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AGRONOMY AND SOILS

Beltwide Evaluation of Commercially Available Plant Growth Regulators

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ABSTRACT

Plant growth regulator (PGR) use has become common in cotton (*Gossypium hirsutum* L.) production over the past 30 years. Plant growth regulators are widely used to manage plant height and suppress vegetative growth in cotton. However, the commercial introduction of new PGRs has prompted questions regarding comparative product performance in regard to height reduction, yield, and fiber quality. The objective of this study was to compare the effect of several commercially available PGRs on cotton growth, development, yield, and fiber quality. Field research was conducted in 2007 and 2008 at 22 locations representing 12 states. Products evaluated included mepiquat chloride, mepiquat chloride plus kinetin, mepiquat chloride plus cyclanilide, and mepiquat pentaborate. A non-ionic surfactant was included with all PGR applications, as well as alone, for comparison purposes. A non-treated check was also included. Application of all PGRs reduced end of season plant height. Plant height reductions varied depending on location. The total number of mainstem nodes was reduced due to PGR application in the Southwestern and Southeastern United States; however, no differences in lint yield, micronaire, or uniformity were observed due to PGR application in any region. Minor differences were present in nodes above cracked boll, fiber length, and fiber strength. No single product provided superior performance in regard to growth regulation, yield, or fiber quality.

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The use of plant growth regulators (PGR) has become commonplace in cotton (*Gossypium hirsutum* L.) production in the United States. The effect of PGRs, especially mepiquat chloride, on cotton growth and development is well documented. Applications of mepiquat chloride result in reduced internode elongation and plant height (Nuti et al., 2006; Reddy et al., 1990; Zhao and Oosterhuis, 2000). Shorter plant height and reduced internode elongation is a result of decreased levels of gibberellic acid in plant tissues. Reduced gibberellic acid affects cell elongation, decreases cell wall relaxation and plasticity and increases cell wall stiffness. Consequently, the capacity of cells to elongate and divide is reduced due to increased friction between cells (Behringer et al., 1990; Biles and Cothren, 2001; Yang et al., 1996). The effect of mepiquat chloride on the number of mainstem nodes is not well characterized. Reduced number of mainstem nodes has been observed following mepiquat chloride application (Kerby et al., 1998; Pettigrew and Johnson, 2005; Reddy et al., 1990; Stuart et al., 1984).

However, additional data indicates no difference in the number of mainstem nodes following application of mepiquat chloride (Zhao and Oosterhuis, 1999; Zhao and Oosterhuis, 2000).

The effect of mepiquat chloride on cotton yield has been inconsistent. Increased yield due to mepiquat chloride has been observed in previous research (Cathey and Meredith, 1988; Kerby, 1985; Kerby et al., 1998; York, 1983a). Increased yields due to mepiquat chloride may be due to redistribution of photo-assimilates between vegetative and reproductive growth (Nuti et al., 2006). However, other research demonstrated no yield response following application of mepiquat chloride (Boman and Westerman, 1994; Kerby et al., 1986; Zhao and Oosterhuis, 2000). Further research indicates mepiquat chloride can negatively impact yields (Cathey and Meredith, 1988; York, 1983a; York, 1983b; Zhao and Oosterhuis, 2000), especially in drought years (Crawford 1981; Kerby, 1985). Yield decreases due to mepiquat chloride may be due to restricted development of nodes and fruiting sites (Kerby, 1985). It has been postulated that yield responses following application of mepiquat chloride will not be seen during long, favorable growing seasons without excess vegetative growth (Kerby, 1985; Kerby et al., 1986). Inconsistent yield responses are likely due to unpredictable weather conditions following mepiquat chloride application (Cathey and Meredith, 1988). However, yield variances in all studies cannot be fully explained by environmental conditions (York, 1983a).

Acceleration of maturity is often claimed as a benefit of mepiquat chloride and has been observed in several experiments (Boman and Westerman, 1994; Cathey and Meredith, 1988; Kerby, 1985; Kerby et al., 1986; York, 1983a; York, 1983b). However, as with yield, the effect of mepiquat chloride on earliness has also been inconsistent. Additional research indicates mepiquat chloride had no effect on earliness (Crawford 1981; Stewart et al., 2000; Yeates et al., 2002). However, the potential for increased earliness exists under conditions for favorable growth or in short season production systems (Kerby et al., 1982).

The effect of mepiquat chloride on yield and fiber quality has also been inconsistent (York, 1983a). Mepiquat chloride application has been shown to have no effect on fiber quality properties (Nichols et al., 2003; Stewart et al., 2001). However, increased fiber length following mepiquat chloride application has been observed (Niles and Bader, 1986; Zhao and Oosterhuis, 1999). Additionally, Boman and Westerman (1994) reported increased fiber strength but no differences in micronaire, length, or uniformity due to mepiquat chloride. Although fiber quality differences have been reported, they are often of little economic significance (Kerby, 1985; Nuti et al., 2006; Siebert and Stewart, 2006).

A prepackaged mixture of mepiquat chloride plus cyclanilide has recently been released. Cyclanilide induces lateral shoot formation and inhibits apical growth in red kidney bean (Pederson et al., 2006) and in apple trees (Elfving and Visser, 2005). Cyclanilide is a PGR registered for use in cotton in combination with other PGRs and acts as a synergist when formulated with mepiquat chloride (Burton et al., 2008). Plant growth regulation effects of cyclanlide are thought to occur due to disrupted auxin movement (Burton et al., 2008) as well as inhibition of gibberillin synthesis (Vodrazka and Collins, 2005). Plant height reductions following application of mepiquat chloride plus cyclanilide were similar to that of mepiquat chloride (O'Berry and Faircloth, 2006; Thomas et al., 2007; Vodrazka and Collins 2005). Mepiquat chloride plus cyclanilide had no effect on total nodes (Vandiver et al., 2006); however, earlier maturity has been observed (O'Berry et al., 2006; Vodrazka and Collins, 2005). Cotton yield response following application of mepiquat chloride plus cyclanilide has been similar in inconsistency to mepiquat chloride. Increased cotton yield following application of mepiquat chloride plus cyclanilide has been observed (Vodrazka and Collins, 2005). However, other research suggests no effect on lint yield following application of mepiquat chloride plus cyclanilide (O'Berry and Faircloth, 2006; Vandiver et al., 2006). Mepiquat chloride plus cyclanilide had no effect on fiber quality properties (Vandiver et al., 2006).

Mepiquat pentaborate is a PGR containing 90 g ai L^{-1} (BASF 2009). However, mepiquat pentaborate contains the same molar concentration of mepiquat as that of mepiquat chloride (Gwathmey and Craig, 2003; Jost et al., 2006). Mepiquat pentaborate has been shown to significantly reduce plant height (Johnson and Pettigrew, 2006; Jones et al., 2009; O'Berry et al., 2007; O'Berry et al., 2009) and internode length (Johnson and Pettigrew, 2006). Plant height reduction following application of mepiquat pentaborate is similar to that of mepiquat chloride (Gwathmey and Criag, 2003; Pettigrew and Johnson 2005). Mepiquat pentaborate has been shown to reduce the number of mainstem nodes (Jones et al., 2009; O'Berry et al., 2009) and to increase earliness (Johnson and Pettigrew, 2006; O'Berry et al., 2007; O'Berry et al., 2009). Yield response following application of mepiquat pentaborate has been inconsistent. O'Berry et al., (2009) reported yield reductions following mepiquat pentaborate application. However, other reports indicate mepiquat pentaborate provided similar yields to that of mepiquat chloride, neither of which were better than the non-treated check (Gwathmey and Craig, 2003; Pettigrew and Johnson 2005). Mepiquat pentaborate has also been shown to have no effect on yield (Gola II et al., 2005; Hamm et al., 2007) while Asher et al. (2005) and Johnson and Pettigrew (2006) reported increased lint yield following application of mepiquat pentaborate. Data regarding the effect of mepiquat pentaborate on fiber quality also is inconsistent. Micronaire values were reduced following mepiquat pentaborate application (Jones et al., 2009; O'Berry et al., 2009) whereas no effect on uniformity was observed (O'Berry et al., 2009). Other research has shown increased fiber length and strength following mepiquat pentaborate application (Jones et al., 2009; O'Berry et al., 2009). Similar to previous research on mepiquat chloride, mepiquat pentaborate also has been shown to improve certain fiber properties; however, differences tend to be small in magnitude and of little economic importance (Johnson and Pettigrew, 2006).

Comparisons among mepiquat chloride, mepiquat pentaborate, and mepiquat chloride plus cyclanilide suggest that height reductions are similar among all PGRs (Barber and Stewart, 2007; Dollar et al., 2006; Everman et al., 2006). No difference in the number of mainstem nodes or earliness has been observed following application of any of these products (Gwathmey and Craig Jr., 2003; Pettigrew and Johnson 2005). Multiple product comparisons have resulted in inconsistent effects on yield and fiber quality. Similar yield responses for all products have been observed (Dollar et al., 2006; Jones et al., 2009). However, multiple applications of mepiquat chloride plus cyclanilide reduced yield when compared to mepiquat chloride or mepiquat pentaborate (Lemon et al., 2008). Fiber quality response is similar for all PGRs (Dollar et al., 2006; Lemon et al., 2008; Osborne et al., 2008). However, treatment with mepiquat chloride plus cyclanilide has improved fiber length uniformity compared to mepiquat chloride (Brown and Knowlton, 2007).

Although extensive research exists regarding individual PGRs, comprehensive data from across the Cotton Belt comparing the impact of several commercially available PGRs on cotton growth, yield, and fiber quality is lacking. Therefore, the objective of this research was to determine the effect of several PGRs on cotton growth, yield, and fiber quality across the Cotton Belt.

MATERIALS AND METHODS

Experiments were conducted at 22 locations in 12 states in 2007 and 2008 to determine the effect of several PGRs on cotton growth, development, yield, and fiber quality. Agronomic and PGR application information is given for all locations in Tables 1 and 2. All management practices including fertilization, insect management, weed management, and defoliation were performed according local extension recommendations. The experimental design was a randomized complete block with treatments replicated three or four times at each location.

Plant growth regulators evaluated in this study included: 1) mepiquat chloride (DuPont™ Mepex®, E.I. du Pont de Nemours and Company, Wilmington, DE 19898), 2) mepiquat chloride + kinetin (Dupont ™ Mepex® Gin Out™, E.I. du Pont de Nemours and Company, Wilmington, DE 19898), 3) mepiquat chloride + cyclanilide (Stance™ Plant Regulator, Bayer CropScience LP, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709), and 4) mepiquat pentaborate (Pentia™ Plant Regulator, BASF Agricultural Products, 26 Davis Dr., Research Triangle Park, NC 27709). Plant growth regulator application rates are given in Table 3. Plant growth regulator applications were initiated at the matchhead square growth stage with a second application made two to three weeks after the initial application. An additional treatment consisting of mepiquat chloride plus cyclanilide at the matchhead square stage followed by a second application two weeks later and a third application when node above white flower five was reached was included. A non-ionic surfactant was included with all treatments at 0.25% v/v. In order to measure the effect of the non-ionic surfactant on cotton growth, a treatment consisting of non-ionic surfactant alone at 0.25% v/v at the matchhead square stage followed by a second application two to three weeks later was included. A non-treated check was also included for comparison purposes. All PGR treatments were applied with a tractor-mounted, compressed air sprayer or a CO_2-pressurized backpack sprayer.

Table 1. Agronomic information for beltwide evaluation of commercially available plant growth regulators.

Location	Year	Region	Cultivar	Planting Date	Seeding Rate	Harvest Date	Date of 1st Application[z]	Date of 2nd Application[y]	Date of 3rd Application[x]
					Seed ha^{-1}				
Safford, AZ	2007	Southwest	DP 164 B2RF	19 April	194,000	28 November	26 June	10 July	17 August
Safford, AZ	2008	Southwest	DP 164 B2RF	15 April	194,000	13 November	25 June	22 July	19 August
Altus, OK	2007	Southwest	FM 9063 B2RF	16 May	128,000	01 November	02 July	16 July	22 August
Altus, OK	2008	Southwest	PHY 485 WRF	12 May	128,000	03 November	08 July	22 July	05 August
Halfway, TX	2007	Southwest	FM 9063 B2RF	17 May	138,000	03 November	17 July	01 August	15 August
Lamesa, TX	2008	Southwest	ST 5458 B2RF	08 May	116,000	01 November	27 June	15 July	06 August
Snook, TX	2007	Southwest	FM 9063 B2RF	19 April	124,000	18 October	07 June	22 June	10 July
Snook, TX	2008	Southwest	DP 555 BR	15 April	119,000	03 September	02 June	18 June	01 July
Rowher, AR	2007	Mid-South	PHY 485 WRF	07 May	136,000	04 October	25 June	11 July	09 August
Rowher. AR	2008	Mid-South	PHY 485 WRF	22 April	136,000	06 October	11 June	25 June	04 August
Alexandria, LA	2007	Mid-South	PHY 485 WRF	24 April	104,000	10 October	04 June	21 June	06 August
Starkville, MS	2008	Mid-South	PHY 485 WRF	07 May	128,000	30 October	18 June	04 July	19 July
Jackson, TN	2007	Mid-South	DP 143 B2RF	30 April	136,000	14 September	17 June	01 July	25 July
Jackson, TN	2008	Mid-South	DP 143 B2RF	03 May	136,000	05 October	03 July	18 July	11 August
Shorter, AL	2007	Southeast	DP 555 BR	27 April	197,000	17 September	22 June	16 July	27 July
Shorter, AL	2008	Southeast	DP 555 BR	23 April	197,000	18 September	18 June	11 July	04 August
Tifton, GA	2007	Southeast	DP 555 BR	23 April	126,000	25 September	11 June	25 June	16 July
Duplin Co., NC	2007	Southeast	DP 117 B2RF	02 May	136,000	17 October	02 July	16 July	26 July
Duplin Co., NC	2008	Southeast	DP 117 B2RF	06 May	151,000	24 October	12 June	23 June	28 July
Florence, SC	2007	Southeast	DP 555 BR	15 May	136,000	03 October	06 July	20 July	26 July
Florence, SC	2008	Southeast	DP 555 BR	20 May	136,000	16 October	01 July	14 July	31 July
Suffolk, VA	2007	Southeast	DP 117 B2RF	30 April	151,000	24 October	25 June	09 July	27 July

[z] First application was made at the matchhead square stage.

[y] Second application was made two to three weeks after matchhead square application.

[x] Third application was made at node above white flower = 5.

Table 2. Agronomic and plant growth regulator application information for beltwide evaluation of commercially available plant growth regulators.

Location	Year	Region	Soil Texture	Irrigation	Row Spacing	Plot Dimensions	Application Pressure	Spray Tip	Application Volume	Speed
					- cm -	# rows * length (m)	---- kPa ----		--- L ha^{-1} ---	Km hr^{-1}
Safford, AZ	2007	Southwest	Clay Loam	Furrow	97	4 * 12.2	207	Flat Fan	140	6.4
Safford, AZ	2008	Southwest	Clay Loam	Furrow	97	4 * 12.2	207	Flat Fan	140	6.4
Altus, OK	2007	Southwest	Clay Loam	Dryland	102	4 * 9.1	172	Flat Fan	94	6.4
Altus, OK	2008	Southwest	Clay Loam	Dryland	102	4 * 9.1	179	Flat Fan	94	6.4
Halfway, TX	2007	Southwest	Clay Loam	Pivot – LEPA[z]	102	4 * variable[y]	228	Flat Fan	140	5.6
Lamesa, TX	2008	Southwest	Fine Sandy Loam	Pivot – LEPA[z]	102	4 * 15.2	221	Flat Fan	140	5.6
Snook, TX	2007	Southwest	Clay Loam	Pivot	102	4 * 12.2	207	Flat Fan	103	6.4
Snook, TX	2008	Southwest	Clay Loam	Pivot	102	4 * 12.2	207	Flat Fan	103	6.4
Rowher, AR	2007	Mid-South	Silt Loam	Furrow	97	4 * 12.2	241	Flat Fan	140	5.5
Rowher. AR	2008	Mid-South	Silt Loam	Furrow	97	4 * 12.2	241	Flat Fan	140	5.5
Alexandria, LA	2007	Mid-South	Silt Loam	Dryland	97	4 * 12.2	331	Flat Fan	140	5.8
Starkville, MS	2008	Mid-South	Silty Clay Loam	Dryland	97	4 * 12.2	303	Flat Fan	140	4.8
Jackson, TN	2007	Mid-South	Silt Loam	Dryland	97	4 * 9.1	221	Flat Fan	114	6.4
Jackson, TN	2008	Mid-South	Silt Loam	Dryland	97	4 * 9.1	221	Flat Fan	114	6.4
Shorter, AL	2007	Southeast	Fine Sandy Loam	Dryland	91	4*15.2	276	Air Induction	140	6.8
Shorter, AL	2008	Southeast	Fine Sandy Loam	Dryland	91	4 * 15.2	276	Air Induction	140	6.8
Tifton, GA	2007	Southeast	Sandy Loam	Pivot	91	4 * 12.2	159	Flat Fan	94	4.8
Duplin Co., NC	2007	Southeast	Sandy Loam	Dryland	97	4 * 9.1	110	Air Induction	140	4.8
Duplin Co., NC	2008	Southeast	Sandy Loam	Dryland	97	4 * 9.1	110	Air Induction	140	4.8
Florence, SC	2007	Southeast	Loamy Sand	Dryland	97	4 * 12.2	276	Flat Fan	187	6.4
Florence, SC	2008	Southeast	Loamy Sand	Dryland	97	4 * 12.2	276	Flat Fan	187	6.4
Suffolk, VA	2007	Southeast	Loamy Sand	Dryland	76	4 * 9.1	221	Flat Fan	140	4.8

[z] Low Energy Precision Application Irrigation

[y] Variable row length due to plots being under center pivot irrigation system.

Table 3. Plant growth regulator application rates.

PGR Treatment[z]	Application Rate		
	1st application[y]	2nd application[x]	3rd application[w]
	------------------------------------ g ai ha^{-1} ------------------------------------		
Mepiquat chloride[v]	24.6	30.9	--
Mepiquat chloride + kinetin[u]	24.6 + 0.015	30.9 + 0.018	--
Mepiquat chloride + cyclanalide[t]	9.7 + 2.4	12.9 + 3.2	--
Mepiquat chloride + cyclanalide	12.9 + 3.2	19.4 + 4.8	--
Mepiquat chloride + cyclanalide	12.9 + 3.2	19.4 + 4.8	19.4 + 4.8
Mepiquat pentaborate[s]	57.6	72.0	--
Non-ionic surfactant	0.25% v/v	0.25% v/v	--

[z] Non-ionic surfactant was included with all plant growth regulator applications.

[y] 1st application was made at the matchhead square stage.

[x] 2nd application made two weeks after matchhead square application.

[w] 3rd application made at node above white flower = 5.

[v] DuPont™ Mepex® Plant Growth Regulator

[u] DuPont™ Mepex® Gin Out™ Plant Growth Regulator

[t] Stance™ Plant Regulator

[s] Pentia™ Plant Regulator

Plant height data from five to ten plants per plot was collected prior to the first and second applications (two weeks after the matchhead square application), two weeks after the second application, and at the end of the growing season. All plant height data are reported as percentage of the non-treated check. Percentage of the non-treated check was determined by dividing the average plant height in a given plot in each replication by the average plant height of the non-treated check in the same replication and multiplying by 100. Plant height data were normalized in this manner to account for variation in plant height across multiple locations. In addition, total nodes and nodes above cracked boll data were collected from five to ten plants per plot prior to defoliation. Defoliation was initiated when cotton was 60% open. Seed cotton was harvested using a cotton picker modified to harvest small plots at all locations except Halfway, TX, Lamesa, TX, and Altus, OK. A cotton stripper was used for plot harvest at these three locations. Seed cotton from each plot was ginned utilizing a 10-saw laboratory gin and lint percent as well as fiber quality data were collected. Lint percent was determined by dividing the mass of lint after ginning by the mass of seedcotton prior to ginning and multiplying by 100. High volume instrument (HVI) fiber quality data were obtained from United States Department of Agriculture classing offices or independent laboratories. Plant height (percent of the non-treated check), total nodes, nodes above cracked boll, lint yield, lint percent, and fiber quality data were subjected to analysis of variance using the PROC MIXED procedure of the Statistical Analysis System (SAS® version 9.2; SAS® Institute Inc.; Cary, NC). Each year-location combination was considered an environment and grouped according to geographical region. Experimental locations in Arizona, Oklahoma, and Texas were grouped to represent the Southwest region; Arkansas, Louisiana, Mississippi, and Tennessee were grouped to represent the Mid-South region; and Alabama, Georgia, North Carolina, South Carolina, and Virginia were grouped to represent the Southeast region. Lint percentage data from the Southwest region were analyzed based upon harvest method. Environments within region, replications (nested within environment), and all interactions of these effects within each region were considered random effects; whereas PGR treatment was considered a fixed effect. Considering environments as a random effect permits inferences about the treatments to be made over a range of environments (Carmer et al., 1989). A similar statistical approach has been used by several researchers utilizing a randomized complete block design (Bond et al., 2005; Hager et al., 2003; Jenkins et al., 1990) as well as those utilizing a factorial arrangement of treatments in a randomized complete block design (Bond et al., 2008; Ottis et al., 2004; Walker et al., 2008). Means were separated using Fisher's Protected LSD at $p \leq 0.05$.

RESULTS AND DISCUSSION

Plant height for all treatments relative to the non-treated check was uniform across all regions prior to the initial PGR application at the matchhead square stage and ranged from 96 to 103% of the height of the non-treated check.

Non-ionic surfactant did not reduce plant height in any region two weeks after application (Table 4). Application of all PGRs with the exception of mepiquat chloride plus cyclanilide at 12.9 + 3.2 followed by 19.4 + 4.8 g ai ha^{-1} provided a 6 to 9% height reduction compared to the non-treated check in the Southwest region two weeks after application (Table 4). A 5 to 8% plant height reduction was observed with all PGRs two weeks after the initial application in the Mid-South (Table 4). Application of all PGRs resulted in significant plant height reduction two weeks after the matchhead square application in the Southeast (Table 4). A 16% plant height reduction was observed following application of mepiquat chloride whereas a 12% plant height reduction was observed following two applications of mepiquat chloride plus cyclanilide compared to the non-treated check in the Southeast region (Table 4).

Table 4. Effect of plant growth regulator application on percent plant height reduction.

PGR[z]	Application Rate			Region											
				% of Untreated Height Prior to 1st Application			% of Untreated Height Prior to 2nd Application			% of Untreated Height Prior to 3rd Application			% of Untreated Height Prior to Harvest		
	1st application[y]	2nd application[x]	3rd application[w]	South-west[v]	Mid-South[u]	South-east[t]	South-west	Mid-South	South-east	South-west	Mid-South	South-east	South-west	Mid-South	South-east
	g ai ha^{-1}			%											
Mepiquat chloride[r]	24.6	30.9	--	102	99	96	92	92	84	86	84	82	95	86	81
Mepiquat chloride + kinetin[q]	24.6 + 0.015	30.9 + 0.018	--	101	102	98	94	95	85	87	87	83	91	95	79
Mepiquat chloride + cyclanalide[p]	9.7 + 2.4	12.9 + 3.2	--	101	101	97	91	95	88	86	90	89	89	88	84
Mepiquat chloride + cyclanalide	12.9 + 3.2	19.4 + 4.8	--	102	103	100	98	95	88	87	89	88	92	88	84
Mepiquat chloride + cyclanalide	12.9 + 3.2	19.4 + 4.8	19.4 + 4.8	100	101	98	94	94	87	86	89	86	92	88	84
Mepiquat pentaborate[o]	57.6	72.0	--	101	103	98	93	93	86	83	85	86	90	86	82
Non-ionic surfactant	0.25% v/v	0.25% v/v	--	103	101	100	100	102	99	100	102	100	99	105	98
Untreated	--	--	--	100	100	100	100	100	100	100	100	100	100	100	100
LSD (0.05)[n]	--	--	--	NSD[m]	NSD	NSD	5	4	3	9	3	3	6	6	4

[z] All plant growth regulator applications included non-ionic surfactant at 0.25% v/v.

[y] 1st application was made at the matchhead square stage.

[x] 2nd application made two weeks after matchhead square application.

[w] 3rd application made at node above white flower = 5.

[v] Southwest region consisted of locations in Snook, TX in 2007 and 2008; Halfway, TX in 2007; Lamesa, TX in 2008; Safford, AZ in 2007; and Altus, OK in 2008.

[u] Mid-South region consisted of locations in Starkville, MS in 2008; Jackson, TN in 2007 and 2008; Rowher, AR in 2007 and 2008; and Alexandria, LA in 2007.

[t] Southeast region consisted of locations in Shorter, AL in 2007 and 2008; Tifton, GA in 2007; Florence, SC in 2007 and 2008; Duplin County, NC in 2007 and 2008; and Suffolk, VA in 2007.

[s] Calculated by dividing the average plant height for each treatment within a given replication by the average plant height of the untreated treatment within the same replication and multiplying times 100.

[r] DuPont™ Mepex® Plant Growth Regulator

[q] DuPont™ Mepex® Gin Out™ Plant Growth Regulator

[p] Stance™ Plant Regulator

[o] Pentia™ Plant Regulator

[n] Least Significant Difference separated by Fishers protected LSD at the 0.05 level of significance.

[m] No Significant Difference

In all regions, significant height reductions were observed following PGR application compared to the untreated check two weeks after the second application. A 13 to 17% height reduction was observed following application of all PGRs compared to the non-treated check in the Southwest region (Table 4). All PGR applications in the Mid-South and Southeast provided 10 to 18% plant height reductions compared to the non-treated check (Table 4). Mepiquat chloride and mepiquat pentaborate provided greater plant height reductions than mepiquat chloride plus cyclanilide in the Mid-South (Table 4). Similarly, mepiquat chloride and mepiquat chloride plus kinetin provided an additional 5 to 7% plant height reduction two weeks after the second treatment compared to two applications of mepiquat chloride plus cyclanilide in the Southeast (Table 4). No reduction in plant height was observed two weeks after the second application in any region following application of non-ionic surfactant alone (Table 4).

Significant reduction in final plant height in all regions was observed following PGR application with the exception of mepiquat chloride in the Southwest. Mepiquat chloride plus kinetin, two or three applications of mepiquat chloride plus cyclanilide, and mepiquat pentaborate reduced final plant height up to 11% compared to the non-treated check in the Southwest region (Table 4). Two applications of mepiquat chloride resulted in plant height similar to that of the non-treated check (Table 4). Plant height reduction in the Mid-South following application of mepiquat chloride, mepiquat pentaborate, and mepiquat chloride plus cyclanilide ranged from 12 to 14% (Table 4). Application of mepiquat chloride plus kinetin resulted in a final plant height similar to that of the non-treated check in the Mid-South (Table 4). Plant height reductions following PGR application ranged from 16 to 21% in the Southeast region. However, mepiquat chloride plus kinetin provided greater plant height reduction than mepiquat chloride plus cyclanilide. Application of non-ionic surfactant had no effect on final plant height in any region (Table 4).

Plant height reduction following application of mepiquat chloride has also been observed by Boman and Westerman (1994), Kerby et al. (1982), and York, (1983a). Plant height reduction following application of mepiquat chloride plus cyclanilide has been shown to be similar to that following application of mepiquat chloride by O'Berry and Faircloth (2006), Thomas et al. (2007), Vandiver et al. (2006), and Vodraska and Collins (2005). Other research indicates that plant height reduction following application of mepiquat chloride, mepiquat chloride plus cyclanilide, and mepiquat pentaborate are similar (Barber and Stewart, 2007; Dollar et al., 2006; Everman et al., 2006).

Regardless of product or application rate, PGR application resulted in reduced number of mainstem nodes in the Southwest and Southeast regions (Table 5). Plants treated with a PGR in the Southwest had approximately 20 mainstem nodes compared to non-treated plants with approximately 22 mainstem nodes (Table 5). Plants treated with PGRs in the Southeast had approximately 18 mainstem nodes compared to 19 mainstem nodes on non-treated plants (Table 5). No difference in the number of mainstem nodes due to PGR was observed in the Mid-South (Table 5). A reduction in the number of mainstem nodes following application of mepiquat chloride has also been observed by Kerby et al. (1998), Pettigrew and Johnson (2005), and Yeates et al. (2002). Furthermore, Jones et al. (2009) and O'Berry et al. (2009) observed a reduction in the total number of mainstem nodes following application of mepiquat pentaborate. Lemon et al. (2008) observed no difference in the number of mainstem nodes following application of mepiquat chloride, mepiquat chloride plus cyclanilide, and mepiquat pentaborate.

Application of mepiquat chloride and mepiquat chloride plus cyclanilide at 12.9 + 3.2 g ai ha^{-1} followed by 19.4 + 4.8 g ai ha^{-1} did not enhance earliness as defined by nodes above cracked boll in the Southwest (Table 5). Earliness was enhanced by application of mepiquat chloride plus kinetin, mepiquat chloride plus cyclanilide at selected rates, mepiquat pentaborate, and non-ionic surfactant in the Southwest (Table 5). Although differences were significant, the magnitude of differences were small indicating that application of any of these products may not dramatically impact earliness. In the Mid-South region, two applications of mepiquat chloride plus cyclanilide or mepiquat pentaborate enhanced earliness compared to the non-treated check. No significant differences with respect to crop maturity were found between any product and the non-treated check in the Southeast region (Table 5). The effect of PGR application on earliness has been inconsistent. Johnson and Pettigrew (2006), O'Berry et al. (2007), and O'Berry et al. (2009) reported increased earliness following application of mepiquat pentaborate. Additionally, O'Berry et al. (2009) and Vodraska and Collins (2005) reported increased earliness following application of mepiquat chloride plus cyclanilide. Crawford (1981), Stewart et al. (2000), and Yeates et al. (2002) did not observe increased earliness following application of mepiquat chloride. No difference in earliness following application of mepiquat chloride, mepiquat chloride plus cyclanilide, or mepiquat pentaborate was reported by Osborne et al. (2008).

Plant growth regulator application had no effect on lint percent following stripper or picker harvest in the Southwest (Table 5). Minor differences in lint percentage due to PGR application were observed in the Mid-South and Southeast regions. Similar lint percentages were observed for the non-treated check as well as following two or three applications of mepiquat chloride plus cyclanilide in the Mid-South and Southeast regions (Table 5). Reductions in lint percentage were observed following two applications of mepiquat chloride compared to the non-treated check in the Mid-South and Southeast regions (Table 5). Lint percentage in the Southeast following application of mepiquat chloride plus kinetin and mepiquat pentaborate was similar to the non-treated check (Table 5). Conversely, significant reductions in lint percent in the Mid-South were observed following application of mepiquat chloride plus kinetin and mepiquat pentaborate (Table 5). Reductions in lint percent due to PGR application, while significant, were small in nature. Reductions in lint percentage following application of mepiquat chloride have been observed by several researchers including Cathey and Meredith (1988), Kerby et al. (1982), and Kerby (1985). A reduction in lint percent following application of mepiquat pentaborate was observed by Johnson and Pettigrew (2006), O'Berry et al. (2007), and O'Berry et al. (2009).

No difference in lint yield due to PGR application was observed in any region (Table 5). Lint yield averaged 1394, 1386, and 1448 kg ha^{-1} in the Southwest, Mid-South, and Southeast regions, respectively (Table 5). Previous research comparing the effect of various plant growth regulators on yield has produced variable results. Yield responses are likely strongly linked to environment and management practices.

Table 5. Effect of plant growth regulator application on lint percent and lint yield.

PGR Treatment[z]	Application Rate			Region												
	1st application[y]	2nd application[x]	3rd application[w]	South-West[v]	Mid-South[u]	South-East[t]	South-West	Mid-South	South-East	Southwest		Mid-South	South-east	South-west	Mid-South	South-east
				Mainstem Nodes			Nodes Above Cracked Boll			Lint Percent				Yield		
										Picker	Stripper	Picker	Picker			
	g ai ha^{-1}			Number						%				kg ha^{-1}		
Mepiquat chloride[s]	24.6	30.9	--	20.3	18.6	17.5	3.7	3.8	3.8	38.7	30.5	40.5	42.4	1447	1361	1415
Mepiquat chloride + kinetin[r]	24.6 + 0.015	30.9 + 0.018	--	20.1	19.1	17.4	2.0	4.2	4.0	38.7	30.1	40.6	43.6	1368	1450	1452
Mepiquat chloride + cyclanalide[q]	9.7 + 2.4	12.9 + 3.2	--	20.4	18.2	17.7	2.3	3.7	4.0	38.4	30.1	41.1	43.3	1401	1339	1443
Mepiquat chloride + cyclanalide	12.9 + 3.2	19.4 + 4.8	--	20.1	18.0	17.8	3.3	3.7	4.0	37.9	30.0	41.1	43.0	1371	1409	1439
Mepiquat chloride + cyclanalide	12.9 + 3.2	19.4 + 4.8	19.4 + 4.8	20.1	18.8	17.8	2.6	4.5	4.1	38.0	30.3	39.7	42.8	1375	1391	1440
Mepiquat pentaborate[p]	57.6	72.0	--	20.0	19.0	17.7	2.4	3.5	4.2	39.3	30.3	41.3	42.6	1385	1458	1490
Non-ionic surfactant	0.25% v/v	0.25% v/v	--	21.4	19.4	18.9	2.6	4.8	4.0	39.4	30.1	41.1	44.4	1385	1326	1482
Untreated	--	--	--	22.3	18.7	19.0	3.9	4.3	4.1	39.0	30.7	41.8	43.5	1419	1354	1419
LSD (0.05)[o]	--	--	--	1.2	NSD[n]	0.7	1.0	0.7	NSD	NSD[n]	NSD[n]	1.0	0.9	NSD	NSD	NSD

[z] All plant growth regulator applications included non-ionic surfactant at 0.25% v/v.

[y] 1st application was made at the matchhead square stage.

[x] 2nd application made two weeks after matchhead square application.

[w] 3rd application made at node above white flower = 5.

[v] Southwest region consisted of locations in Snook, TX in 2007 and 2008; Halfway, TX in 2007; Lamesa, TX in 2008; Safford, AZ in 2007 and 2008; and Altus, OK in 2007 and 2008. Harvest data collected with a cotton picker modified for small plots in Snook, TX and Safford, AZ. Harvest data in Halfway, TX, Lamesa, TX, and Altus, OK collected with a cotton stripper.

[u] Mid-South region consisted of locations in Starkville, MS in 2008; Jackson, TN in 2007 and 2008; Rowher, AR in 2007 and 2008; and Alexandria, LA in 2007.

[t] Southeast region consisted of locations in Shorter, AL in 2007 and 2008; Tifton, GA in 2007; Florence, SC in 2007 and 2008; Duplin County, NC in 2007 and 2008; and Suffolk, VA in 2007.

[s] DuPont™ Mepex® Plant Growth Regulator

[r] DuPont™ Mepex® Gin Out™ Plant Growth Regulator

[q] Stance™ Plant Regulator

[p] Pentia™ Plant Regulator

[o] Least significant difference separated by Fishers protected LSD at the 0.05 level of significance.

[n] No significant difference

Effects of PGR application on fiber quality were small in all regions. Micronaire was unaffected by plant growth regulator application in any region (Table 6). Micronaire averaged 4.3, 4.5, and 4.5 in the Southwest, Mid-South, and Southeast, respectively (Table 6). Fiber length from the Southeast region averaged 1.12 inches and was unaffected by PGR application (Table 6). In the Mid-South, increased fiber length was observed following application of all plant growth regulators compared to the non-treated check (Table 6). Application of mepiquat chloride at 12.9 + 3.2 g ai ha^{-1} resulted in increased fiber length compared to the non-treated check in the Southwest region. All other PGR applications in the Southwest resulted in fiber length similar to that of the non-treated check. While significant differences exist in fiber length due to PGR application in the Southwest and Mid-South, these differences were minor and are equivalent to approximately 1/32 of an inch or less. No difference in fiber strength due to PGR application was observed in the Southwest or Southeast regions. Fiber strength averaged 30.3 and 29.5 g tex^{-1} in the Southwest and Southeast, respectively (Table 6). Fiber strength in the Mid-South was greater following three applications of mepiquat chloride plus cyclanilide compared to mepiquat chloride plus kinetin, mepiquat chloride plus cyclanilide at 9.7 + 2.4 g ai ha^{-1} followed by 12.9 + 3.2 g ai ha^{-1}, mepiquat pentaborate, or non-ionic surfactant (Table 6). Similar to fiber length, differences in fiber strength in the Mid-South, while significant, were minor. No differences in uniformity were observed due to PGR application in any region (Table 6). Fiber uniformity averaged 81.8, 83.2, and 81.6% in the Southwest, Mid-South, and Southeast, respectively. Previous research comparing mepiquat chloride, mepiquat chloride plus cyclanilide, and mepiquat pentaborate indicates similar response in fiber quality properties regardless of PGR applied (Dollar et al., 2006; Jones et al., 2009; Lemon et al., 2008; Osborne et al., 2008).

Table 6. Effect of plant growth regulator application on fiber quality.

PGR[z]	Application Rate			Region											
	1st application[y]	2nd application[x]	3rd application[w]	South-west[v]	Mid-South[u]	South-east[t]	South-west	Mid-South	South-east	South-west	Mid-South	South-east	South-west	Mid-South	South-east
				Micronaire			Length			Strength			Uniformity		
	g ai ha^{-1}						-------- Inches --------			--------- g tex^{-1} ---------			----------- % -----------		
Mepiquat chloride[s]	24.6	30.9	--	4.3	4.5	4.5	1.16	1.14	1.11	30.0	30.4	29.7	81.7	83.4	81.8
Mepiquat chloride + kinetin[r]	24.6 + 0.015	30.9 + 0.018	--	4.2	4.5	4.5	1.16	1.14	1.10	30.2	30.0	29.6	81.5	83.2	81.5
Mepiquat chloride + cyclanalide[q]	9.7 + 2.4	12.9 + 3.2	--	4.2	4.5	4.5	1.17	1.13	1.11	30.3	29.9	29.5	81.8	83.1	81.7
Mepiquat chloride + cyclanalide	12.9 + 3.2	19.4 + 4.8	--	4.3	4.5	4.5	1.18	1.12	1.21	30.8	30.2	29.3	81.9	83.1	81.7
Mepiquat chloride + cyclanalide	12.9 + 3.2	19.4 + 4.8	19.4 + 4.8	4.3	4.5	4.4	1.17	1.15	1.11	30.5	31.0	29.4	81.9	83.5	81.5
Mepiquat pentaborate[p]	57.6	72.0	--	4.3	4.6	4.4	1.17	1.14	1.11	30.4	29.8	29.8	81.8	83.2	81.8
Non-ionic surfactant	0.25% v/v	0.25% v/v	--	4.3	4.5	4.5	1.16	1.12	1.09	30.0	29.8	29.3	81.8	83.0	81.4
Untreated	--	--	--	4.3	4.6	4.6	1.16	1.11	1.08	30.2	29.7	29.0	81.7	83.3	81.4
LSD (0.05)[o]	--	--	--	NSD[n]	NSD[n]	NSD[n]	0.01	0.01	NSD[n]	NSD[n]	0.8	NSD[n]	NSD[n]	NSD[n]	NSD[n]

[z] All plant growth regulator applications included non-ionic surfactant at 0.25% v/v.

[y] 1st application was made at the matchhead square stage.

[x] 2nd application made two weeks after matchhead square application.

[w] 3rd application made at node above white flower = 5.

[v] Southwest region consisted of locations in Snook, TX in 2007 and 2008; Halfway, TX in 2007; Lamesa, TX in 2008; Safford, AZ in 2007 and 2008; and Altus, OK in 2008.

[u] Mid-South region consisted of locations in Starkville, MS in 2008; Jackson, TN in 2007 and 2008; Rowher, AR in 2007 and 2008; and Alexandria, LA in 2007.

[t] Southeast region consisted of locations in Shorter, AL in 2007 and 2008; Florence, SC in 2007 and 2008; Duplin County, NC in 2007 and 2008; and Suffolk, VA in 2007.

[s] DuPont™ Mepex® Plant Growth Regulator

[r] DuPont™ Mepex® Gin Out™ Plant Growth Regulator

[q] Stance™ Plant Regulator

[p] Pentia™ Plant Regulator

[o] Least significant difference separated by Fishers protected LSD at the 0.05 level of significance.

[n] No significant difference

Application of mepiquat chloride, mepiquat chloride plus kinetin, mepiquat chloride plus cyclanilide, and mepiquat pentaborate generally reduced plant height throughout the growing season resulting in reduced plant height at the end of the growing season compared to the non-treated check. The magnitude of difference in plant height reduction varied depending on region, management practices, and growing conditions within each region. Generally, all PGRs provided similar end-of-season plant height reductions with the exception of mepiquat chloride in the Southwest and mepiquat chloride plus kinetin in the Mid-South. Reduction in total nodes was similar for all PGRs. In addition, minor differences in nodes above cracked boll were observed in the Southwest and Mid-South while no differences were observed in the Southeast due to PGR application. Differences in lint percent, albeit minor, were observed. Plant growth regulator application had no effect on yield. No differences in micronaire or uniformity were observed due to PGRs. Minor differences in fiber length were observed in the Southwest and Mid-South as well as fiber strength in the Mid-South due to selected PGRs.

No one PGR provided consistently superior performance compared to others examined in this study in regard to plant height reduction, reduction in total nodes, lint percent, yield, or fiber quality. Based upon this two-year Beltwide evaluation, growers are advised to use a PGR to manage excessive plant height and select the PGR that best suits their personal preferences, management style, and/or farming operation requirements.

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