants m^{-2}). The boll weight of the last harvest was 6.0–6.3% lower than those of the first two harvests at 1.5 plants m^{-2}. Leaf senescence as indicated by reduced Pn and leaf area index (LAI) in later season occurred earlier at 1.5 plants m^{-2} than other plant densities. It was concluded that cotton yield is relatively stable across a wide range of plant densities even under intensive field management. The stability was achieved mainly through manipulation of dry matter accumulation and partitioning. The reduced boll weight of the last harvest was mainly due to earlier leaf senescence at 1.5 plants m^{-2}, which might explain the lower cotton productivity per unit ground area at such a low plant density.

1. Introduction

The adjustment of plant density has been an important agronomic practice for enhancing yield and profitability of cotton (*Gossypium hirsutum* L.) world-wide (Bednarz et al., 2006). Establishment of an acceptable population of cotton seedlings is paramount for high yields (Siebert et al., 2006). Many studies have shown that cotton yield was reduced at extremely high or low plant density (Smith et al., 1979; Bridge et al., 1973; Hawkins and Peacock, 1971). Although the optimum plant density varies with location, environment, cultivar and grower's preference (Silvertooth et al., 1999; Dong et al., 2006a, 2006b), the final lint yield of cotton is relatively stable across a wide range of plant population densities (Bednarz et al., 2000; Siebert et al., 2006). The lint yield of cotton is a function of three important factors––the number of bolls per unit ground area, boll weight and lint percentage. Yield stability across a certain range of population densities was achieved through adjusting the number of bolls and boll weight (Bednarz et al., 2000).

Plant population density is inversely related to mainstem node number and monopodial branch number (Jones and Wells, 1997; Fowler and Ray, 1977; Buxton et al., 1979). Decreased plant density resulted in greater fruiting site production and fruit retention

* Corresponding authors. Tel.: +86 531 83179255; fax: +86 531 88618941.
E-mail addresses: aeeneji@yahoo.co.uk (A.E. Eneji), donghz@saas.ac.cn (H. Dong).

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but heavier fruit production of individual plants, while fruiting site production, fruit retention and boll weight were reduced as population density increased (Siebert et al., 2006; Bednarz et al., 2000; Jones and Wells, 1997). Higher plant densities also produced longer sympodial and monopodial plastocrons (Kerby et al., 1990; Kerby and Buxton, 1978) and longer boll maturation period (Buxton et al., 1979; Galanopoulou-Sendouka et al., 1980). These combined effects resulted in fewer bolls and less seedcotton on a per-plant basis, suggesting that yield stability across a range of population densities is achieved through manipulation of boll occurrence and boll weight under extensive management (Bednarz et al., 2000). Since intensive management involving plant pruning and topping considerably affects plant growth and development as compared with extensive management, it is necessary to determine if such yield stability exists under intensive management.

The economic yield of cotton is basically influenced by the balance of assimilate allocation between vegetative and reproductive organs (Reta-Sánchez and Fowler, 2002; Jones et al., 1996; Kerby et al., 1993). In China, intensive farming technologies involving plastic mulching, plant topping and pruning have been widely adopted for cotton production in the last 40 years (Dai and Dong, 2014). High yielding *Bt* (*Bacillus thuringiensis*) transgenic cotton has also been widely used in the Yellow River and Yangze River valleys in the last decade (Dai and Dong, 2014). Although most studies have consistently shown that cotton yield is determined by biomass accumulation and its proportion partitioned to reproductive organs (Saleem et al., 2010; Bange and Milroy, 2004; Wells and Meredith, 1984), these studies were mostly performed under extensive management with non-transgenic cotton varieties. There is little information on how dry matter accumulation and partitioning impact yield stability under intensive cotton farming. Therefore, a four-year experiment was carried out to study the effect of plant densities on dry matter accumulation and allocation, yield and yield components under intensive managements. The objective of this investigation was to determine (a) if cotton yield ranging from 3.3 to 10.5 plants m^{-2} can be stabilized through manipulation of the number of bolls and boll weight under intensive managements; (b) how such yield stability can be determined by adjusting the dry matter accumulation and partitioning; (c) how cotton yield is affected at extremely low plant population density.

2. Materials and methods

2.1. Experimental site and cultivar

The study was carried out from 2010 to 2013 at the Experimental Station of Shandong Cotton Research Center, Linqing (115°42′E, 36°61′N). It is located in the northwest of Shandong province in the Yellow River valley of China. The soil of the experimental site was sandy loam and contained 1.06% organic matter, 572 mg kg^{-1} total N, 15.5 mg kg^{-1} available P and 159 mg kg^{-1} available K. The climate is temperate and monsoonal with an average rainfall of about 600 mm with greater distribution in July and August. Cotton is usually planted in mid-April and harvested at the end of October, with a period of nearly 6 months for growth and development.

K836, a high-yielding commercial *Bt* (*B. thuringiensis*) transgenic cotton (*G. hirsutum* L.) cultivar, was used in the experiment. The cultivar was developed by Shandong Cotton Research Center and officially registered and released by the Shandong Crop Cultivar Registration Committee. The growth and developmental period from emergence to initial boll-opening in the experimental site was about 130 days. Acid-delinted seeds treated with imidacloprid (Gaucho FS600, Bayer CropScience, Monheim, Germany) were kindly provided by the Luyi Cottonseed Company Ltd., Jinan, Shandong.

2.2. Experimental design and field management

Cotton is usually planted at a population density of 4.5–6 plants m^{-2} in the Yellow River valley. Therefore, six density gradients, 1.5, 3.3, 5.1, 6.9, 8.7 and 10.5 plants m^{-2} were arranged in a randomized complete block design with four replications. Each plot contained six rows with 10 m in row length and 80 cm in row spacing.

For each year, soil was irrigated with well water at 1500 m^3 ha^{-1} 20–25 days before sowing. The amount of irrigation water was determined with a water meter. Soils were then ploughed and harrowed when their mellowness was considered physically acceptable. Cotton was sown on 25 April 2010, 28 April 2011, 27 April 2012 and 25 April 2013. With manual hill-drop planting methods, four seeds were dropped into the prepared furrow at a hill-hill distance in the same row of 83.3, 37.9, 24.5, 18.1, 14.4 and 11.9 cm for the six density (1.5, 3.3, 5.1, 6.9, 8.7 and 10.5 plants m^{-2}) treatments, respectively. The seeds were quickly covered with moist soil from both sides of the furrow and then mulched with plastic film (120 cm in width, and 0.008 mm in thickness) along the rows.

Seedlings were freed from mulching by cutting film above hills at full emergence, and thinned to 1.5, 3.3, 5.1, 6.9, 8.7 or 10.5 plants m^{-2} by leaving one vigorous plant per hill at the two-leaf stage. Vegetative branches (plant pruning) and growth terminals (plant topping) on the main stems of cotton plants in each plot were totally removed at squaring in mid-June and at peak boll-setting in mid-July according to local intensive management guidelines (Dai and Dong, 2014). A compound fertilizer was used to supply 81 kg ha^{-1} each of N, P_2O_5 and K_2O at sowing, followed by 101 kg N ha^{-1} as urea (45% N) at early flowering. Other management practices, including insect and weed control, and chemical control with plant growth regulators were conducted according to local agronomic practices.

2.3. Data collection

Data were collected for plant biomass at critical stages of crop growth, leaf area index, net photosynthetic rate, biological yield, lint yield and yield components. Twenty plants in the central two rows per plot were randomly tagged at maturity to determine yield components, biological yield and the ratio of fruit dry matter to total aboveground dry matter.

2.3.1. Yield and yield components

Plants in the central two rows of each plot were manually harvested three times (15 September and 10 and 28 October 2010; 17 September and 13 and 29 October 2011; 16 September and 11 and 30 October 2012; 14 September and 13 and 30 October 2013). Seedcotton was weighed for each plot after sun-drying. The number of bolls in the central two rows was recorded and the average boll size calculated. Seedcotton was ginned in a 10-saw gin, and then lint yield and lint percentage were obtained.

2.3.2. Biomass accumulation and partitioning and harvest index

Plant samples were collected from 1.0 m^2 area within each plot at 15-day intervals from 60 days after sowing (about peak squaring) to harvest. Total biomass including vegetative (stem, leaves and branches) and reproductive organs (squares, flowers, unopened bolls and open bolls) were separated. The dry weight (DW) of each partition was determined after oven drying at 75 °C to a constant weight. Dry matter partitioning as indicated by the ratio of dry weight of fruiting forms (DWFF) including squares, flowers, green bolls and open bolls to plant biomass (PB) was determined. Boll load per leaf area was also determined by dividing DWFF by leaf area (LA).