The *Journal of Cotton Science 21:183–189 (2017)*
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AGRONOMY AND SOILS

The Effects of Mepiquat Chloride Applied to Cotton at Early Bloom and Physiological Cutout

Guy D. Collins, Keith L. Edmisten, Randy Wells, and Jared R. Whitaker

ABSTRACT

Mepiquat chloride (MC), a plant growth regulator, is commonly used to manipulate growth and maturity of cotton. Most MC is applied during the pre-bloom period, at first bloom, or soon thereafter. However, there have been claims that late-season or cutout MC applications can increase yields and improve defoliation possibly through enhancing leaf maturity and reducing regrowth. Experiments were conducted during 2007 and 2008 in North Carolina and in two locations in Georgia during 2010 to investigate the effects of MC applied at early bloom versus cutout (nodes above white bloom = 3 to 4) on growth, defoliation, regrowth potential, and lint yield of cotton. Treatments consisted of a factorial arrangement of three MC rates (0, 0.05, and 0.1 kg ai ha^{-1}) applied at early bloom and two MC rates {0 and 0.05 kg ha^{-1}} applied at physiological cutout. Mepiquat chloride applied at early bloom reduced plant height in most environments and had variable effects on other growth characteristics. In some environments, MC applied at early bloom increased terminal regrowth and reduced basal regrowth in one year but had no effect on basal regrowth-to-height ratio. At most locations, cutout applications of MC had little or no practical effect on plant height, nearly all growth characteristics, crop maturity, defoliation, regrowth potential, yield, or fiber quality. Results from this experiment suggest that plant modifications resulting from MC occur when applications are made earlier in the season and that MC applied at cutout offers little or no advantage in plant management, lint yield, or fiber quality.

G.D. Collins, Department of Crop and Soil Sciences, Upper Coastal Plains Research Station, 2811 Nobles Mill Pond Road, Rocky Mount, NC 27801; K.L. Edmiston and R. Wells*, Department of Crop and Soil Sciences, North Carolina State University, Williams Hall, Box 7620, Raleigh, NC 27695; and J.R. Whitaker, Department of Crop and Soil Sciences, University of Georgia, 2306 Rainwater Rd., Tifton, GA 31793-5766.
*Corresponding author: rwells@ncsu.edu

Cotton production in the Southeastern United States (U.S.) often requires vegetative growth management to prevent the adverse effects of excessive growth or delayed maturity. One way that cotton growth can be manipulated to achieve optimal, harvest-efficient plant height is through the use of plant growth regulators (Cothren, 1994). Plant growth regulators containing *N,N*-dimethyl piperidinium chloride, or mepiquat chloride (MC) (Cothren, 1994) or mepiquat pentaborate (*N,N*-dimethyl piperidinium pentaborate) (Johnson and Pettigrew, 2006; O'Berry et al. 2009) are commonly used to manipulate growth and maturity of cotton.

Plant growth regulators containing MC affect cell elongation and expansion by inhibiting gibberellins synthesis, hormones that promote stem elongation (Hake et al., 1991). Research across the cotton belt has indicated that mepiquat-containing products can reduce plant height (Johnson and Pettigrew, 2006; Jost and Dollar, 2004; Nichols et al. 2003; Nuti et al. 2006; O'berry et al. 2009; Pettigrew and Johnson, 2005; Reddy et al. 1992; Ritchie et al. 2008; Siebert and Stewart, 2006; York, 1983a), number of nodes (Jost and Dollar, 2004; Nichols et al. 2003; Nuti et al. 2006; Reddy et al. 1992; Siebert and Stewart, 2006), height-to-node ratio (Johnson and Pettigrew, 2006; Nichols et al. 2003; Nuti et al. 2006; O'berry et al. 2009), internode length (Nuti et al. 2006; Reddy et al. 1992), nodes above white flower (NAWF) (Johnson and Pettigrew, 2006; O'Berry et al. 2009; Pettigrew and Johnson, 2005), and days required to reach nodes above white bloom equal to five (Craig and Gwathmey, 2005) while increasing flower production during the early part of the season (Pettigrew and Johnson, 2005) and the proportion of fruit retained on lower branches (Nuti et al. 2006; Prince et al., 2000). The improved retention of bolls at lower fruiting sites on the plant can promote early maturity (Nuti et al. 2006), and is thought to be a result of improvements in light penetration to lower leaves in the canopy and/or by diverting carbohydrates towards boll development as opposed to vegetative structures (Hake et al. 1991). O'Berry et al. (2009) and York (1983a) noted that improvements in earliness and maturity due to mepiquat application. They further suggested benefits from an earlier harvest and avoidance of unfavorable late-season weather conditions.

Researchers and extension recommendations have suggested that other advantages associated with reduced vegetative growth may include improved insect management (Edmisten, 2009), reduced liklihood of boll rot (Edmisten, 2009; Jost and Dollar, 2004), improved harvest efficiency (Jost and Dollar, 2004) due to shorter, more uniform plants, and potentially increased yields (Edmisten, 2009; Jost and Dollar, 2004). Yield response to MC has been inconsistent. Some researchers have reported yield increases due to MC application in some environments (Coccaro et al. 2004; Elbehar et al. 1996; Elbehar and Welch, 1996; Nichols et al. 2003; Siebert and Stewart, 2006; York, 1983a; York, 1983b) while others have reported no yield response (Craig and Gwathmey, 2005; Edmisten, 1994; Prince et al., 2000; York, 1983a) or yield losses due to MC (O'Berry et al. 2009; York, 1983a).

The optimal MC application rate or strategy is variable among environments, regions, or agronomic systems. Some researchers and extension recommendations have suggested that environmental conditions that would likely result in excessive vegetative growth, and thus a favorable response to MC application, include high plant populations, excessive fertility or soil moisture (Edmisten 2009; Nichols et al. 2003; O'Berry et al. 2009), and/or the utilization of late-maturing varieties (Edmisten 2009). York (1983b) suggested that mepiquat can offset the unfavorable effects of high plant populations, especially in conditions that promote rank growth or late maturity.

In the Southeastern U.S., it is generally recommended that MC be applied during the pre-bloom period to soon after the bloom period begins (especially in irrigated environments) to guide the plant into the bloom stage to the point where the increasing boll load can inhibit or control terminal growth; rarely is it recommended that MC be applied late into the bloom period, unless prior applications failed to suppress growth. It is generally thought that the potential advantages of MC application are non-existent or miniscule beyond mid-bloom in the Southeastern U.S. However, there have been some claims, primarily by consultants and industry representatives that MC applied at physiological cutout (cessation of upward effective blooming) may also be advantageous. Additionally, several labels for MC-containing products suggest positive results from cutout or late-season applications (http://www.cdms.net/LDat/ld75P004.pdf; http://www.cdms.net/ldat/ld6BH006.pdf).

There have been claims that MC applied late in the season can further enhance boll maturity and potentially increase yield, promote rapid leaf maturity which could facilitate defoliation, and possibly inhibit or reduce re-growth potential. Regrowth is the renewed growth that appears in the basal and terminal regions of the plant after boll demands for photosynthates have been met, and environmental conditions promote renewed vegetative growth. Some researchers have reported that greatest yield of Pima cotton was achieved through MC applied sequentially at mid- to late-bloom (Munk et al., 1998) while researchers in Arkansas assign negative effects on fiber yield to late-season applications (Cordell et al. 2005). These observations warrant an investigation of the effects of MC applied at cutout for cotton grown in the Southeastern U.S. The objective of this experiment was to investigate and contrast the effects of MC applied at early bloom and cutout on plant stature, defoliation, re-growth, lint yield, and fiber quality of cotton.

MATERIALS AND METHODS

Experiments were conducted in four environments (ENV1, ENV2, ENV3 and ENV4) between 2007 and 2010 in North Carolina and Georgia (Table 1). Late-maturing cultivars suitable for these environments were planted at a rate of 13.1 seeds m^{-1} in early to mid-May using a two-row vacuum planter. Plots contained four rows 12.2 m long and spaced 0.97 m apart. Treatments consisted of a factorial arrangement of 0, 0.05, or 0.1 kg a.i. ha^{-1} MC applied at early bloom (5 to 6 white blooms per 7.6 m of row or at plant heights of 75 to 85 cm if blooming was not yet initiated) and 0 and 0.05 kg ha^{-1} MC applied at physiological cutout [3 to 4.5 nodes above white flower (NAWF) and no earlier than three weeks of bloom period if a suspended cutout was observed]. Treatments were arranged in a randomized complete block design containing four replications. Nitrogen fertilization rates were 101 and 123 kg ha^{-1} for the North Carolina and Georgia environments, respectively. All other production and pest management practices were conducted according to the Cooperative Extension recommendations for that region.

Table 1. Experimental environments with location, planting date, cultivar, nodes above white flower (NAWF) at cutout MC application and soil type

Environment	Location	Planting Date	Cultivar	NAWF at cutout MC application	Soil Type
ENV1	Beulaville, NC	2 May 2007	Deltapine 164 B2RF[Z]	4.3	Norfolk fine sandy loam[Y]
ENV2	Beulaville, NC	6 May 2008	Deltapine 164 B2RF	3.7	Norfolk fine sandy loam
ENV3	Attapulgus, GA	13 May 2010	Deltapine 0949 B2RF	0.9	Dothan loamy sand[X]
ENV4	Tifton, GA	14 May 2010	Deltapine 0949 B2RF	3.2	Tifton sandy loam[W]

[Z] Both cultivars are medium to late maturity

[Y] fine-loamy, kaolinitic, thermic, Typic Kandiudult

[X] fine-loamy, kaolinitic, thermic Plinthic Kandiudult

[W] fine-loamy, kaolinitic, thermic, Plinthic Kandiudult

The early bloom treatments received MC (Mepex®, Nufarm Americas Inc., Burr Ridge IL.) at the respective rates on 27 June, 1 July, 6 July and 7 July when plant heights were 84, 75, 87 and 103 cm in environments ENV1, ENV2, ENV3 and ENV4, respectively. The cutout applications of MC in ENV1 were made on 26 July for early bloom MC applications and 7 August for treatments receiving no early bloom MC. Cutout MC treatments for ENV2, ENV3 and ENV4 were applied on 28 July, 2 August and 3 August, respectively.

Mepiquat chloride was applied using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} using TeeJet® XR110-02 flat-fan nozzles (TeeJet Technologies, Wheaton, IL). Plant heights were recorded for six plants in the center two rows of each plot on the day of early bloom application and plant height and NAWF on the day of cutout application in all environments. The number of total nodes and sympodial nodes, and mapping of fruit in all node zones were collected for six plants per plot in ENV1 and ENV2 only.

On the day of defoliation, percent open boll counts were recorded on a randomly chosen 1-m section of row within each plot, and nodes above cracked bolls (nodes between highest first position cracked boll and highest harvestable boll) were recorded for six plants per plot in ENV1 and ENV2. Defoliants were applied using the same sprayer used for MC application. Percent defoliation was determined at 7 and 14 days after treatment (DAT) in all environments. Percent dessication was recorded at 7 and 14 DAT in ENV1 and ENV2 only. Juvenile growth, or regrowth, was collected from six plants in the center two rows of each plot at approximately 20 days after defoliation. Regrowth was separated as either terminal or basal regrowth and was air-dried for one week at room temperature. Terminal regrowth included regrowth on the top four nodes of the plant, and basal regrowth included all other regrowth on the plant.

The center two rows of each experimental unit were harvested with a two-row spindle picker on 12, 17, 20 and 26 October for ENV1, ENV2, ENV3 and ENV4, respectively. Seed cotton weights for each plot were recorded and sub-samples were collected for lint percentage and high volume instrumentation analysis. Harvest data included lint yield, micronaire, length, length uniformity, and strength.

Data for maturity parameters, defoliation, regrowth, lint yield, and fiber quality parameters were subjected to analysis of variance using the general linear model in SAS version 9.1.3 (SAS Institute, Cary NC). Means of significant main effects and interactions were separated using Fisher's Protected LSD at $p \leq 0.05$ or 0.1.

RESULTS AND DISCUSSION

There were very few interactions between MC applied at early bloom and at cutout, therefore main effects are primarily discussed. Interactions between main effects and years were infrequent, but are discussed accordingly.

Environments. Rainfall and irrigation amounts are presented in Figure1A. Irrigation (2.5 cm) was applied on 14 June and 7, 13, 18, and 26 July in ENV4. Adequate moisture was available in all four environments with rainfall totals ranging from 39 to 46 cm at the beginning of September. Heat unit (HU) accumulation (Fig. 1B) was quite different between the North Carolina (ENV1 and ENV2) and Georgia (ENV3 and ENV4) environments. The mean total seasonal HU accumulation was 31% greater in the Georgia than in North Carolina environments. The rate of accumulation was also greater in Georgia than North Carolina. Regression analysis of the period from mid-June to the end of September revealed an increase of 87 and 72 HU/week in Geogia and North Carolina, respectively.

Increased heat unit accumulation at lower latitudes was reported by Wells and Edmisten (2009) and was implicated in both early and late season growth differences across the cotton growing regions.

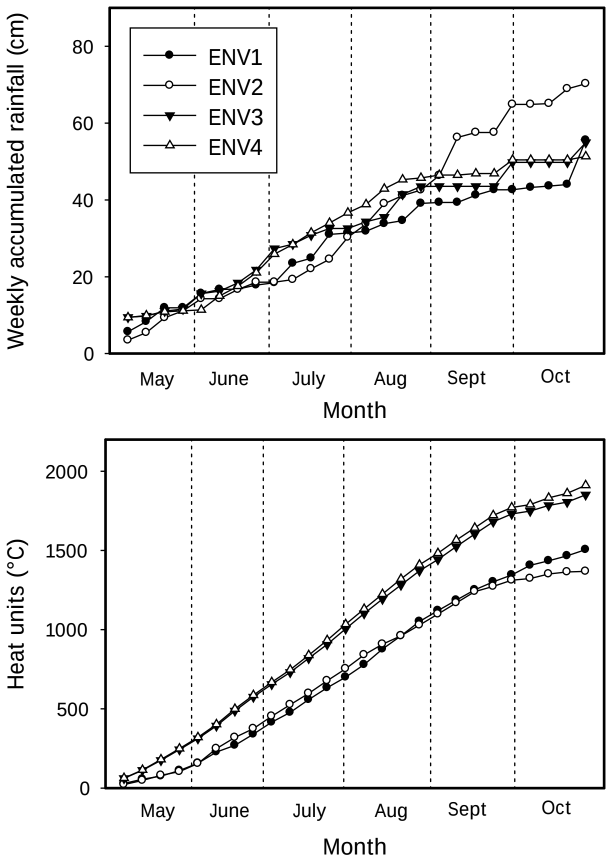

Figure 1. Weekly cumulative rainfall and irrigation amounts (A) and weekly accumulated heat units (B) from the four environments (ENV) studied. Discriptions of the environments are contained in Table 1.

Early Bloom Mepiquat Chloride Treatments. Growth characteristics most affected by early bloom MC treatments were those representing plant stature namely, plant height, number of sympodial nodes, total nodes and height-to-node ratio (Table 2). All locations, except ENV4, showed a main effect for MC applied at early bloom on plant height. In ENV1, ENV2 and ENV3, plant height was reduced 14.2% by the 0.05 kg ha^{-1} rate and 19.8% by the 0.1 kg ha^{-1} rate. These effects are similar to previous reports (Johnson and Pettigrew 2006; Nichols et al. 2003; Nuti et al. 2006; O'Berry et al. 2009; Pettigrew and Johnson, 2005; Reddy et al. 1992; Ritchie et al. 2008; Siebert and Stewart, 2006). In ENV1 and ENV2, MC increased sympodial boll retention from 43.6% to 49.0 and 51.8% for the 0.05 and 0.1 kg ha-1 MC treatments, respectively. Further, the 0.1 kg ha^{-1} rate reduced the number of sympodial nodes 14.6% (Table 2). Mepiquat chloride applied at early bloom at both rates reduced the number of nodes per plant 7 to 9%. In ENV1, height-to-node ratio was reduced 10% by the 0.05 kg ha^{-1} rate and 15% by the 0.1 kg ha^{-1} rate, while in ENV2, only the 0.1 kg ha^{-1} rate reduced height-to-node ratio 8%. Mepiquat chloride applied at early bloom had no effect on the node of first sympodium, and the number of sympodial and total bolls per plant.

Effects of early bloom MC treatments on boll development and late season events were evident only in ENV1 (data not shown). In that environment, MC treatments increased boll number at nodes eight to ten by an average of 39% (2.5 vs. 1.8). Similar findings were reported by Nuti et al. (2006), where MC applied at early bloom increased the number of bolls 23 to 33% on nodes eight through ten. These data indicate that MC can promote earlier maturity in some environments. Further, the 0.05 and 0.1 kg ha^{-1} MC treatments increased terminal regrowth by 65%. However, the values were relatively minor (2.7 and 3.9 g plant^{-1}, respectively). Basal regrowth was decreased by the 0.05 and 0.1 kg ha^{-1} MC treatments 25 and 33%, respectively when compared with the 34.9 g plant^{-1} found in the zero treatment. No early bloom MC treatments effects were evident in percent open bolls or nodes above cracked boll at the time of defoliation. In addition, neither defoliation nor desiccation percentages were affected by the early bloom MC treatments.

In ENV1, lint percentage was increased from 37 to 38% by the 0.1 kg ha^{-1} rate applied at early bloom as compared with the 0 treatment but only at $\alpha = 0.1$ ($p = 0.0695$). However, both MC rates applied at early bloom reduced lint percentage 2 % at all other locations also at $\alpha = 0.1$ ($p = 0.0501$) (Table 3). Biological significance of such differences seems trivial at best. Sympodial boll retention was significatly increased by 11 and 15.7% in response to the 0.05 and 0.1 kg ha^{-1} MC treatments. Neither rate had any effect on fiber yield, micronaire, fiber length, uniformity index, or fiber strength. Generally, the response of fiber yield to MC applications during early reproductive growth was variable. York (1983a) reported that, out of eight environments, three showed yield increases and one showed a yield decrease. Others have reported fiber yield increases (Coccaro et al. 2004; Elbehar et al. 1996; Elbehar and Welch, 1996; Nichols et al. 2003; Siebert and Stewart, 2006; York, 1983a; York, 1983b), decreases (O'Berry et al. 2009; York, 1983a) and no response to MC applications (Craig and Gwathmey, 2005; Edmisten, 1994; Prince et al., 2000; York, 1983a). In all cases, the environment x MC interaction appears extremely important in explaining reproductive responses.

Mepiquat Chloride Treatments at Cutout. At all locations, MC applied at cutout had no effect on plant height (Table 4). In ENV1 and ENV2, MC applied at cutout had no effect on sympodial and total node number, the node of first sympodium, the number of sympodia and the total number of bolls. Cutout MC increased height-to-node ratio 2% at these locations. Boll distribution in all node zones were generally unaffected by MC applied at cutout in ENV1 and ENV2 (data not shown). Mepiquat chloride applied at cutout also had no effect on percent open bolls, nodes above cracked boll, percent defoliation and and percent desiccation at seven DAT in ENV1 and ENV2 (data not shown). At all locations, terminal regrowth was not affected by MC applied at cutout. Further, basal regrowth was only affected by the MC applied at cutout in ENV1 ($\alpha = 0.1$, $P = 0.064$). Basal regrowth-to-height ratio was also reduced by MC applied at cutout in NC 2007, but not at any other location. There was substantial regrowth in all instances and MC treatments applied at cutout did little to hinder regrowth (data not shown).

At all locations, MC applied at cutout reduced lint percentage 1.7%, and more importantly reduced lint yield 2.6% but only at the 0.1 level of significance ($p = 0.0929$) (Table 5). Cordell et al (2005) reported that MC applications at cutout or later decreased fiber yield by 129.9 kg ha^{-1} or greater. Cutout MC affected neither fiber quality nor sympodial boll retention at any location (Table 5).

Table 2. Effect of mepiquat chloride (MC) applied at early bloom on growth characteristics measured at the time of the cutout MC treatments. Internodal length was measured in ENV1 and ENV2 only

MC rate applied at early bloom	Plant height		Internodal length			Node of first sympodium	Sympodia per plant	Sympodial bolls per plant	Bolls per plant
	ENV1 ENV2 ENV3	ENV4	Total nodes per plant	ENV1	ENV2				
kg ha^{-1}	---------- cm ----------		--- no. ---	---------- cm ----------		------------------------------ no. ------------------------------			
0	126.9	117.5	19.5	7.21	5.3	5.2	12.1	8.5	8.71
0.05	109.0	119.5	18.2	6.49	5.1	5.2	11.1	8.59	9.05
0.1	101.7	115.6	17.8	6.14	4.9	5.2	10.3	7.96	8.39
LSD(0.05)	4.6	NS	1.1	0.30	2.132	NS	1.01	NS	NS

Table 3. Effect of mepiquat chloride applied at early bloom on lint percentage, lint yield, fiber quality parameters and sympodial boll retention[Z]

MC rate applied at early bloom	Lint percentage		Lint yield	Micronaire	Upper half mean length	Uniformity index	Fiber strength	Sympodial Boll Retention
	ENV1	ENV2 ENV3 ENV4						
-kg ha^{-1}-	---------- % ----------		--- kg ha^{-1} ---	---- Units ----	----- cm -----	----- % -----	--- g tex^{-1} ---	----- % -----
0	37.0	39.7[X]	1262.4	4.7	2.8	81.6	29.3	43.6
0.05	37.9	38.8	1301.9	4.8	2.8	81.9	29.6	49.0
0.1	38.0[Y]	38.7	1321.4	4.8	2.9	81.7	29.5	51.8
LSD(0.05)	NS	NS	NS	NS	NS	NS	NS	3.8

[Z] **Data are pooled over locations unless otherwise noted.**

[Y] **Denotes values significantly higher than that of the non-treated control only at $\alpha = 0.1$ ($p = 0.07$).**

[X] **Denotes values significantly higher than all other treatments only at $\alpha = 0.1$ ($p = 0.0501$).**

Table 4. Effect of mepiquat chloride applied at cutout on growth characteristics measured at date of defoliation in ENV1 and ENV2 w Plant height was measured in all environments

MC rate applied at cutout	Plant height	Total nodes per plant	Internodal length	Node of first sympodium	Sympodiaper plant	Sympodial bolls per plant	Bolls per plant
kg ha^{-1}	-- cm --	------ no. ------	------ cm ------	--------------------------------------- no. ---------------------------------------			
0	113.3	18.9	5.8	5.2	11.3	8.5	8.9
0.05	114.3	18.1	5.9	5.2	11.0	8.2	8.5
LSD(0.05)	NS	NS	0.1	NS	NS	NS	NS

Table 5. Effect of mepiquat chloride applied at cutout on lint percentage, lint yield, and fiber quality parameters[Z]

MC rate applied at cutout	Lint percentage	Lint yield	Micronaire	Upper half mean length	Uniformity index	Fiber strength	Sympodial boll retention
kg ha^{-1}	------ % ------	- kg ha^{-1} -	---- Units ----	------- cm -------	------- % ------	--- g tex^{-1} ---	--------- % --------
0	39.1	1312.2[Y]	4.8	2.8	81.8	29.3	48.3
0.05	38.4	1278.3	4.8	2.8	81.7	29.6	47.9
LSD(0.05)	0.37	NS	NS	NS	NS	NS	NS

[Z] Data are pooled over locations.

[Y] Denotes significance between treatments only at $\alpha = 0.1$ ($p = 0.0929$).

In summary, MC applied at early bloom reduced plant stature as measured as plant height, nodal characteristics and height-to-node ratio. These data also suggest that there were little to no other advantages in terms of maturity or preparation for harvest. Although yield was unaffected by early bloom applications of MC in both years, the use of MC applied at appropriate rates and rates is still warranted for growth management purposes under growth promoting conditions (i.e. higher plant populations, low abiotic and biotic stress, adequate soil fertility and tilth). More importantly, results from this experiment also suggested that applying MC at cutout has little to no advantageous effects on plant growth, maturity, harvest preparation, or fiber yield. Most importantly, lint yields were reduced by MC applied at cutout at the $p \leq 0.1$ level which clearly negates any other potential advantage in management. These results also show little response to both the strikingly different total HU accumulation and rate of HU accumulation in Georgia versus North Carolina.

ACKNOWLEDGEMENT

This research was supported by Cotton Incorporated and the Georgia Cotton Commission

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