Effects of Several Commercial Plant Growth Regulator Formulations on Yield and Allelochemicals of Cotton (*Gossypium hirsutum* L.)

Paul A. Hedin* and Jack C. McCarty, Jr.

Crop Science Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Mississippi State, Mississippi 39762-5367

In recent years, a number of kinetin-based commercial plant growth regulators have been evaluated for their effects on various crop plants. In a study at Mississippi State during 1986–1992, five commercial plant growth regulators and urea were evaluated as foliar sprays on growing cotton (*Gossypium hirsutum* L.) plants for their effects on yield, agronomic traits, and pest allelochemicals. Of the five tested, the activities of three (Burst, Foliar Triggrr, and Maxon) were attributed by their providers to cytokinins. FPG-5 contained cytokinins, IAA, GA, and several inorganic micronutrients, and PG-IV contained IBA, GA, and micronutrients, but no cytokinins. FPG-5 and Foliar Triggrr caused statistically significant increases in yield, but only in 1992. The foliar application of urea had a consistently negative effect on yield. Formulations containing IAA/IBA, GA, and inorganic micronutrients did not appear to cause more positive yield trends than those whose potencies were attributed to their cytokinin content. Positive trends in bud gossypol were observed upon treatment with Burst, Foliar Triggrr, and PG-IV.

INTRODUCTION

In recent years, a number of kinetin-based commercial plant growth regulator preparations have been evaluated for their effects on yield and agronomic traits of various crop plants. Cytokinins were discovered as a result of efforts to find factors that would stimulate plant cells to divide, and subsequently they were shown to affect various plant processes. The synthetic cytokinin, kinetin, was identified by Miller et al. (1955) as a result of its ability to stimulate cell division. Kinetin is not naturally occurring but results from heat-induced degradation of DNA. The basis for foliar application of cytokinins to field plants is inferred from the improved growth of plants in cytokinin-containing solutions. While in some situations cytokinins may not be active unless other hormones are present, cytokinins alone can nevertheless evoke a variety of physiological, metabolic, biochemical, and developmental processes when applied to plants. A detailed description of the roles of cytokinins in plant growth can be found in a review chapter by Taiz and Zeiger (1991) and in papers by Weaver (1972) and Elliott (1982).

Guinn (1986) has reviewed the hormonal relationships in growing cotton (*Gossypium hirsutum* L.) plants. Cytokinins can either inhibit or promote abscission, depending on time and site of application, and can promote the ability of an organ to compete for metabolites. Guinn (1986) reported that exogenous applications of cytokinins may promote, rather than retard, abscission unless applied directly to the abscission zone. Retained bolls, however, tended to contain more cytokinin. Urea has been used as a foliar application in the nursery trade to darken leaf color and to reduce stress. In some preliminary tests, it appeared to increase the yield of cotton lint (Hedin and McCarty, 1991).

The use of bioregulators on cotton has been investigated extensively, and the literature has been cited in several of our previous papers (Hedin et al., 1984, 1988a,b; McCarty et al., 1987; McCarty and Hedin, 1989; Hedin and McCarty, 1991). The focus of our present study is several commercial kinetin preparations. Preliminary results from several field tests showed that kinetin and two commercial kinetin formulations tended to increase yield of cotton, pest resistance, and four allelochemicals: gossypol, condensed tannins, flavonoids, and anthocyanins (Hedin et al., 1984, 1988a,b; McCarty et al., 1987; McCarty and Hedin, 1989). These allelochemicals have been shown to be toxic to the tobacco budworm [*Heliothis virescens* (F.)], a major pest of cotton, and therefore could be associated with yield (Hedin et al., 1984, 1988a,b).

* Author to whom correspondence should be addressed.

MATERIALS AND METHODS

1986–1992 Bioregulator Field Tests. The commercial cotton cultivars Stoneville 213 (ST-213), Deltapine 50 (DPL-50), and DES-119, well adapted for the study area, were grown each year on the North Farm at Mississippi State University. The cotton was planted about May 1 in single-row (0.97 × 12.8 m; W × L) plots. Insects were controlled all season with fenvalerate (DuPont Agricultural Products, Wilmington, DE) and Cythion (American Cyanamid, Princeton, NJ). The growth regulator formulations were applied at three rates (zero, low, high, see Table I for rates) to plants whose squares were "match head" in size on about July 10 and July 24. Each compound was handled as a separate randomized complete block experiment with five replications.

The timing of applications and rates were in general those recommended by the provider or as tested previously by us (Hedin et al., 1988a,b; Hedin and McCarty, 1991). Normally, two rates, with the second application generally 3-fold higher, were used to improve the likelihood that a response would be elicited. Each compound or formulation was weighed or measured and dissolved in 5–10 mL of H_2O. One milliliter each of Span 80 and Tween 80 was then added. The solutions were made up to 1.25 L with water just before use. They were applied with a CO_2-pressurized backpack sprayer delivering 203 L/ha at 207 kPa of pressure. For allelochemicals analyses, plant material (terminal leaves and squares) was collected generally 2 and 4 weeks after the application of the chemicals (about July 31 and August 14) and placed in the freezer (−20 °C) until processed.

The plots were machine harvested one time for yield determination when cotton was fully open (about September 30). Prior to machine harvest, 25 open bolls were hand harvested from each plot, weighed, and ginned to determine boll size, lint percentage, and seed index. Seed index is the weight in grams of 100 fuzzy seeds. The lint percentage determined was used in calculating lint yields.

Procurement of Bioregulators. Of the five commercial bioregulators, the activity of three was attributed to cytokinins.

Table 1. Summary of Changes in Yields and Agronomic Traits of Cotton Treated with Selected Commercial Plant Growth Regulators and Urea[a–c]

				yield change, %		lint %		boll size		seed index	
year	cultivar	compd	control yield, kg ha^{-1}	low	high	low	high	low	high	low	high
1986	ST-213	Burst	1393	−10.6	+1.7	−0.2	−0.1				
1988	DPL-50	Burst	1397	−11.6	−7.0	−1.4	−1.3	0.0	0.0	−3.9	−2.9
	av	Burst	1395	−11.1	−2.7	−0.8	−0.7	0.0	0.0	−3.9	−2.9
1988	DPL-50	Triggrr	1397	−3.0	−5.5	−1.6	+0.3	−1.8	+3.6	+0.9	−2.0
1989	DPL-50	Triggrr	1212	0.0	−7.0	+0.4	+0.2	−1.8	0.0	0.0	−1.9
1990	DPL-50	Triggrr	1528	−4.5	−5.9	−0.9	−0.6	−8.5	−6.4	−4.4	−7.7
1990	DPL-50	Triggrr	1269	−5.9	−15.0	+0.2	−0.9	0.0	+6.3		
1991	DES-119	Triggrr	1447	+1.2	+0.9	+0.4	+0.1	−2.0	0.0		
1991	DPL-50	Triggrr	1399	−4.6	+4.5	+0.2	+0.3	−5.3	−3.5		
1992	DPL-50	Triggrr	1128	+7.1	−0.8	+0.9	0.0	−4.3	+2.1		
1992	DES-119	Triggrr	1084	+15.5*	+12.6*	+1.2	+0.7	+8.5	+6.4		
	av	Triggrr	1308	+0.7	−2.0	+0.1	+0.0	−1.9	+1.1	−1.8	−3.9
1990	DPL-50	PG-IV	1269	−8.6	−13.7	+0.2	+0.3	0.0	+4.2		
1991	DPL-50	PG-IV	1146	−2.9	−6.7	−0.7	−0.5	+3.7	+1.9		
1991	DES-119	PG-IV	1343	+0.5	−10.1*	−0.1	−0.6	+4.0	+2.0		
1992	DPL-50	PG-IV	977	+1.5	−2.4	+0.5	+0.6	−4.0	−2.0		
	av	PG-IV	1184	−2.4	−8.2	0.0	0.0	+0.9	+1.5		
1992	DPL-50	FPG-5	977	+8.4	+8.4	−0.9	+0.3	+2.0	−4.0		
1992	DES-119	FPG-5	927	−1.8	+5.7	+0.4	+1.0	+4.2	+4.2		
	av	FPG-5	952	+3.3	+7.1	−0.3	+0.6	+3.1	+0.1		
1990	DPL-50	Maxon	1269	+2.3	+6.4	+0.4	+0.5	+2.1	+4.2		
1990	DPL-50	Maxon	1528	−2.1	+5.2	+0.5	+0.3	+2.1	+6.4		+5.5
	av	Maxon	1399	+0.1	+5.8	+0.5	+0.4	+2.1	+5.3		+5.5
1989	DPL-50	urea	1212	−5.0	−9.0	+0.3	+0.9	+1.8	+3.5	+0.9	−1.9
1990	DPL-50	urea	1528	−2.6	−0.3	+0.4	−0.1	+6.4	+6.4	+1.1	+6.6
1990	DPL-50	urea	1269	0.0	−14.5	−0.1	+0.4	+2.0	+2.0		
1991	DPL-50	urea	1399	−2.4	0.0	+1.0	+0.1	+1.8	−5.3		
1991	DES-119	urea	1447	−13.7	−12.5	+0.2	+0.4	−3.9	−3.9		
	av	urea	1371	−4.7	−7.3	+0.4	+0.3	+1.6	+0.5	+1.0	+2.4

[a] Values marked with an asterisk were statistically significant. [b] Rates and numbers of applications: Burst, 0.56 × 2 and 1.12 × 2 L ha^{-1} commercial; Triggrr, 0.56 × 2 and 1.68 × 2 L ha^{-1} commercial, 0.56 × 3 and 1.68 × 3 L ha^{-1} commercial, 1990, one test; PG-IV, 0.14 × 4 and 0.42 × 4 (and) 0.28 × 2 and 0.84 × 2 L ha^{-1} commercial; FPG-5, 0.56 × 2 and 1.12 × 2 L ha^{-1} commercial; Maxon, 0.28 × 2 and 0.84 × 2 (and) 0.28 × 3 and 0.84 × 3 L ha^{-1} commercial; urea, 60 × 2 and 188 × 2, 1989 (and) 188 × 2 and 1876 × 2, 1990–1991, g ha^{-1} crystalline. [c] Percent change of yield, boll size, and seed index from the specific control that accompanied the test. Lint percent is reported as numerical change.

A fourth contained cytokinins and also IAA and GA. The fifth did not contain cytokinin but did contain IBA and GA. Burst, a mixture of cytokinins including zeatin, was obtained from Burst Agritech, Overland Parks, KS. Foliar Triggrr, a commercial preparation with cytokinin (0.012%) as the stated active ingredient, was obtained from Westbridge Chemical Co., San Diego, CA. Maxon, stated to contain cytokinins as the active ingredient, was obtained from Terra International, Blytheville, AR. FPG-5 Foliar, stated to contain the micronutrients Mg (0.5%), Cu (0.05%), Fe (0.10%), B (0.02%), Mo (0.0005%), and Co (0.0005%) and the hormones cytokinin (150–200 ppm) IAA Auxin (300–400 ppm), and gibberellic acid (concentration not stated), was obtained from Baldridge Bio-Research, Inc., Cherry Fork, OH. PG-IV, stated to contain the micronutrients Mg (1.0%), Cu (0.05%), Zu (0.05%), Fe (0.10%), B (0.02%), Mo (0.0005%), and Co (0.0005%) and the hormones indolebutyric acid (0.001%) and gibberellic acid (0.001%), was obtained from Microflo, Lakeland, FL. Urea was obtained from J. T. Baker Chemical Co., Phillipsburg, NJ.

Analysis of Allelochemicals. Plant tissue (Ca. 25 terminal leaves and 25 squares (buds)] from each replication was collected, freeze-dried, and ground prior to allelochemical analysis. Analysis of allelochemicals (gossypol, tannin, anthocyanin, flavonoid) was conducted following the procedures described by Hedin et al. (1988a). In brief, the terpenoid aldehydes were analyzed at 550 nm according to the phloroglucinol procedure, the condensed tannins by analysis of the chromophore at 550 nm produced by boiling with 1-butanol-HCl (95:5), the anthocyanin by measurement of a methanol–water–HCl (79:19:3) extract at 540 nm, and the flavonoids by measurement of a 70% aqueous acetone extract complexed with diphenylboric acid–ethanolamine at 440 nm.

Statistical Procedures. Data obtained from the various analyses and measurements were subjected to the analysis of variance, and lsd values were calculated using SAS (1985).

RESULTS AND DISCUSSION

Table 1 presents a summary of changes in yields and agronomic traits of cotton treated with several commercial bioregulators and urea from 1986 to 1992. The percent changes are based on yields of controls that accompanied the individual tests. A summary of changes in the contents of gossypol, tannins, and flavonoids in squares (buds) of the treated cottons is given in Table 2. Experimental conditions (i.e., rates, numbers of applications, cultivars, climate) were varied over the several-year period. While this may limit the ability to make rigorous comparisons, obvious efficacy would nevertheless be apparent.

Over the study period, the average (overall) yield of controls was 1400 kg ha^{-1}, and the average lint percent, boll size, and seed index were 39.2, 5.3, and 10.1, respectively. The average contents of bud allelochemicals of the controls during the period were as follows: gossypol, 0.32%; tannins, 11.99%; and flavonoids, 1.78%.

The only compounds whose application caused a statistically significantly increase in yield were Triggrr (15.5%) and FPG-5 (8.4%), both in 1992. However, the treatment with Triggrr did not result in a significant yield increase in 1988–1991, while FPG-5 was not tested previously so its continuity could not be evaluated (Table 1). There were a few statistically significant changes, mostly negative, of lint percent, boll size, and seed index upon the various treatments (Table 1). Treatment with Burst and PG-IV appeared to elicit negative trends in yield, while the trends with Maxon were slightly positive.

Table 2. Summary of Changes in the Allelochemicals of Cotton Squares (Buds) Treated with Selected Commercial Plant Growth Regulators and Urea[a–c]

			gossypol		tannins		flavonoids	
year	cultivar	compd	low	high	low	high	low	high
1986	ST-213	Burst	+9.5	+28.6*	+16.6	+3.8	+2.7	-0.9
1988	DPL-50	Burst	-6.1	-4.1	+11.4	+8.8	+2.3	+0.5
	av	Burst	+1.7	+12.3	+14.0	+6.3	+2.5	-0.2
1988	DPL-50	Triggrr	-16.7*	-24.5*	+21.7	+19.0	-18.9	-27.6
1989	DPL-50	Triggrr	0.0	0.0	-4.5	+2.7	-3.2	-2.3
1990	DPL-50	Triggrr	-5.4	+2.7	-4.4	-10.8	+5.1	+7.1
1990	DPL-50	Triggrr	0.0	0.0	-10.1	-2.1	-8.3	-6.9
1991	DES-119	Triggrr	0.0	+29.7*	+6.8	+1.9	-5.4	-8.1
1991	DPL-50	Triggrr	+2.8	+8.3			+1.7	+1.1
	av	Triggrr	-3.2	+2.7	+1.9	+1.9	-4.8	-3.8
1990	DPL-50	PG-IV	0.0	+3.0	+5.4	+8.7	+2.0	+3.0
1991	DPL-50	PG-IV	-16.2*	+10.8*	-29.0	-33.3	+1.7	+1.1
1991	DES-119	PG-IV	+6.3	+3.1			+8.2	+1.5
	av	PG-IV	-3.3	+5.6	-11.8	-12.3	+4.0	+1.9
1990	DPL-50	Maxon	-16.2*	+2.7	-3.4	-8.5	+8.6	+7.6
1990	DPL-50	Maxon	+3.0	+6.1*	-16.2	-20.3	+4.1	+1.8
	av	Maxon	-6.6	+4.4	-9.8	-14.4	+6.4	+4.7
1989	DPL-50	urea	+3.3	-3.3	-0.5	+1.4	-5.1	-2.8
1990	DPL-50	urea	-6.0	+2.3	-4.5	-1.5	-1.0	+1.5
1990	DPL-50	urea	+4.9	0.0	-1.9	-3.4	-4.6	+4.6
1991	DPL-50	urea	+10.8*	+8.1*	+3.4	+13.9		
1991	DES-119	urea	-4.3	-4.3			-6.0	-3.7
	av	urea	+1.7	+0.6	-1.6	+2.6	-4.2	+1.5

[a] The average contents during the study period of controls were as follows: gossypol, 0.32%; tannins, 11.99%; flavonoids, 1.78%. [b] See Table 1 for rates and numbers of applications. [c] Percent change of gossypol, tannins, and flavonoids from the specific control that accompanied the test; values marked with an asterisk were statistically significant.

With regard to allelochemicals, positive trends in square gossypol were noted in some tests, particularly at the high rate, for Burst, Triggrr, and PG-IV (Table 2). Differences in responses to cultivars were not evident. Effects of the bioregulators on tannins and flavonoids were mixed, tending to be slightly increased. These results indicate that these bioregulators have only a limited positive effect on allelochemicals—secondary compounds—and presumably their indirect effect on insects is marginal. Other bioregulators have been reported to have a significant effect on insects, however (Hedin, 1990).

Urea was evaluated to determine if it had a positive effect on yield because it was known to be used as a foliar application in the nursery trade and reputedly has also been used as a foliar application to counteract stress in growing cotton. Typically, leaf color darkens in intensity when urea is applied. However, in our tests that were conducted over a 3-year period (Table 1), yield was actually decreased by 4.7 and 7.3% at the low and high levels (see rates in Table 1), respectively. In one test, nearly 400 g ha^{-1} (10 times the low level) was applied over the season, resulting in about a 10% decrease in yield.

In previous years, kinetin appeared to induce positive trends in yields of cotton, though not statistically significant (Hedin and McCarty, 1991). Of the present commercial bioregulators tested that were stated to contain cytokinins, Triggrr, FPG-5, and Maxon, all showed positive yield trends in 1992 tests only, while Burst appeared to cause a negative trend. However, the changes were statistically significant in only two instances. The inclusion of IAA and GA in the FPG-5 formulation gave no noticeable improvement over the commercial cytokinin formulations.

The PG-IV formulation that contained IBA and GA, but not cytokinins, appeared to cause slightly negative trends. Finally, the two formulations containing inorganic micronutrients (FPG-5 and PG-IV) did not appear to be superior for yield over those that did not.

ACKNOWLEDGMENT

We thank M. Petty, R. McPherson, and R. Hayes for technical assistance.

LITERATURE CITED

Elliott, M. C. The Regulation of Plant Growth. In *Plant Growth Regulator Potential and Practice*; Thomas, T. H., Ed.; BCPC Publications: London, 1982; pp 57–98.

Guinn, G. Hormonal Relations During Reproduction. In *Cotton Physiology, Number One, The Cotton Foundation Reference Book Series*; Mauney, J. R., McD. Stewart, J., Eds.; The Cotton Foundation: Memphis, TN, 1986; pp 113–136.

Hedin, P. A. Bioregulator-Induced Changes in Allelochemicals and Their Effects on Plant Resistance to Pests. *Crit. Rev. Plant Sci.* **1990**, *9*, 371–379.

Hedin, P.A.; McCarty, J. C., Jr. Effects of Kinetin Formulations on Allelochemicals and Agronomic Traits of Cotton. *J. Agric. Food Chem.* **1991**, *39*, 549–553.

Hedin, P. A.; Jenkins, J. N.; McCarty, J. C., Jr.; Mulrooney, J. E.; Parrott, W. L.; Borazjani, A.; Graves, C. H., Jr.; Fuller, T. H. Effects of 1,1-Dimethylpiperdinium Chloride on the Pests and Allelochemicals of Cotton and Pecan. In *Bioregulators: Chemistry and Uses*; Ory, R. L. Rittig, F. R., Eds.; ACS Symposium Series 257; American Chemical Society: Washington, DC, 1984; pp 171–191.

Hedin, P. A.; Jenkins, J. N.; Thompson, A. C.; McCarty, J. C., Jr.; Smith, D. H.; Parrott, W. L.; Shepherd, R. L. Effects of Bioregulators on Flavonoids, Insect Resistance, and Yield of Seed Cotton. *J. Agric. Food Chem.* **1988a**, *36*, 1055–1061.

Hedin, P. A.; McCarty, J. C., Jr.; Jenkins, J. N. Effects of CCC and PIX Related Bioregulators on Gossypol, Protein, Yield and Seed Properties of Cotton. *J. Miss. Acad. Sci.* **1988b**, *33*, 49–57.

McCarty, J. C., Jr.; Hedin, P. A. Effects of Bioregulators on Allelochemicals, Proteins, and Agronomic Traits of Cotton. *Miss. Agric. For. Exp. Stn. Res. Rep.* **1989**, *14*, 1–5.

McCarty, J. C., Jr.; Jenkins, J. N.; Hedin, P. A.; Shepherd, R. L.; Parrott, W. L. The Effects of Plant Growth Regulators on Cotton Yield in Two Environments. *Miss. Agric. For. Exp. Stn. Res. Rep.* **1987**, *12*, 1–4.

Miller, C. O.; Skoog, F.; von Saltza, M. H.; Strong, F. M. Kinetin, a Cell Division Factor from Deoxyribonucleic Acid. *J. Am. Chem. Soc.* **1955**, *77*, 1392.

SAS. *User's Guide: Statistics*, version 5 ed.; SAS Institute: Cary, NC, 1985; 956 pp.

Taiz, L.; Zeiger, E. Cytokinins. In *Plant Physiology*; Taiz, L., Zeiger, E., Eds.; Benjamin/Cummings Publishing: Redwood City, CA, 1991; pp 452–472.

Weaver, R. J. *Plant Growth Substances in Agriculture*; Freeman: San Francisco, 1972; pp 99–103.

Recieved for review September 16, 1993. Revised manuscript received January 3, 1994. Accepted March 21, 1994.[⊗] Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

[⊗] Abstract published in *Advance ACS Abstracts*, May 1, 1994.