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Managing mepiquat chloride and plant density for optimal yield and quality of cotton

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ABSTRACT

The growth regulator mepiquat chloride (MC) is used in cotton production across the globe to control plant growth and maximize yield and quality of cotton. With the conversion from hand picking to mechanical harvesting in China, plant densities are increased, and more compact plants are required, leading to the need to reconsider MC application schedules. Experiments were carried out in 2009 and 2010 to identify optimal use schedules of MC at four plant densities: 3.0, 4.5, 6.0 and 7.5 plants m^{-2}. Eleven MC schedules were compared with respect to their effect on cotton yield and quality. Application of MC at squaring stage or at both squaring and flowering stages significantly improved cotton quality parameters: fiber length (by 1.7%) and fiber strength (by 2.8%) at all tested plant densities without significant loss of yields. However, average lint yield of all MC treatments over all densities and years was decreased by 4.6% due to a decrease in boll density and lint percentage which was only partly offset by an increase in boll weight. No effects on yield were also observed if MC applications were started at flowering stage, but such later starting application schedules only slightly improved fiber quality. The results suggest that use of MC at squaring or at both squaring and flowering stages is a viable strategy to improve cotton architecture, productivity and quality at high plant density in mechanized cotton production in the Yellow River cotton growing region in China.

1. Introduction

Cotton (*Gossypium hirsutum*) is a widely grown fiber crop across the globe. About 4 million hectares are grown annually in China, accounting for 20% of the world's cotton production (Dong et al., 2006b). The cotton plant is a perennial with indeterminate growth, continuing vegetative growth after fruiting has been initiated (Oosterhuis, 2001).

Smallholder farmers in the Yellow River and Yangtze River cotton growing regions still often grow cotton at low densities of around 3.5 plants m^{-2}, the advantage of low plant density being easier branch trimming (removal of vegetative branches) and hand harvesting. Mechanical harvesting is increasingly used, however, and it requires higher densities of 6.5–9.0 plants m^{-2} in combination with a lower and more compact plant (Dong et al., 2006a). The plant growth regulator mepiquat chloride, N,N-dimethylpiperidinium chloride (abbreviated here as MC), can be applied to manipulate plant structure to facilitate mechanical harvesting at high plant density, and is widely used for this purpose across the globe (Cathey and Meredith, 1988; Reddy et al., 1992). There is limited empirical knowledge base on the optimum use of MC at high plant densities in the Yellow River and Yangtze River cotton producing regions, which are characterized by a hot and humid summer monsoon, which promotes abundant vegetative growth.

MC is considered advantageous for controlling plant structure under conditions that promote vegetative growth, which is detrimental to fiber yield and quality (Kerby, 1985; Constable, 1995; Oosterhuis and Egilla, 1996). Excessive vegetative growth results in more shade within the plant canopy, increased fruit abscission, and reduced yield (Guinn, 1974). Use of MC results in a shorter and more compact plant, lower leaf area index due to smaller leaf size (Reddy et al., 1990) and earlier maturity (York, 1983a; Kerby, 1985). MC affects plant structure through interference with hormonal

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Table 1
Monthly weather data of experimental site during cotton growing season in 2009 and 2010.

Month	Average temperature (°C)			Precipitation (mm)			Sunshine hours (h)		
	2009	2010	30 years[a]	2009	2010	30 years	2009	2010	30 years
April	15.6	11.4	14.5	21.3	27.3	18.8	268.8	244.8	241.7
May	21.8	21.7	20.4	25.9	34.3	32.6	294.4	282.5	289.2
June	26.3	25.3	25.5	102.6	27.5	68.9	307.0	256.1	203.2
July	26.8	28.4	26.7	106.8	86.3	194.7	257.1	244.7	118.3
August	24.5	24.9	25.5	214.2	195.8	121.1	195.5	198.8	206.3
September	19.7	20.0	19.9	53.8	52.3	46.8	174.7	184.0	186.2
October	14.6	12.7	13.9	12.6	9.3	21.9	224.0	200.9	149.4
Total[b]	21.3	20.6	20.9	537.2	432.8	504.8	1721.5	1611.8	1394.3

[a] Indicates an average over thirty years from 1979 to 2008.
[b] Indicates total values except for temperature which is averaged.

regulatory processes. As these processes respond in complex ways to growing conditions and plant density, optimal MC schedules are difficult to identify. Stewart (2005) suggested that the optimal time for applying MC in Louisiana cotton is shortly after observation of the first flower buds ('squares') or at early flowering. He et al. (1984, 1991) suggested for Chinese cotton applying MC at all early development stages including seedling stage, squaring stage, flowering stage and boll stage, but these studies were conducted at low plant densities.

Cotton lint yield is determined by boll density (the number of bolls per unit area), individual boll weight and the percentage of lint (fiber) per boll. MC and plant density can be used to manipulate these yield components (Stewart, 2005). The yield response to MC varies, however. Some studies showed a negative yield response to MC (Zhao and Oosterhuis, 2000) while other showed no response (Nichols et al., 2003; Pettigrew and Johnson, 2005), or a positive response, especially under conditions that favor excessive vegetative growth, such as surplus nitrogen (Kerby et al., 1982), high plant density (York, 1983b), late planting (Cathey and Meredith, 1988), or warm and humid growing conditions (Gwathmey and Clement, 2010).

Much research has been done to determine the optimum plant density for yield and quality in cotton. Some studies reported no significant relationship between yield and plant density (Hawkins and Peacock, 1973; Baker, 1976; Jones and Wells, 1998; Bednarz et al., 2000), whereas others demonstrated a yield reduction at very high or low density (Bridge et al., 1973; Smith et al., 1979). Optimal plant density depends on environmental factors such a s temperature, rainfall and crop management, with lower optimal density at conditions favoring lush vegetative growth such as in Yellow River (Dong et al., 2010, 2012) and Yangtze River regions of China, and higher optimal density in conditions under which vegetative growth is more restrained, such as in Northwestern continental China (Xinjiang), which is characterized by hot dry growing conditions.

Plant density and MC application affect the quality of cotton lint (Cathey and Meredith, 1988; Siebert and Stewart, 2006). Important quality traits are fiber length, fiber strength and micronaire. Longer fiber results in higher quality yarn. Fiber strength is measured by assessing the force at which a standard fiber sample will break in units of cN (centiNewton: 1 cN = 1.02 g) per tex (ICC standard which means fiber weight per 1000 m yarn). Micronaire measures the air permeability of the fibers and depends on their fineness (linear density), strength and maturity (degree of cell-wall development) (Saville, 2004). The textile industry prefers micronaire ranged from 3.7 to 4.2. When the micronaire is lower than 3.5, the fibers are thin and considered immature, while fibers with micronaire greater than 4.9 are considered too thick for textile.

Even though many studies have been done to identify optimal application schedules of MC, several questions remain unanswered for Yellow River cotton growing region in China: (1) What is the optimal MC schedule in the hot and humid monsoon climate of this region? (2) Are there differences in optimal MC schedules between low and high plant density, as found by York (1983b)? (3) What is the effect of MC on yield components and quality traits? (4) Are effects of plant density and MC consistent between years? The objective of this study is to answer these questions and identify optimal schedules of MC application at different plant densities in the Yellow River cotton growing region.

2. Materials and methods

2.1. Experimental design

Field experiments were conducted at Hejian experimental station (Lat. 38°24′ N, Long. 116°06′ E, Elev. 11 m) of China Agricultural University in Hebei province, China, in 2009 and 2010. The soil is a sandy loam with 10.3 g kg^{-1} organic matter, 900 mg kg^{-1} total N, 12.6 mg kg^{-1} available P, and 163.5 mg kg^{-1} available K in the top 40 cm of the soil profile. Climate is a temperate monsoon. Table 1 provides monthly average daily temperatures, total precipitation and sunshine hours. Average rainfall (1979–2008) was 505 mm during the cotton growing season (April to October) and total sunshine hours 1394 h. In 2009, rainfall was 537 mm, 6% above the long term average, and in 2010 433 mm, 14% below the long term average. Total sunshine hours were 1722 h in 2009, and 1612 h in 2010, 23 and 16% higher than the long term average, respectively.

Cotton was sown at a row distance of 90 cm on April 20 in 2009 and on April 25 in 2010. The cultivar was Guoxin3 (GX3), a high-yielding commercial Bt (*Bacillus thuringiensis*) transgenic upland cotton variety. Fertilizer was given according to common practice in both years: 225 kg ha^{-1} N, 150 kg ha^{-1} P_2O_5 and 225 kg ha^{-1} K_2O. In each of the years, a single irrigation of 50 mm was applied, on July 10 in 2009 and on July 2 in 2010. The experiments were arranged in a split plot design with four replicates. Each plot consisted of six rows of cotton with a row length of 8 m.

The main plot treatment was plant density (3.0, 4.5, 6.0 and 7.5 plants m^{-2}). Plant distance within the row was 37.0 cm at a density of 3.0 plants m^{-2}, 24.7 cm at a density of 4.5 plants m^{-2}, 18.5 cm at a density of 6.0 plants m^{-2} and 14.8 cm at a density of 7.5 plants m^{-2}.

The sub-plot treatment was MC application schedule. There were 11 MC schedules, including an MC free control (Table 2). MC was applied in one through four of four plant stages: (1) seedling stage (4 main stem leaves); (2) squaring stage (i.e. after first square and before first open flower; 10 main stem leaves); (3) flowering stage (i.e. after first open flower and before first open boll; 16 main stem leaves); and (4) boll stage (i.e. after first open boll; 22 main stem leaves). The dose at each stage was tailored to the plant size: 6, 18, 45 and 60 g ha^{-1}. The treatment code (T*xy*) represents the