Influence of Nitrogen Fertilization and Foliar Application of Plant Growth Retardants and Zinc on Quantitative and Qualitative Properties of Egyptian Cotton (*Gossypium barbadense* L. Var. Giza 75)

Zakaria M. Sawan,*,† Mahmoud H. Mahmoud,† and Osama A. Momtaz§

Cotton Research Institute, Soils and Water Research Institute, and Agricultural Genetic Engineering Research Institute, Agricultural Research Center, 9 Gamaa Stree, Giza 12619, Egypt

Field experiments, in two successive seasons, at the Agricultural Research Center, Giza, Egypt, determined the effect of N fertilization (addition at rates of 107 or 161 kg of N/ha) and foliar application of plant growth retardants (Pix, Cycocel, or Alar, each applied once at 300 ppm, 75 days after planting) and zinc (applied at 0.0 or 50 ppm, two times: 80 and 95 days after planting) on growth, mineral uptake, yield components, yield, and fiber properties of Egyptian cotton cultivar Giza 75. Dry matter yield, N and Zn uptake per plant, number of opened bolls per plant, boll weight, seed index, lint index, seed cotton yield per plant, and seed cotton and lint yield per hectare increased with increasing N rate and by foliar application of plant growth retardants (with best results when Pix was applied) and zinc. The earliness of harvest increased by the application of Zn in season I and Pix in season II only. Treatments generally had no effect on lint percentage and fiber properties, except in season II when Pix and Cycocel were applied, the 2.5% span length tended to increase over the control.

Keywords: *Nitrogen; plant growth regulators; zinc; cotton yield; fiber properties*

INTRODUCTION

Cotton is the most important fiber crop in the world as well as in Egypt. Increasing cotton production and quality is an urgent national goal to meet the consistent demand for this crop. The indeterminate and perennial habits of the cotton plant present difficulties to producers and researchers attempting to predict cotton growth stages. Most decisions regarding production inputs depend upon plant growth stage and yield potential. Thus, efforts have been made in recent years to better predict cotton growth and development. Cotton plant growth monitoring techniques have been shown to be effective tools for quantifying vegetative vigour (Oosterhuis et al., 1993). Nitrogen fertilization is an important input for optimization of cotton production. It is considered the limiting element for cotton production. Despite possible effects of excessive nitrogen in promoting vegetative growth, yield of cotton is probably more often limited by a deficiency rather than by an excess of nitrogen (Halevy et al., 1987). Organic matter provides the only lasting form of nitrogen in soil but, in warm areas where cotton is grown, many soils have been largely depleted of organic matter. Therefore, for maximum yields, most soils require annual fertilization with some form of nitrogen. Scientists are working hard to find different means for increasing crop production by formulating new compounds to arrive at such a goal. Some of these compounds exhibit hormonal traits [plant growth regulators (PGR)], while others have nutrient effects. PGR have certain advantages for the regulation of key processes in plants. The PGR Pix, Cycocel, and Alar can be used to manage the vegetative development of cotton plants. They tend to offset the effects of excessive water and/or nitrogen by decreasing both overall plant height and length of lateral branches (Wang et al., 1985; Reddy et al., 1990). The use of these same materials at rates lower than required to inhibit plant size cause increases in boll weight, number of open bolls at harvest, and yield, which appears to be partly due to less shedding of flowers and/or bolls. These chemicals may enhance yield function by increasing photosynthesis or by increasing the retention of, and partitioning of, photosynthate into fruiting forms (Guinn, 1984). Zinc deficiency, one of the most common micronutrient deficiencies, is becoming increasingly significant in crop production. The concentration of water soluble Zn in soil solution decreases with increasing pH (e.g. soils in Egypt). Liming thus depresses Zn uptake (Cottenie and Kiekens, 1974). Although only small amounts of zinc are removed from the field by a cotton crop (14.2 g/bale), zinc is critical for several key enzymes in the plant. Most notable are the enzymes that convert carbon dioxide with bicarbonate. It allows respiration in root tips during anaerobic conditions (lack of oxygen) and builds proteins (Oosterhuis et al., 1991). The main objective of this study was to evaluate the effect of N rates and foliar application of PGR (Pix, Cycocel, or Alar) and zinc (in chelated form) during square initiation and bolling stage on growth, yield, and fiber properties of Egyptian cotton.

MATERIALS AND METHODS

Two field experiments were conducted at the Agricultural Research Center, Ministry of Agriculture in Giza, Egypt, on the cotton cultivar Giza 75 (*Gossypium barbadense* L.) for seasons I and II. The soil type in both seasons was a clay loam. Average mechanical analysis (Kilmer and Alexander, 1940) and chemical characteristics (Chapman and Pratt, 1961) for

* Author to whom correspondence should be addressed (e-mail gert@ageri.sci.eg).

† Cotton Research Institute.

‡ Soils and Water Research Institute.

§ Agricultural Genetic Engineering Research Institute.

Table 1. Mechanical and Chemical Analyses of Soil Samples

	season I	season II
mechanical analysis		
clay (%)	45.27	39.00
silt (%)	27.21	27.49
fine sand (%)	18.49	26.60
coarse sand (%)	4.12	2.32
texture	clay loam	clay loam
chemical analysis		
organic matter (%)	1.81	1.58
calcium carbonate (%)	2.97	2.90
total soluble salts (%)	0.13	0.11
pH (1:2.5)	8.04	8.10
total nitrogen (%)	0.12	0.08
available nitrogen (mg/kg of soil)	34.00	57.00
available phosphorus (mg/kg of soil)	14.00	19.00
available potassium (mg/kg of soil)	300.00	310.00
available zinc (mg/kg of soil)	1.36	1.30
calcium (mequiv/100 g)	0.20	0.20

soil in both seasons are illustrated in Table 1. Each experiment included 16 treatments of the following combinations: (1) Two nitrogen rates (107 or 161 kg of N/ha) were applied as ammonium nitrate with lime (33.5% N) in two equal amounts, one after thinning (6 weeks after planting) and the other before the second irrigation (2 weeks after thinning). (2) Three PGR, 1,1-dimethylpiperidinium chloride (mepiquat chloride or Pix), 2-chloroethyltrimethylammonium chloride (chloromequat chloride, Cycocel or CCC), and succinic acid 2,2-dimethylhydrazide (daminozide, SADH, B-Nine, Kylar, or Alar), were used. Each was foliar sprayed once at 300 ppm, 75 days after planting (during square initiation and bolling stage) at volume solution of 960 L/ha. Water was used as a control treatment. (3) Two zinc treatments were applied (0.0 and 50 ppm of Zn) as chelated form [ethylenediaminetetraacetic acid (EDTA)]. Each was foliar sprayed two times: 80 and 95 days after planting at volume solution of 960 L/ha. Treatments can be summarized as follows (N rate is at kg/ha, PGR were applied at 300 ppm, and Zn rate is in ppm):

	treatment no.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
N	107								161							
PGR	0	0	Px	Px	Cyc	Cyc	A	A	0	0	Px	Px	Cyc	Cyc	A	A
Zn	0	50	0	50	0	50	0	50	0	50	0	50	0	50	0	50

A randomized complete block design with four replications was used. Seeds were planted on March 19 and 23 in seasons I and II, respectively, in plots 1.8 m × 4 m, including three ridges. Cultural practices were those used for cotton on the research station. Ten days after the last spray of zinc in season II (105 days after planting), five plant samples (shoots) were randomly chosen from the first and third ridges, transferred to the laboratory, and oven-dried at 70 °C for 24 h to determine the dry matter yield (grams per plant). Total nitrogen and zinc were determined by using the dry-ash method (Chapman and Pratt, 1961). Micronutrients were determined by atomic absorption spectrophotometry. Ten plants were randomly chosen from the center ridge of each plot to determine number of opened bolls per plant, boll weight (grams of seed cotton per boll), and seed cotton yield in grams per plant. Earliness, as percentage of total yield harvested in the first picking, was calculated as follows: seed cotton yield in the first picking was divided by the total seed cotton yield and multiplied by 100. First hand-picking took place on September 25 and 29 and final picking on October 11 and 15 in seasons I and II, respectively. Total seed cotton yield of each plot (including 10 plant subsamples) was ginned to determine seed cotton and lint yield (kilograms per hectare), lint percentage (lint percent of seed cotton), seed index (grams per 100 seeds), and lint index (grams of lint per 100 seeds). Fiber tests were made at a relative humidity of 65 ± 2% and temperature of 20 ± 1 °C to determine fiber length in terms of 2.5 and 50% span length (millimeters) and uniformity ratio as measured by a digital fibrograph; Micronaire reading included combined measure of fiber fineness and maturity, as measured by a Micronaire instrument, and flat bundle strength (expressed by grams per tex) was measured by stelometer tester at $^1/_8$ in. gauge length [according to American Society for Testing Materials (ASTM), 1979]. Results were analyzed as a factorial experiment (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Plant Growth and Mineral Content. The interaction between N rate and foliar application of PGR and zinc showed no significant effects for any of the measured characters. Table 2 indicates that there were significant effects on growth and nutrient content of cotton plants (105 days after sowing), under the high N rate regime (161 kg of N/ha) compared with the lower rate (107 kg of N/ha). These findings coincide with the fact that N is an essential nutrient in building the plant dry matter as well as many energy-rich compounds which regulate photosynthesis (Wankhade and Kene, 1990; Guhe and Sagare, 1992). Han et al. (1991) found that nitrogen concentration increased with increasing N rate for all of the above-ground parts of the cotton canopy. Treatment with PGR significantly enhanced growth and N and Zn uptake of cotton plants. The greatest increase in plant yield was obtained from Pix followed by Cycocel treatments. These increases have been noted probably from increasing photosynthetic rate, dry weight, and chlorophyll content of cotton plant (Wu et al., 1985). For foliar application of chelated zinc, the dry matter yield, N uptake, Zn concentration, and Zn uptake were significantly increased over those of plots not treated with Zn. Treatment with 50 ppm of Zn was rather low in N concentration in comparison with the other parameters. Similar findings were obtained by Mahmoud et al. (1985) and Sharma et al. (1988). Although zinc is needed in small amounts in the crop, it has been identified as a component of almost 60 enzymes (Amberger, 1974); therefore, it has a role in many plant functions.

Yield Components. *Number of Opened Bolls per Plant.* The number of opened bolls per plant significantly increased at high N rate in both seasons (Table 3). Hearn (1975) stated that N deficiency limits both rate and duration of flowering and may be the major factor in cut-out of cotton production. Anisimov and Bulatova (1982) found that N deficiency decreased the auxin content and markedly increased the content of inhibitors in the leaves and stems. These results confirmed those obtained by Ali et al. (1992) when nitrogen was applied at 107−202 kg/ha and by El Kalla et al. (1994) when nitrogen was applied at 107−214 kg/ha. Applying the three PGR (Pix, Cycocel, and Alar) increased the number of opened bolls per plant as compared with the untreated control in both seasons. Only Pix and Cycocel significantly increased the number of opened bolls per plant in season I; however, all three growth retardants significantly increased this component in season II. Such increases in boll opening may be due to increased photosynthetic activity of leaves following application of these substances (Wu et al., 1985; Gardner, 1988). Increased photosynthesis greatly increased flowering and boll retention (Wang et al., 1985; Kler et al., 1989). These results agreed with those for Cycocel, when applied at 58 ppm 75 days after sowing (Kler et al., 1989), and for Pix, when applied at

Table 2. Influence of N Rate and Foliar Application of Plant Growth Retardants and Zn on Dry Matter Yield and Uptake of N and Zn by Cotton Plants (Season II, Sampled 105 Days after Planting)[a]

		N		Zn	
treatment	dry matter yield (g/plant)	concn/dm (%)	N uptake (μg/plant)	concn/dm (ppm)	Zn uptake (μg/plant)
N					
107 kg/ha	33.69	2.518	848.7	46.88	1582.9
161 kg/ha	37.33**	2.764**	1032.6**	47.69	1786.4**
lsd 0.05	1.469	0.1143	56.45	NS	118.45
lsd 0.01	1.962	0.1527	75.39	NS	158.20
PGR					
0 ppm, control	33.23	2.601	865.7	46.13	1533.3
Pix, 300 ppm	36.59**	2.664	978.0*	47.88	1749.8*
Cycocel, 300 ppm	36.22**	2.649	961.3*	47.63	1742.4*
Alar, 300 ppm	35.99*	2.651	957.7*	47.50	1712.9*
lsd 0.05	2.077	NS	79.83	NS	167.51
lsd 0.01	2.775	NS	NS	NS	NS
Zn					
0 ppm, control	34.07	2.620	896.5	44.72	1524.6
50 ppm	36.95**	2.663	984.8**	49.84**	1844.6**
lsd 0.05	1.469	NS	56.45	2.643	118.45
lsd 0.01	1.962	NS	75.39	3.530	158.20

[a] *, significant at 5% level; **, significant at 1% level; and NS, not significant.

Table 3. Effect of N Rate and Foliar Application of Plant Growth Retardants and Zn on Yield Components of Cotton[a]

	no. of opened bolls/plant		boll wt (g)		lint (%)		seed index (g)		lint index (g)	
treatment	season I	season II	season I	season II	season I	season II	season I	season II	season I	season II
N										
107 kg/ha	11.02	11.61	2.430	2.482	34.62	34.53	10.11	10.46	5.35	5.52
161 kg/ha	11.79**	12.32**	2.474**	2.535**	34.43	34.33	10.25**	10.63**	5.38	5.56*
lsd 0.05	0.441	0.336	0.0274	0.0282	NS	NS	0.096	0.083	NS	0.036
lsd 0.01	0.589	0.450	0.0366	0.0377	NS	NS	0.129	0.111	NS	NS
PGR										
0 ppm, control	10.81	11.29	2.416	2.470	34.59	34.50	10.05	10.43	5.31	5.49
Pix, 300 ppm	11.77*	12.33**	2.474*	2.531*	34.52	34.45	10.27*	10.62**	5.41**	5.58**
Cycocel, 300 ppm	11.62*	12.28**	2.464*	2.521*	34.52	34.38	10.24*	10.59**	5.39**	5.55*
Alar, 300 ppm	11.43	11.97**	2.454	2.510*	34.48	34.40	10.17	10.55*	5.35	5.53
lsd 0.05	0.624	0.476	0.0387	0.0399	NS	NS	0.137	0.117	0.054	0.051
lsd 0.01	NS	0.636	NS	NS	NS	NS	NS	0.156	0.072	0.069
Zn										
0 ppm, control	11.09	11.54	2.434	2.488	34.60	34.49	10.12	10.48	5.36	5.52
50 ppm	11.72**	12.39**	2.470*	2.528**	34.45	34.37	10.24*	10.61**	5.38	5.56*
lsd 0.05	0.441	0.336	0.0274	0.0282	NS	NS	0.096	0.083	NS	0.036
lsd 0.01	0.589	0.450	NS	0.0377	NS	NS	NS	0.111	NS	NS

[a] *, significant at 5% level; **, significant at 1% level; and NS, not significant.

10−100 ppm once at 90 days or twice at 90−110 days from sowing (Sawan and Sakr, 1990), and for Cycocel and Alar, when sprayed at 250−500 or 750 ppm, 105 days after planting (Sawan and Gregg, 1993). Application of Zn significantly increased the number of opened bolls per plant over the untreated control in both seasons. Zinc is required in the synthesis of tryptophan, a precursor of indole-3-acetic acid synthesis (Oosterhuis et al., 1991), which is the major hormone that inhibits abscission of squares and bolls. This result was previously confirmed by Shrivastava and Singh (1988), when zinc sulfate was applied at 50 kg/ha, and by Gomaa (1991), when cotton was sprayed with 0.4 kg of Zn SO_4/ha.

Boll Weight. Boll weight increased with increasing N rate in both seasons (Table 3). Stanev (1976) reported that additional N increased the photosynthetic activity of leaves by 50−60%. This, in turn, might account for a higher accumulation of metabolites, thus directly impacting boll weight. Similar results were obtained by Ali et al. (1992) and El Kalla et al. (1994). Boll weight was increased by growth retardant application relative to the control in both seasons. Only Pix and Cycocel gave significant increases in the first season, but all three growth retardants gave significant increases in the second season. Pix treatment resulted in the highest boll weight for the growth retardants, followed by Cycocel. Increased boll weight from the application of the three growth retardants may be due to increased photosynthetic pigments (Wu et al., 1985; Gardner, 1988), which stimulate photosynthetic activity and subsequently dry matter accumulation. These in turn increase formation of fully matured bolls and their weight. Similar results were obtained by Sawan and Gregg (1993) with Cycocel and Alar and by McCarthy and Hedin (1994) with Pix. Application of Zn significantly increased boll weight as compared to the control in both seasons. This could be attributed to the favorable effect of this nutrient on the photosynthetic activity of leaves and plant metabolism (Jyung et al., 1975), which might account for higher accumulation of metabolites in reproductive organs (bolls). This result agreed with those of Sharma et al. (1988).

Lint Percentage. Lint percentage was not significantly affected by N rate (Table 3), which agreed with the results of Elayan (1992), who applied nitrogen at 36−143 kg/ha, although a slight reduction in lint percentage was observed at the highest N rate. None of the three growth retardants or Zn affected lint percentage as compared with the control in the two seasons. Lint percentage was slightly numerically less due to the application of these substances. Shrivastava

Table 4. Effect of N Rate and Foliar Application of Plant Growth Retardants and Zn on Yield and Yield Earliness in Cotton[a]

	seed cotton yield/plant (g)		seed cotton yield/ha (kg)		lint yield/ha (kg)		yield earliness (%)	
treament	season I	season II	season I	season II	season I	season II	season I	season II
N								
107 kg/ha	26.83	28.85	2834.9	2993.4	980.3	1032.6	75.20	69.16
161 kg/ha	29.22**	31.28**	3089.2**	3243.8**	1062.8**	1112.8**	75.02	69.11
lsd 0.05	1.368	1.119	157.10	122.62	49.64	37.04	NS	NS
lsd 0.01	1.828	1.495	209.83	163.77	66.31	49.47	NS	NS
PGR								
0 ppm, control	26.17	27.92	2766.7	2890.2	956.1	996.4	74.82	68.63
Pix, 300 ppm	29.18*	31.25**	3086.1*	3247.9**	1064.4*	1117.7**	75.31	69.92*
Cycocel, 300 ppm	28.68*	31.01**	3030.2*	3214.6**	1044.6*	1104.1**	75.24	69.12
Alar, 300 ppm	28.09	30.08**	2965.1	3121.8*	1021.2	1072.7**	75.08	68.86
lsd 0.05	1.935	1.583	222.17	173.41	70.21	52.38	NS	0.940
lsd 0.01	NS	2.114	NS	231.61	NS	69.97	NS	NS
Zn								
0 ppm, control	27.04	28.76	2859.2	2981.4	988.3	1027.4	74.67	68.92
50 ppm	29.01**	31.36**	3064.9*	3255.9**	1054.9**	1118.1**	75.55*	69.35
lsd 0.05	1.368	1.119	157.10	122.62	49.64	37.04	0.829	NS
lsd 0.01	1.828	1.495	NS	163.77	66.31	49.47	NS	NS

[a] *, significant at 5% level; **, significant at 1% level; and NS, not significant.

Table 5. Effect of N Rate and Foliar Application of Plant Growth Retardants and Zn on Fiber Properties of Cotton[a]

	2.5% span length (mm)		50% span length (mm)		uniformity ratio (%)		Micronaire reading		flat bundle strength (g/tex)	
treatment	season I	season II	season I	season II	season I	season II	season I	season II	season I	season II
N										
107 kg/ha	31.15	31.23	15.48	15.79	49.68	50.56	4.00	4.14	30.04	30.36
161 kg/ha	31.20	31.26	15.56	15.83	49.86	50.67	4.02	4.16	30.10	30.48
lsd 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PGR										
0 ppm, control	31.07	30.93	15.44	15.64	49.71	50.56	3.98	4.13	29.98	30.19
Pix, 300 ppm	31.25	31.36*	15.56	15.88	49.80	50.66	4.02	4.16	30.10	30.46
Cycocel, 300 ppm	31.24	31.45*	15.54	15.92	49.77	50.62	4.01	4.14	30.08	30.40
Alar, 300 ppm	31.15	31.25	15.51	15.82	49.80	50.62	4.03	4.18	30.12	30.65
lsd 0.05	NS	0.335	NS	NS	NS	NS	NS	NS	NS	NS
Zn										
0 ppm, control	31.12	31.22	15.48	15.80	49.76	50.62	4.00	4.14	30.03	30.27
50 ppm	31.24	31.28	15.55	15.83	49.78	50.61	4.02	4.16	30.11	30.58
lsd 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a] *, significant at 5% level; and NS, not significant.

and Singh (1988) found that Zn did not impact lint percentage. Sawan and Gregg (1993), using Cycocel and Alar, and Hayes et al. (1995) using Pix did not find any significant response with regard to lint percentage when these compounds were applied to cotton. These results confirmed the present findings.

Seed Index. Seed index significantly increased with increasing N rate in both years (Table 3). This may be due in part to enhanced photosynthetic activity, as N is essential for photosynthesis as a component of chlorophyll, enzymes, and membranes (Stanev, 1976). Similar findings were obtained by Kashyap et al. (1988) and Sawan et al. (1989) when nitrogen was applied at 108 or 216 kg/ha. In both seasons, application of all PGR increased seed index as compared to untreated control. In season I, only Pix and Cycocel produced significant increases, but in season II, increases were significant with all tested growth retardants; Pix gave the highest seed index in both years, followed by Cycocel. This indicates that treated cotton bolls had larger photosynthetically supplied sinks for carbohydrates and other metabolites than untreated bolls (Wu et al., 1985; Gardner, 1988). This agreed with previous works of Sawan and Gregg (1993), with Cycocel and Alar, and of Hayes et al. (1995), with Pix. Zinc significantly increased seed index compared with the untreated control in both years. This again might be due to its favorable effect on photosynthetic activity, which improves mobilization of photosynthates and directly influences boll weight that coincides with increased seed index (Jyung et al., 1975). In this connection, Kashyap et al. (1988), with increases in Zn levels up to 15 ppm, and Sawan et al. (1989) noted that application of Zn increased seed index.

Lint Index. Lint index increased as N rate increased numerically in both seasons (Table 3) but was statistically significant only in season II. Similar results were obtained by Janardan Singh and Warsi (1985). Application of all growth retardants increased lint index compared to the untreated control in both seasons. Increases were significant with the application of Pix and Cycocel, with the most pronounced effect from Pix. These results were in agreement with those obtained by Kler et al. (1989) with Cycocel, by Sawan and Sakr (1990) with Pix, and by Sawan and Gregg (1993) with Cycocel and Alar. Application of Zn showed lint index was numerically greater over the control in both seasons but was statistically significant only in season II. Sawan (1985) found that application of Zn tended to increase lint index.

Yield. Seed cotton yield per plant, as well as seed cotton and lint yield per hectare, significantly increased by raising the N rate in either season (Table 4). This could be attributed to the fact that N is an important nutrient for controlling new growth and preventing abscission of squares and bolls (Varma, 1982) and is also essential for photosynthetic activity (Stanev, 1976). These results confirmed those obtained by Elayan (1992) and El Kalla et al. (1994). In both seasons, all PGR generally increased seed cotton yield per plant, as well as seed cotton and lint yield per hectare, compared to the untreated control. In season I, only Pix and Cycocel produced statistically significant increases; in season II, increases were significant with all tested growth retardants. The highest increase in cotton yield was with Pix, followed by Cycocel. These results may be attributed to the promoting effect of these substances on numerous physiological processes, leading to improvement of all yield components. Pix application increased the carbon dioxide uptake and fixation in cotton plant leaves (Gausman et al., 1980). In cotton stems, the xylem was expanded with Pix treatment, perhaps increasing the transport ability and accounting for heavier bolls (Schott and Rittig, 1982). Cycocel and Alar have also been associated with increased photosynthesis (Wu et al., 1985; Gardner, 1988) through increased total chlorophyll concentration of plant leaves. In their studies, increased photosynthesis greatly increased flowering, boll retention, and yield. These results agreed with those obtained by Gadakh et al. (1992) with Pix and Cycocel and by Sawan and Gregg (1993) with Cycocel and Alar. Application of Zn significantly increased seed cotton yield per plant and seed cotton and lint yield per hectare in both seasons, as compared to untreated plants. These increases could be due to favorable effects of this nutrient on yield components of number of opened bolls per plant, boll weight, or both. Results obtained here confirmed those of Gomaa (1991).

Yield Earliness. Earliness of yield was not significantly affected by N rate in either season (Table 4), although a slight decrease in yield earliness was observed at the higher N rate. Similar results were obtained by McConnell et al. (1993) when cotton was treated with 56−224 kg of N/ha. Earliness of yield was enhanced numerically by all growth retardants over the control in both years, but was statistically significant only with Pix application in season II. Heydendorff-Scheel et al. (1983) reported that, after treatment with Pix, the cotton canopy closes more slowly and provides an improved microclimate (especially better light conditions) that results in earlier maturity. Similar results were obtained by Sawan and Gregg (1993) with Cycocel and Alar and by Hayes et al. (1995) with Pix. Yield earliness increased numerically with Zn application over the control in both seasons, but was statistically significant only in season I.

Fiber Properties. Nitrogen rate and application of Zn had no significant effect in either season on fiber length parameters (2.5 and 50.0% span length and uniformity ratio), Micronaire reading, or flat bundle strength (Table 5). The mean values of these characters tended to increase slightly by the use of high N rate and application of Zn. Others have reported similar findings. Elayan (1992) found that fiber properties were not significantly affected by N rates. Shrivastava and Singh (1988) observed that Zn application did not affect all of the fiber properties. The three growth retardants had no significant effect on the fiber properties tested in either season with one exception, a 2.5% span length in season II. The mean value of this character was significantly increased over the untreated control by using Pix and Cycocel. All fiber properties tended to improve numerically with the application of these substances compared with the control but with no definite trend due to the different growth retardants. Studies on natural growth substances suggested that there may be specific elongation hormones for cotton fiber (Mitchell et al., 1967), so failure to improve fiber properties consistently may simply be due to failure to test the right compound. Potential chemical improvement of fiber length should not be ignored. Sawan and Sakr (1990) with Pix and Sawan and Gregg (1993) with Cycocel and Alar found that fiber quality was not significantly affected by these substances.

Under the conditions of this study it is concluded that addition of N at 161 of kg/ha, spraying cotton plants with PGR (especially Pix), and application of Zn have the most beneficial effects of treatments examined in this study on cotton productivity and quality.

ACKNOWLEDGMENT

We thank Prof. Dr. Magdy Madkour, Director of AGERI, for his encouragement in progressing with this work, excellent ideas, and helpful discussions. We also thank all GERT staff for assistance.

LITERATURE CITED

Ali, S. A.; Abd El Aal, S. A.; El Hillw, S. S. Effect of hill spacing and nitrogen levels on Egyptian cotton variety Giza 81 at late sowing date. *J. Agric. Sci.* (*Mansoura Univ., Egypt*) **1992**, *17*, 3430−3436.

Amberger, A. Micronutrients, dynamics in the soil, and function in plant metabolism. In *Proceedings of the Egyptian Botany Society Workshop*, Cairo, Egypt; 1974; Vol. 1, pp 81−90.

American Society for Testing Materials. *Annual Book of ASTM Standards. Part 33: Textiles, Fibers, Zippers*; ASTM: Philadelphia, 1979.

Anisimov, A. A.; Bulatova, T. A. The content of auxins and growth inhibitors in plants under various mineral conditions. *Fiziol. Rast. (Moscow)* **1982**, *29*, 908−914.

Chapman, H. D.; Pratt, P. F. *Methods of Analysis for Soils, Plants and Waters*; University of California, Division of Agricultural Science: Los Angeles, 1961; pp 60−61, 150−179.

Cottenie, A.; Kiekens, L. Quantitative and qualitative plant response to extreme nutritional conditions. In *Plant Analysis and Fertilizer Problems*; Wehrmann, J., Ed.; German Society for Plant Nutrition: Hannover, 1974; Vol. 2, pp 543−556.

Dabre, W. M.; Tiwane, A. K.; Belorkar, V. T.; Rainchwar, S. P. Effect of Cycocel on growth and yield parameters (*Gossypium hirsutum L.*). *J. Soils Crops* **1991**, *1*, 187−188.

Elayan, S. E. D. A comparative study on yield, some yield components and nitrogen fertilization of some Egyptian cotton varieties. *Assiut J. Agric. Sci.* **1992**, *23*, 153−165.

El-Kalla, S. E.; El Kassaby, A. T.; Leilah, A. A.; Ghonema, M. H.; Ismail, M. M. Effect of sowing dates, population and distribution of plants and nitrogen fertilizer levels on growth and yield of Egyptian cotton “Giza 75.” In *Proceedings of the Sixth Conference of Agronomy*, Sept, 1994; Faculty of Agriculture, Al Azhar University: Cairo, Egypt, 1994; pp 95−108.

Gadakh, S. R.; Pol, K. M.; Patil, V. A. Effects of growth retardants on hybrid cotton (Varlaxmi). *J. Maharashtra Agric. Univ.* **1992**, *17*, 137.

Gardner, F. P. Growth and partitioning in peanut as influenced by gibberellic acid and daminozide. *Agron. J.* **1988**, *80*, 159−163.

Gausman, H. W.; Walter, H.; Rittig, F. R.; Escobar, D. E.; Rodriguez, R. R. Effect of mepiquat chloride (Pix) on CO2 uptake of cotton plant leaves. In *Proceedings of the Plant Growh Regulator Working Group*; Abdel Rahman, M., Ed.; Plant Growth Regulator Working Group, 1−6: Longmont, CO, 1980.

Gomaa, M. A. Response of cotton plant to phosphatic and zinc fertilization. *Ann. Agric. Sci.* (*Moshtohor, Egypt*) **1991**, *29*, 1051−1061.

Guhe, Y. S.; Sagare, B. N. Response of cotton to levels of moisture and nitrogen grown on Ustochrepts, Ustifluvents, and Chromusterts. *Agropedology* **1992**, *2*, 75−79.

Guinn, G. Boll Abscission in Cotton. In *Crop Physiology: Advancing Frontiers*; Gupta, U. S., Ed.; Mohan Primlani for Oxford & IBH Publishing: New Delhi, India, 1984; pp 177−225.

Halevy, J.; Marani, A.; Markovitz, T. Growth and NPK uptake of high-yielding cotton grown at different nitrogen levels in permanent-plot experiment. *Plant Soil* **1987**, *103*, 39−44.

Han, T.; Cothren, J. T.; Hons, F. M. Cotton yield and nutrient uptake as affected by Pix and rate of nitrogen application. Presented at the Joint Meeting: Cotton Improvement and Physiology Conferences; 1991; p 1028.

Hayes, R. W.; Jenkins, J. N.; McCarty, Jr., J. C. Effects of Pix at low rate multiple application reproductive and vegetative structures in cotton. In *Proceedings of the Beltwide Cotton Conferences*, San Antonio, TX; National Cotton Council: Memphis, TN, 1995; p 577.

Hearn, A. B. Response of cotton to water and nitrogen in a tropical environment. II. Date of last watering and rate of application fertilizer. *J. Agric. Sci. Cambridge* **1975**, *84*, 419−430.

Heydendorff-Scheel, R. C. von; Schott, P. E.; Rittig, F. R. Mepiquat-chloride, a plant growth regulator for cotton. *Z. Pflanzenkrankh. Pflanzenschutz* **1983**, *90*, 585−590.

Janardan Singh; Warsi, A. S. Effect of sowing dates, row spacings and nitrogen levels on ginning out-turn and its components in hirsutum cotton. *Indian J. Agron.* **1985**, *30*, 263−264.

Jyung, W. H.; Ehmann, A.; Schlender, K. K.; Scala, J. Zinc nutrition and starch metabolism in *Phaseolus vulgaris* L. *Plant Physiol.* **1975**, *55*, 414−420.

Kashyap, J.; Sharma, J. C.; Taneja, A. D.; Gupta, V. K. Effect of Zn on seed weight, gossypol and oil content of H-777 and G-27 cultivars of cotton. *J. Indian Soc. Cotton Improvement* **1988**, *13*, 159−162.

Kilmer, V. J.; Alexander, L. T. Methods of making mechanical analysis of soils. *Soil Sci.* **1940**, *68*, 15.

Kler, D. S.; Raj, D.; Dhillon, G. S. Modification of micro-environment with cotton canopy for reduced abscission and increased seed yield. *Environ. Ecol.* **1989**, *7* (4), 800−802.

Mahmoud, M. H.; Abdel Aziz, I. M.; Ashoub, M. A. Effect of P and Zn on growth, mineral content and yield of Egyptian cotton (*Gossypium barbadense* L.). *Ann. Agric. Sci.* (*Ain Shams Univ.*, Cairo, Egypt) **1985**, *30*, 993−1010.

McCarty, J. C., Jr.; Hedin, P. A. Effects of 1,1-dimethylpiperidinium chloride on the yields, agronomic traits, and allelochemicals of cotton (*Gossypium hirsutum* L.), a nine year study. *J. Agric. Food Chem.* **1994**, *42*, 2302−2304.

McConnell, J. S.; Baker, W. H.; Miller, D. M.; Frizzell, B. S.; Varvil, J. J. Nitrogen fertilization of cotton cultivars of differing maturity. *Agron. J.* **1993**, *85*, 1151−1156.

Mitchell, J. W.; York, G. D.; Worley, J. F. Growth-acceleration substances in cotton fibers. *J. Agric. Food Chem.* **1967**, *15*, 329−333.

Oosterhuis, D.; Hake, K.; Burmester, C. Leaf Feeding Insects and Mites. *Cotton Physiol. Today* **1991**, *2*, 1−7.

Oosterhuis, D. M.; Bourland, F. M.; Tugwell, N. P. Physiological basis for the nodes-above-white-flower cotton monitoring system. In *Proceedings Beltwide Cotton Conferences*, New Orleans, LA,; National Cotton Council: Memphis, TN, 1993; pp 1181−1183.

Reddy, V. R.; Baker, D. N.; Hodges, H. F. Temperature and mepiquat chloride effects on cotton canopy architecture. *Agron. J.* **1990**, *82*, 190−195.

Sawan, Z. M. Effect of nitrogen fertilization, and foliar application of calcium and micro-elements on yield components, and fiber properties of Egyptian cotton. *Egypt. J. Agron.* **1985**, *10*, 25−37.

Sawan, Z. M.; Gregg, B. R. Influence of growth retardants and plant density on cotton yield and fiber properties. *Ann. Bot. (Rome)* **1993**, *51*, 33−42.

Sawan, Z. M.; Sakr, R. A. Response of Egyptian cotton (*Gossypium barbadense*) yield to 1,1-dimethylpiperidinium chloride (Pix). *J. Agric. Sci. Cambridge* **1990**, *114*, 335−338.

Sawan, Z. M.; Maddah El Din, M. S.; Gregg, B. Effect of nitrogen fertilisation and foliar application of calcium and micro-elements on cotton seed yield, viability and seedling vigour. *Seed Sci. Technol.* **1989**, *17*, 421−431.

Schott, P. E.; Rittig, F. R. New Findings on The Biological Activity of Mepiquat Chloride. In *Chemical Manipulation of Crop Growth and Development*; McLaren, J. S., Ed.; Butterworth Scientific: London, 1982; pp 415−424.

Sharma, J. C.; Tomar, N. K.; Gupta, V. K. Effect of levels and methods of zinc application and growth, yield attributes and yield of cotton (*Gossypium hirsutum* L.). *Agric. Sci. Dig., India* **1988**, *8*, 165−169.

Shrivastava, U. K.; Singh, D. Effect of nitrogen and zinc on growth and yield of cotton. *Indian J. Agron.* **1988**, *33*, 257−260.

Snedecor, G. W.; Cochran, W. G. *Statistical Methods*, 7th ed.; Iowa State University Press: Ames, IA, 1980.

Stanev, V. Changes in indices of photosynthetic of sunflower in relation to fertilizers and plant density. *Fiziol. Rast.* **1976**, *11*, 28.

Varma, S. K. Endogenous nitrogen content in flower buds and bolls of cotton (*Gossypium hirsutum* L.) in relation to abscission. *Agric. Sci. Dig., India* **1982**, *2*, 113−115.

Wang, J. X.; Chem, W. H.; Yu, Y. L. The yield increasing effect of growth regulators on cotton and their application. *China Cottons* **1985**, *3*, 32−33.

Wankhade, S. T.; Kene, H. K. Pattern of biomass production in upland cotton in response to genotypes, nitrogen, and plant densities. *Ann. Plant Physiol.* **1990**, *4*, 59−65.

Wu, L. Y.; Chen, Z. H.; Yuan, Y. N.; Hu, M. Y. A comparison of phsyiological effects of DPC and CCC on cotton plants. *Plant Physiol. Commun.* **1985**, *5*, 17−19.

Received for review December 15, 1995. Revised manuscript received April 28, 1997. Accepted April 30, 1997.[⊗] We acknowledge the Cotton Improvement Project for financing this work.

JF950817P

[⊗] Abstract published in *Advance ACS Abstracts*, June 1, 1997.