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Effect of Plant Growth Regulators on Agronomic Characteristics, Lint Quality, Pests, and Predators in Cotton

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Abstract Field experiments were conducted with some commercial plant growth regulators (PGRs) to determine their effects on agronomic characteristics, pest densities, and predators when administered as a foliar spay on cotton at Adnan Menderes University Agricultural Research Center located in Aydin, Turkey, during the 2006 and 2007 cotton-growing seasons. The three commercial PGRs, Pix, Tonic, and Turbo pamuk, were sprayed at recommended doses and application time during the study. Application of PGRs significantly positively affected the yield, plant height, average number of open bolls, and predators, and significantly decreased the population densities of some economically important cotton pests. However, lint quality, ginning turnout, and average of seed cotton weight were not affected by the treatments. More yield was obtained in Pix- and Turbo pamuk-treated plots. The lowest densities of *Bemisia tabaci*, *Frankliniella* spp., and leaves infested with *Liriomyza trifolii* were recorded in Pix-treated plots. Although Turbo pamuk and Tonic numerically lowered the pest population densities compared to the control, the changes were not significant and these PGRs were not as effective as Pix. Furthermore, *Empoasca* spp. was not affected by the treatments. Populations of predators were not affected by the PGRs in Aranea orders, but were affected in Heteroptera, Neuroptera, Coleoptera, and Thysanoptera. Pix proved more suitable than others to producing resistance against pests and increasing the yields. PGRs neither enhanced any insect attack nor reduced predators in the study. Therefore, PGRs may be considered a component of Integrated Pest Management to provide higher yields in cotton.

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Introduction

Cotton is a major economic crop with an indeterminate growth habit, and it is very responsive to environmental changes and management. Excessive vegetative growth results in shade within the plant, leads to increased fruit abscission, and reduces yield (Guinn 1974). Consequently, researchers are searching diligently to find different means of increasing crop production. Plant growth regulators (PGRs) are applied in some instances to control undesirable vegetative growth of crop plants in an effort to enhance fruiting and increase yield and lint. PGRs decrease cotton vegetative growth by modifying the production of plant hormones such as gibberellins, auxins, and cytokinins. The most commonly used growth regulator is mepiquat chloride which decreases vegetative growth by reducing gibberellic acid formation. It has been used worldwide on cotton fields to decrease plant height, number of nodes, and leaf area and to enhance lint yield. The compound has also been shown to increase the water potential of leaves and transpiration rate (Kerby and others 1982; Stuart and others 1984; Zummo and others 1984). Application of ethephon at reduced rates in the late season did not affect yield (Jones and others 1990). On the other hand, ethephon used at harvest to enhance boll opening led to increased yields (Scott 1990). Application of triacontanol, NAA, Atonik, Recine, and Cytozyme have significantly increased seed cotton yield (Pothiraj and others 1995); Abro and others (2004) found that naphthalene acetic acid significantly delayed maturity of cotton and positively affected plant height, number of bolls, and yield.

Besides increasing the agronomic characteristics of cotton, PGRs, directly or indirectly, are bound to play a vital role in the patterns of growth and reproduction of associated phytophagous insects (Waring and Cobb 1992) as well as affect insect-plant interactions (Nazir and others 2003). Chlormequat chloride has been shown to suppress fecundity and survival of some aphid species (Tahori and others 1965; Honeyborne 1969; Smith 1969) and also to reduce whitefly infestations (Fischer and Shanks 1979), and aphid (*Hyperomyzus lactucae* L.) densities (Singer and Smith 1976). Also, gibberellic acid has been reported to reduce *Tetranychus telarius* Gorse and *Panonychus ulmi* (Koch) (Rodriquez and Campbell 1961; Eichmeier and Guyer 1960). Some researchers have recommended the use of PGRs like GA_3, coumarin, and IAA as successful chemosterilants against some insect pests (Salama and El-Sharabay 1972; Pandey and Teotia 1980; Thakur and Kumar 1984). Similarly, the effect of some PGRs on other pests has been mentioned by Zummo and others (1984), Henneberry and others (1988), Hedin and others (1988), and Coffelt and Schultz (1988).

Many new PGR compounds have been developed and tested on cotton with variable and sometimes disappointing results due to varied environments and production practices. With the current use of PGRs on cotton, research scientists and pest management practitioners need to know their impact on phytophagous cotton pests to optimize Integrated Pest Management (IPM) strategies (Nazir and others 2003; Abro and others 2004). Therefore, the purpose of this study was to investigate the effect of some commercial PGRs used as foliar sprays on cotton plants for agronomic characteristics, lint quality, pests, and predators.

Materials and Methods

Plant Material and Soil Type

Field experiments were conducted at Adnan Menderes University Agricultural Research Center located in Aydin, Turkey, during the 2006 and 2007 cotton-growing seasons. The cotton cultivar Nazilli 84S was planted on May 2, 2006, and May 4, 2007. The soil type was 12% clay, 23% silt, and 65% sand with a loamy sand structure.

Experiment Design and Applications

The experiment consisted of a randomized complete block design with three replications in each year. Each plot consisted of 8 rows × 15 m and row spacing was 0.70 m.

Table 1 Trade names, compounds (active ingredient/L), and recommended rates of plant growth regulators

Trade names	Compounds (active ingredient/L)	Recommended rates
Atonik	Sodium 5-nitroguaiacolate (1 g/L)	50 mL/da
	Sodium ortho-nitrophenolate (2 g/L)	
	Para-nitrophenolate (3 g/L)	
Turbo pamuk	α-Naphtylacetamide (1.18%/L)	60 g/100 L
	α-Naphtylacetic acide (0.43%/L)	
Pix	Mepiquat chloride (50 g/L)	50 g/100 L

There were 2-m spaces left between blocks to reduce the edge effects. The treatments consisted of the control and the commercial PGRs Pix (BASF distributor, Istanbul, Turkey), Tonic (Cansa Chemical Company, Istanbul, Turkey), and Turbo pamuk (Anadolu Seed Company, Istanbul Company, Turkey) as trade names that were sprayed with a CO_2-pressurized backpack sprayer in water as carrier at 750 L ha^{-1} using Tee-jet nozzle tips; the pressure was set at 207 kPa (Table 1). Each treatment was applied at recommended rates at the beginning of the square formation (June 28, 2006 and June 27, 2007), first flower (July 12, 2006 and July 12, 2007), and 2 weeks after first flower (July 26, 2006 and July 25, 2007).

Sampling of Agronomic Characteristics

Seed cotton samples were hand-harvested from all plants in 4 m of the four middle rows in each 8-row plot. The first hand-picking was done on October 4, 2006 and October 15, 2007, and the second picking occurred on November 9, 2006 and November 11, 2007. The yield was normalized or converted to total yield in kg ha^{-1}. The mean number of open bolls and height per plant were recorded by checking 10 plants per replication at harvest. Plant heights were measured from the ground surface to the plant terminal on October 4, 2006 and October 15, 2007. Twenty-five open bolls were picked from each plot and used to determine open boll seed weight (g) per boll. Bolls were ginned to determine ginning turnout percentage, lint yield, and lint quality. Fiber quality was tested at the Söke Trade Chamber. All parameters were estimated in HVI.

Sampling of Pests and Natural Enemies

The population densities of pests were recorded at weekly intervals from ten plants randomly selected per each replicate. Sixty leaves per replicate were checked visually. The sampling was conducted after application of PGRs and finished on August 25, 2006 and August 24, 2007. *Empoasca* spp. and *B. tabaci* populations were recorded per leaf.

Populations of *Frankliniella* spp. were calculated per flower and the infestation of *Liriomyza trifolii* was recorded as percentage rate per plant. Populations of *Asymmetrasca decedens* Paoli and *Empoasca decipiens* Paoli nymphs were counted together and recorded as *Empoasca* spp. (Table 5). Also, adults and nymphs of *Frankliniella occidentalis* (Pergande) and *F. intonsa* (Trybom) were counted together and recorded as a *Frankliniella* spp. The other cotton pests were not included due to low populations among the treatments.

Natural enemies were determined by using 50 net sweeps for each treatment. Additional species were recorded in each order and total amounts were given under that order in Table 5. No insecticidal and herbicidal applications were carried out in the experimental plots in the year. All cultural practices, including hoeing, fertilizing, and irrigation, were conducted as needed.

Statistical Analysis

Data were analyzed by one-way analysis of variance (ANOVA) and separated by Duncan's multiple range test ($p < 0.05$) using the SAS computer program (SAS Institute 1999).

Results

Agronomic Characteristics

Seed yields of cotton treated with selected commercial PGRs are presented in Table 2. There was an interaction between the years. The highest yields in 2006 were observed with 3586 ± 46.5 kg/ha in Pix-treated plots and 3416 ± 50.8 kg/ha in Turbo pamuk-treated plots (df = 3, $F = 6.435$, $p < 0.05$). In 2007 the highest yields also were observed in the same treatments with 2922 ± 28.4 kg/ha and 2837 ± 35.2 kg/ha being statistically different than other treatments (df = 3, $F = 7.648$, $p < 0.05$).

Table 2 Yields of cotton treated with commercial plant growth regulators in 2006 and 2007

Treatments	Yields (kg ha^{-1})	
	2006	2007
Pix	3586 ± 46.5aA	2922 ± 28.4aB
Turbo pamuk	3416 ± 50.8aA	2837 ± 35.2aB
Tonic	3308 ± 23.0bA	2513 ± 55.5bB
Control	3335 ± 33.0bA	2501 ± 11.6bB

Small letters designate the differences among the treatments within each year ($p < 0.05$)

Capital letters designate the differences between the years ($p < 0.05$)

Plant height was affected by the treatments, with the lowest height of 78.5 ± 2.3 in Pix-treated plots (df = 4, $F = 12.912$, $p < 0.05$). During the experiments, interactions were not noted for ginning turnout percentage (df = 1, $F = 1.074$, $p > 0.05$) or mean numbers of boll seed cotton weight (df = 3, $F = 0.212$ $p > 0.05$) between the years; therefore, the data were combined. Among the treatments statistical differences were not observed in ginning turnout percentage (df = 3, $F = 0.397$, $p > 0.05$) and seed cotton weight per boll (df = 3, $F = 0.354$, $p > 0.05$). Mean number of open bolls per plant was the highest in Pix and in Turbo pamuk, both of which were higher than Tonic-treated and control plots (df = 3, $F = 12.562$, $p < 0.05$) (Table 3).

The data related to fiber properties were combined between years due to lack of interaction (df = 1, $F = 0.241$, $p > 0.05$) (Table 4). None of the treatments had a significant effect on micronaire (df = 3, $F = 0.124$, $p > 0.05$), length (df = 4, $F = 0.512$, $p > 0.05$), uniformity ratio (df = 3, $F = 1.813$, $p > 0.05$), strength (df = 3, $F = 0.480$, $p > 0.05$), or elongation (df = 3, $F = 0.821$, $p > 0.05$).

Population Densities of Economically Important Pests

Aphis gossypii Glover, *Tetranychus cinnabarinus* (Boisd.), *Pectinophora gossypiella* Saunders, *Thrips tabaci* Lind., and *Heliothis armigera* (Hübn.) were rarely found so the population densities of these pests were not compared among the treatments.

The lack of interaction between the years of the population densities of *Empoasca* spp. (df = 1, $F = 1.084$, $p > 0.05$), *B. tabaci* (df = 1, $F = 0.831$, $p > 0.05$), and *Frankliniella* spp. (df = 1, $F = 0.549$, $p > 0.05$) and the infestation rate of *L. trifolii* (df = 1, $F = 0.040$, $p > 0.05$) allowed the data to be combined over years for each pest.

There was no significant effect of the application of PGRs on the population densities of *Empoasca* spp. in cotton compared with the control plot. A higher population (0.64 ± 0.6) of *Empoasca* spp. in the seasons was observed in the control plot followed by Turbo pamuk-, Tonic-, and Pix-treated plots (df = 3, $F = 1.252$, $p > 0.05$) (Table 5).

The average abundance of *B. tabaci* was affected by the treatments. The highest population density was observed in the control plot with 0.34 ± 0.6 per leaf, which was statistically greater than for any of the PGR treatments. The lowest population (0.12 ± 0.2) for *B. tabaci* was recorded in Pix-treated plots, which was lower than in Turbo pamuk- and Tonic-treated plots (df = 3, $F = 12.312$, $p < 0.05$).

The average abundance of *Frankliniella* spp. per flower was statistically affected by the treatments (df = 3, $F = 7.613$, $p < 0.05$). The highest population was again

Table 3 Mean values for agronomic characteristics of cotton treated with commercial plant growth regulators averaged over 2006 and 2007

Treatments	Plant height (cm)	Ginning turnout (%)	Mean seed cotton weight per boll (g)	Mean number of bolls per plant
Pix	78.5 ± 2.3b	46.1 ± 1.1a	4.9 ± 0.5a	15.1 ± 0.9a
Turbo pamuk	96.8 ± 4.5a	47.0 ± 0.9a	4.8 ± 0.4a	14.5 ± 1.4a
Tonic	96.9 ± 6.5a	47.2 ± 1.2a	4.9 ± 0.5a	10.4 ± 1.1ab
Control	97.1 ± 4.0a	46.6 ± 0.9a	4.6 ± 0.5a	10.2 ± 0.8ab

Small letters designate the differences among the treatments ($p < 0.05$)

Table 4 Mean values for fiber properties of cotton treated with commercial plant growth regulators over 2006 and 2007

Treatments	Micronaire (mc/index)	Fiber length (mm)	Uniformity ratio (%)	Strength (1000 lb in.$^{-2}$)	Elongation (%)
Pix	4.7 ± 0.1a	28.1 ± 0.6a	84.3 ± 0.4a	29.6 ± 0.6a	6.1 ± 0.4a
Turbo pamuk	4.8 ± 0.1a	28.5 ± 0.7a	84.4 ± 0.5a	29.8 ± 0.4a	6.1 ± 0.4a
Tonic	4.8 ± 0.2a	28.1 ± 0.6a	84.0 ± 0.3a	29.3 ± 0.5a	5.8 ± 0.3a
Control	4.9 ± 0.1a	28.9 ± 0.6a	84.1 ± 0.3a	30.3 ± 0.5a	6.0 ± 0.3a

Small letters designate the differences among the treatments ($p < 0.05$)

Table 5 Average abundance of *Empoasca* spp., *B. tabaci*, *Frankliniella* spp., and *L. trifolii* populations in cotton treated with commercial plant growth regulators over 2006 and 2007

Treatments	*Empoasca* spp. (No. per leaf ± SE)	*B. tabaci* (No. per leaf ± SE)	*Frankliniella* spp. (No. per flower ± SE)	*L. trifolii* (infestation rate [%] ± SE)
Pix	0.43 ± 0.4a	0.12 ± 0.2b	2.9 ± 0.4b	9.5 ± 4.9c
Turbo pamuk	0.58 ± 0.4a	0.15 ± 0.3b	5.6 ± 0.8ab	15.3 ± 4.6b
Tonic	0.52 ± 0.3a	0.26 ± 0.2ab	4.6 ± 1.2ab	13.7 ± 4.2b
Control	0.64 ± 0.6a	0.34 ± 0.6a	7.4 ± 1.2a	22.2 ± 6.4a

Small letters designate the differences among the treatments ($p < 0.05$)

observed in the control treatment at 7.4 ± 1.2. The lowest population was observed in Pix-treated plots at 2.9 ± 0.4.

The infestation rate of *L. trifolii* was also statistically affected by the treatment (df = 3, $F = 9.562$, $p < 0.05$). The highest infestation rate per plant was observed in the control plot at 22.2% and the lowest was in the Pix-treated plot at 9.5 ± 4.9.

Population Densities of Natural Enemies

During the experiment there was no interaction of years with respect to the population density of natural enemies Aranea (df = 1, $F = 0.493$, $p > 0.05$), Coleoptera (df = 1, $F = 0.178$, $p > 0.05$), Heteroptera (df = 1, $F = 0.308$, $p > 0.05$), Neuroptera (df = 1, $F = 0.433$, $p > 0.05$), and Thysanoptera (df = 1, $F = 0.243$, $p > 0.05$). Thus, the data over the years were combined (Table 6). There was no significant effect of PGRs on the population density of Aranea (df = 3, $F = 2.102$, $p > 0.05$). Populations of predators were not affected by the PGRs in Aranea orders but were affected in Heteroptera, Neuroptera, Coleoptera, and Thysanoptera. The highest amount of Aranea species in the experiment was observed in Turbo pamuk-treated plots at 0.20 ± 0.2. The highest population of Coleoptera was

Table 6 Average abundance of predator populations (numbers per 50 sweep net ± SE) in cotton treated with plant growth regulators over 2006 and 2007

Treatments	Aranea	Coleoptera	Heteroptera	Neuroptera	Thysanoptera
Pix	0.18 ± 0.1a	2.0 ± 0.6a	1.3 ± 0.6b	0.6 ± 0.1b	0.4 ± 0.2b
Turbo pamuk	0.20 ± 0.2a	1.6 ± 0.5b	2.9 ± 0.5a	1.0 ± 0.2ab	0.7 ± 0.2a
Tonic	0.16 ± 0.1a	1.6 ± 0.5b	3.0 ± 0.5a	0.8 ± 0.2b	1.3 ± 0.4a
Control	0.17 ± 0.1a	1.5 ± 0.4b	3.3 ± 0.6a	1.7 ± 0.8a	1.0 ± 0.4a

Small letters designate the differences among the treatments ($p < 0.05$)

observed at 2.0 ± 0.6 in Pix-treated plots (df = 3, $F = 5.312$, $p < 0.05$). Population densities of Heteroptera were the lowest in Pix-treated plots at 1.3 ± 0.6 (df = 3, $F = 9.210$, $p < 0.05$). The highest population densities of Neuroptera were observed in the control plot at 1.7 ± 0.8 (df = 3, $F = 9.435$, $p < 0.05$). The highest density of Thysanoptera was recorded in the Tonic-treated plots at 1.3 ± 0.4, whereas the lowest amount was observed in the Pix-treated plots at 0.4 ± 0.2 (df = 3, $F = 23.512$, $p < 0.05$).

Discussion

Our study revealed that application of PGRs affected the yield, plant height, average number of open bolls per plant, and the population densities of some economically important pests and some predators. The yield in 2006 was significantly higher than in 2007. The reason for the difference was due to environmental conditions in the region. Drought or lack of precipitation was an important factor in 2007. Higher temperatures and periodic episodes of heat stress, however, may also have exacerbated effects on many aspects of crop growth and development leading to reduced yields. The accumulated precipitation was 518.0 and 288.3 mm by November 15, 2006 and November 15, 2007, respectively. The temperature and heat period above 32°C, which is the optimum temperature for photosynthesis, was higher in 2007. Temperatures above 32°C are reported to decrease gross photosynthesis (Perry and Krieg 1981) and boll size (Stockton and Walhood 1960) and to also decrease the boll-fill period (Yfloulis and Fasoulas 1978). Such temperatures and low precipitation likely reduced the yield in 2007. Gencsoylu and Yalcin (2004) reported that temperature reduced the yield by over almost 50% in cotton.

Pix and Turbo pamuk increased the yield and average number of bolls in both years compared to the control. The increase occurred in the absence of differences on ginning turnout percentage and average seed weight between the treatments. The increases appear to be partly due to less shedding of flowers and bolls. It has been suggested that PGR chemicals may enhance yield by increasing photosynthesis or increasing the retention of photosynthate into fruiting forms (Guinn 1974). Many studies support the findings of this study (Pothiraj and others 1995; Rashdi 1998; Cook and Kennedy 2000; Lamas 2001; Djanaguiraman and others 2005).

Plant height was reduced by Pix treatment resulting in a shorter plant canopy. Height reduction results from reduced internode elongation (Reddy and others 1992). The lower height is accomplished by reducing the amount of gibberellic acid (GA) in the plant. The reduced amount of GA affects movement between cells due to decreased cell wall relaxation, decreased cell wall plasticity, and increased cell wall stiffness (Behringer and others 1990; Potter and Fry 1993; Yang and others 1996). By increasing the amount of friction between cells, the ability of the cells to elongate and replicate is hampered. Thus, plant height is reduced (Biles and Cothren 2001). The lint quality, including micronaire, fiber length, uniformity ratio, strength, and elongation, was not affected by the PGRs; these data are supported by the findings of Sawan and Sakr (1990), Sawan and Gregg (1993), and Jost and Dollar (2004).

The changes in plant growth development due to growth regulator use in cotton affected the insect populations. *B. tabaci*, *Frankliniella* spp., and *L. trifolii* populations were affected by the PGRs compared to the control plot. The lowest pest population densities in all experiments were recorded in Pix-treated plots. Rashdi (1998) reported that application of Pix significantly reduced infestation of thrips and whitefly in cotton. Nazir and others (2003) found that Pix and cytokin were more effective on Jassids, thrips, and whiteflies than were Atonic and Cytoplex. Similar effects on insect population densities were obtained in the present study.

Population densities of *Frankliniella* spp. were lowest in the Pix-treated plot. Wang and Chen (1984) reported that more seed protein content may be affected by the role of Pix in protein synthesis, encouraging the conversion of amino acids into protein. Amino acids play a central role in host selection/utilization for *F. occidentalis* feeding on flower tissue in field conditions. The population might be affected by the protein level in the plant tissue.

The actual reductions in pest density in cotton may be also attributed to the enhanced production of secondary biochemicals like tannin and gossypol (Norman and Sparks 1997). These metabolites are associated with resistance to cotton pests (Zummo and others 1984). The cotton plants treated with bioregulators may also help biological as well as physiologic forces exert pressure on the population of sucking complex and others (Nazir and others 2003).

The PGRs did not affect the population densities of natural enemies in Aranea orders but did so in Coleoptera, Neuroptera, and Thysanoptera. The low population in Heteroptera and Neuroptera was recorded in the Pix-treated plot. It was thought that the natural enemies in the orders were affected mainly because of the population of *B. tabaci* because Heteroptera and Neuroptera species have greater efficiency on *B. tabaci*. Populations of Thysanoptera species were also the lowest in Pix-treated plots due to low populations of *Frankliniella* spp. on the flowers. Population densities of natural enemies may be related to low populations of insects in the plots.

Pix proved to be more suitable than other PGRs to producing resistance against pests and increasing yields.

PGRs did not enhance insect attack nor reduce predators in the study. Therefore, PGRs may be considered a component of Integrated Pest Management and provide greater yields in cotton fields. The findings were supported by other research from Salama and El-Sharaby (1972), Pandey and Teotia (1980), and Nazir and others (2003).

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