AGRONOMIC DIFFERENCES IN GROWTH AND YIELD BETWEEN *Bt* AND CONVENTIONAL COTTON

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Abstract

Cotton (*Gossypium hirsutum* L.) varieties containing a gene that encodes an insecticidal protein were released commercially in 1996. The insecticidal protein encoded by the gene proved especially effective in reducing damage to cotton plants from lepidopteran pests by using limited additional pesticide applications. The gene was transferred from the bacterium *Bacillus thuringiensis* var. *kurstaki* to the cotton variety Coker 312. Coker 312 is considered to be an extremely vigorous variety that exhibits rank vegetative growth. Therefore, *Bt* cotton varieties exhibit rank vegetative growth similar to their recurrent parent Coker 312. Traditionally, mepiquat chloride (1,1-dimethylpiperidinium chloride) has been applied to suppress rank vegetative growth. Mepiquat chloride (MC), a plant growth regulator, reduces main stem elongation of cotton plants. Current crop simulation models estimate that the optimum concentration of MC needed to reduce main stem elongation lies between 10 and 12 ppm. However, transgenic varieties, such as the *Bt* varieties, may behave differently toward MC than their conventional counterparts. To test this hypothesis, a field experiment was conducted at the Texas Agricultural Experiment Station in Corpus Christi, Texas during the 1998 growing season. The factorial field experiment was arranged as a randomized complete block design with four replications. The experiment consisted of 2 varieties and 5 variable rates of MC. The varieties planted included a *Bt* variety (DPL 33^B) and the same variety without the *Bt* gene (DPL 5415). Pix® (4.2% MC) was applied in a single application near the 12-node stage at the following rates: 5, 10, 15, and 20 oz/A. Weekly height, node number, and dry weight determinations were collected. In addition, plots were harvested by hand twice to determine yield. Data was analyzed using regression, ANOVA, LSD, and analysis of covariance. Significant differences in plant height were observed between the different MC rates. The control plants were the tallest, followed by plants treated with the 5, 10, 15, and 20 oz MC/A rates, respectively. Analysis of covariance results detected no significant differences in the growth rate between the *Bt* and the conventional varieties. However, the *Bt* variety was numerically taller than the conventional variety in the control, 5, and 10 oz MC/A rates. Furthermore, no significant differences in final plant height were observed between the two varieties. The MC-height reduction model developed in this study was similar to an existing MC concentration-height reduction model. In addition, no significant differences in yield were observed between the *Bt* and the conventional varieties. However, the Bt variety was significantly earlier than its conventional counterpart. A significant reduction in total yield was observed for the 20 oz MC/A application rate. Thus, we concluded that *Bt* varieties behave similarly with respect to vegetative growth to applications of MC as their conventional counterparts. Therefore, current MC application rate strategies should suffice for suppressing rank vegetative growth of *Bt* cotton.

Introduction

Lepidopteran pests cost cotton producers $200 million dollars in insecticide applications and $100 million dollars in yield reductions each year (Deaton, 1996). To combat the yield reduction problems associated with lepidopteran pests, a transgenic cotton variety containing the insecticidal protein δ-endotoxin was developed. The gene responsible for encoding the insecticidal protein, CryIA, was transferred from the bacterium *Bacillus thuringiensis* var. *kurstaki* into cotton (*Gossypium hirsutum* L.) (Jenkins et al., 1997). The varieties transformed by the insertion of the CryIA gene are referred to as *Bt* varieties. The *Bt* varieties proved especially important in controlling the following lepidopteran pests when limited additional pesticide applications were used: tobacco budworm (*Heliothis virescens*) (Jenkins et al., 1997), pink bollworm (*Pectinophora gossypiella*) (Wilson et al., 1992), cotton leafperforator (*Bucculatrix thurberiella*) (Flint et al., 1996), cotton bollworm (*Helioverpa zea*) (Deaton, 1995), and saltmarsh caterpillar (*Estigmene acrea*) (Wilson et al., 1992).

Cotton, an indeterminant plant, experiences rank vegetative growth, especially under heavily fertilized and heavily watered conditions. Traditionally, mepiquat chloride (1,1-dimethylpiperidinium chloride) has been applied to cotton for suppressing rank vegetative growth. Mepiquat chloride (MC) influences many agronomic characteristics of cotton plants including maturity, main stem elongation, and fruit distribution (Landivar, 1998). In 1994, Landivar et al. published a regression equation relating plant height reduction to the MC concentration in the plant. They observed that the optimum MC concentration for height reduction lies between 10 and 12 ppm. MC concentrations above 15 ppm do not cause further significant differences in plant height. Furthermore, the effect of MC on height reduction diminishes when the MC concentration drops below 5 ppm.

Controlling lepidopteran pests through limited additional pesticide applications is a desirable characteristic exhibited by the transgenic *Bt* cotton varieties. However, these

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varieties exhibit rank vegetative growth. The recurrent parent for the *Bt* varieties, Coker 312, is an extremely vigorous variety. Similar to their recurrent parent Coker 312, the *Bt* varieties are also very vigorous. Suppressing rank vegetative growth of the Bt varieties may require more MC than is required to suppress rank growth in conventional varieties (Jones et al., 1996; Mitchener, 1996). The objectives of this field experiment include the following: 1) to determine the relationship between vegetative growth and MC concentration for both a conventional and a transgenic *Bt* variety; 2) to determine the relationship between MC and yield for both a conventional and a transgenic *Bt* variety. In addition, a model will be developed relating the MC concentration to height reduction. This model will be compared to an existing MC concentration-height reduction model developed for a non-transgenic variety (Landivar et al., 1994).

Materials and Methods

To test the response of *Bt* cotton to variable rates of mepiquat chloride, a field experiment was conducted at the Texas A&M Agricultural Experiment Station in Corpus Christi, Texas during the 1998 growing season. The factorial field experiment was arranged as a randomized complete block design with four replications. Plants were seeded in a 38 in. row spacing at a density of 5 plants per row ft. Plots were fertilized and drip irrigated to prevent water and nutrient stresses. The factors consisted of 2 varieties and 5 application rates of mepiquat chloride. The varieties planted included a *Bt* variety (DPL 33^B) and the same variety without the transgene (DPL 5415). At the 12-node stage, Pix (4.2% MC) was applied to the plots with a backpack sprayer at the following rates: 5, 10, 15, and 20 oz/A. In addition to these application rates, a control that did not receive an application of MC was established.

Data collected for the field experiment consisted of weekly growth measurements and yield determinations. Weekly growth measurements of the cotton plants included height, node number, and dry weight. These measurements were collected for 6 weeks. In the dry weight analysis, plants were separated into leaves, stem, and fruit, and placed in a 150° F oven for 1 week to dry. Yield and earliness for each treatment were determined from two hand-harvests of 50 row-ft per plot.

To determine the effect of variable application rates of MC on plant height, the MC concentration in ppm was estimated. The MC concentration of the plant was calculated by dividing the total plant dry weight into the amount of MC applied to the plot per acre on a broadcast basis. Growth rates were calculated for each of the MC application rates to determine differences in response to MC by the 2 varieties. In addition, the response of MC concentration on height was compared to the height of the control. Data for the field experiment were analyzed using ANOVA, LSD, regression, and analysis of covariance.

Results and Discussion

No significant differences in vegetative growth were detected between the *Bt* and the conventional variety. Final plant height, number of main stem nodes, and the height to node ratio were statistically the same for both varieties (Table 1). Conversely, MC rate did significantly affect the vegetative growth of the cotton plants. The control plants were taller than any of the plants treated with MC. Plants receiving the lowest rate of MC were slightly shorter than the control. Similarly, the plants receiving the highest MC rate were the shortest plants. No significant differences were observed between MC rates for the number of main stem nodes. However, the control plants contained numerically more nodes than all of plants treated with MC. Significant differences were detected for the height to node ratio between MC rates. The highest height to node ratio was observed in the control plants. The 5, 10, and 15 oz/A MC rates produced plants with height to node ratios close to 1.3 in/node. The lowest height to node ratio was detected in the plants treated with 20 oz MC/A (Table 2).

Regression and analysis of covariance procedures performed on the data indicated that the two varieties grew at a similar rate. Control plants that did not receive an application of MC grew at the fastest rate. Conversely, plants receiving the highest rate of MC (20 oz/A) grew at the slowest rate. Analysis of covariance performed on the growth rate curves indicated that the slope of the curves was the same for both varieties. This implies that the *Bt* variety and the conventional variety grew at the same rate with regard to MC. Similarly, no significant differences in height (the intercept) were detected for the 15 and 20 oz/A growth rate curves. However, significant differences in the intercept were observed with the control and the lower MC rates. This indicates that the *Bt* variety is slightly taller than the conventional variety. The difference between the two varieties at the lower MC rates is approximately 1 in; therefore, the difference in height between the two varieties is probably not biologically significant (data not shown). Similar to the growth rates, MC concentration decreased in the plants at a similar rate for the two varieties (data not shown). MC concentration was estimated by dividing the weight of MC broadcasted to the plot/A by million grams of plant biomass. Because the growth rate and MC concentration curves were similar for the two varieties, one MC concentration-height reduction model was devised for both varieties (Figure 1). The model devised for the two varieties was similar to an existing MC concentration-height reduction model (Landivar et al., 1994). MC concentrations greater than 15 ppm did not cause further significant reductions in plant height. The effect of MC on height reduction diminished when the MC concentrations dropped below 5 ppm. The optimum concentration for MC-induced height reduction was between 5 and 15 ppm.

Significant differences in yield were observed with the two varieties and the variable rates of MC. A significant reduction in total yield was observed with the highest rate of MC (20 oz/A). However, no significant differences in total yield were detected between the lower rates of MC and the control (Figure 2). The transgenic variety DPL 33^{B} exhibited numerically higher yields than the conventional variety DPL 5415. However, significant differences in earliness were detected between the two varieties. During the first hand-harvest, statistically more cotton was harvested from the transgenic variety than the conventional variety. This trend was reversed for the second harvest; statistically more cotton was harvested from the conventional variety than the transgenic variety during the second harvest (Figure 3).

Conclusions

Vegetative growth of the cotton plants was influenced by MC rate and was not variety. No significant differences were detected among the two varieties in height, number of main stem nodes, and the height to node ratio. In addition, growth rate and MC concentration curves were similar for the two varieties. On the other hand, MC application rate did significantly affect vegetative growth. The control plants exhibited the tallest height, the most main stem nodes, and the highest height to node ratio. Applications of MC significantly reduced plant height, the number of main stem nodes, and the height to node ratio. Similarly, significant differences in growth rate and MC concentration were detected for the different MC rates. Similarities in the growth rate and the MC concentration allowed us to pool data from both varieties to devise a single MC concentration-height reduction model. The calculated model was similar to an existing MC concentration-height reduction model developed for a non-transgenic variety. Thus, we concluded that *Bt* and conventional varieties behave similarly with regard to MC-induced height reduction. Therefore, current MC application rate and timing strategies should suffice for suppressing rank vegetative growth of *Bt* cotton.

Both variety and the MC application rate significantly influenced yield. No significant differences were detected in total yield between the two varieties. However, more cotton was harvested during the first harvest in the *Bt* variety than in the conventional variety. This trend was reversed during the second harvest; thus, we concluded that the *Bt* variety was significantly earlier than the conventional variety. MC application rate significantly influenced total yield. No significant differences in total yield were observed with the control, 5, 10, and 15 oz MC/A treatments. However, the highest rate (20 oz MC/A) exhibited significantly lower total yield than the control and lower MC rates. Thus, extremely high rates of MC may cause a decrease in total yield.

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Table 1. The effect of variety on plant height, node count, and height to node ratio.

Variety	Height (in)	Nodes	Height:Node (in/node)
33B	30.4 a	22.2 a	1.37 a
5415	31.1 a	22.8 a	1.36 a
p-value	0.4052	0.1527	0.4300

Table 2. The effect of MC on plant height, node count, and height to node ratio.

MC rate (oz/A)	Height (in)	Nodes	Height:Node (in/node)
0	36.9 a	23.6 a	1.56 a
5	31.3 b	22.7 ab	1.38 b
10	29.7 bc	22.6 ab	1.32 b
15	29.2 c	22.1 b	1.32 b
20	26.5 d	21.8 b	1.21 c
p-value	0.0001	0.1024	0.0001

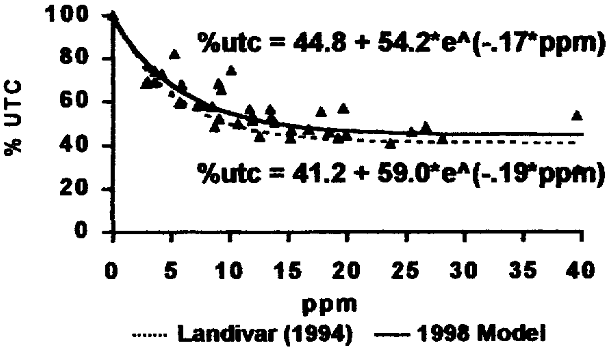

Figure 1. MC concentration-height reduction model developed for both varieties.

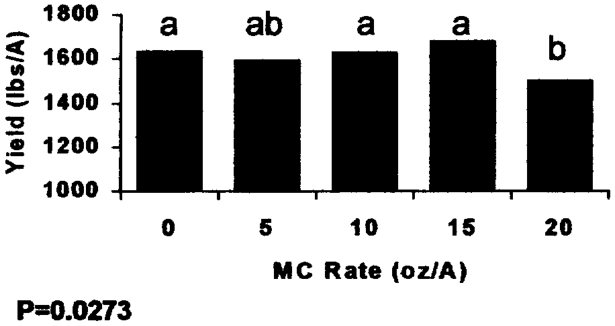

Figure 2. The effect of mepiquat chloride on total yield.

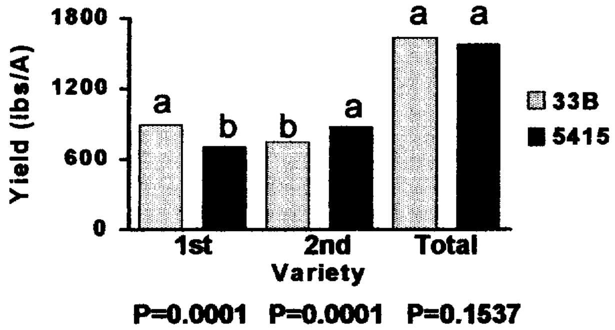

Figure 3. Differences in yield and earliness between the transgenic variety DPL 33^B and the conventional variety DPL 5415. Yield as a indicator of earliness between 1st and 2nd refer the the first and second hand-harvests, respectively.