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Growth, Yield Components, Yield and Fiber Properties of Egyptian Cotton (*Gossypium barbadense* L.) as Affected by Potassium Fertilization and Foliar Application of Zinc and Phosphorus

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ABSTRACT

Two experiments were conducted at the Agricultural Research Center, Giza, Egypt, to investigate the effect of soil potassium fertilization and foliar application of chelated zinc and phosphorus on yield components, yield and fiber properties of cotton (*Gossypium barbadense* L.) cv. 'Giza 86'. Potassium (0.0 and 47.4 kg of K ha^{-1}) was soil-applied eight weeks after sowing, while chelated zinc (0.0 and 57.6 g of Zn ha^{-1}, applied twice at 70 and 85 days after sowing) and phosphorus (0.0, 576, 1152 and 1728 g of P ha^{-1}, applied twice at 80 and 95 days after sowing) were applied to the foliage. Dry matter yield of cotton plants (shoots), total chlorophyll concentration, K, Zn and P-uptake $plant^{-1}$, number of opened bolls $plant^{-1}$, boll weight, seed index, lint index, seed cotton and lint yield ha^{-1} and earliness of harvest increased with the application of potassium and Zn and P at different concentration rate. Treatments generally had no significant effect on lint percentage and fiber properties, with exceptions for micronaire reading and flat bundle strength in the first season, and uniformity ratio in the second season, where the mean values of these characters increased significantly over the untreated control by applying K, and for the micronaire reading in the first season, when applying P at 1728 g ha^{-1}, and uniformity ratio in the second season, when applying P at 1152 and 1728 g ha^{-1}, where the mean values of these characters increased significantly over the untreated control by applying P. Under the conditions of this study, applying K fertilization at 47.4 kg ha^{-1} combined with spraying cotton plants with zinc at 57.6 g ha^{-1} and also with P at 1728 g ha^{-1} improved growth and yield of Egyptian cotton.

Keywords: boll weight, earliness of harvest, flat bundle strength, micronaire reading, number of opened bolls $plant^{-1}$

INTRODUCTION

Since cotton production covers a wide range of environments and economic circumstances, yields and hence nutritional requirements vary greatly. Supplying optimal quantities of mineral nutrients and using balanced macro- and micro-nutrient doses to growing crop plants is one way to improve crop yields (Zubillaga *et al.* 2002). Mineral nutrients has several roles in formation, partitioning, and utilizetion of photosynthates. Therefore, mineral nutrient deficiencies substantially impair production of dry matter and its partitioning between the plant organs (Marschner *et al.* 1996; McDonald *et al.* 1996). Deficiencies of mineral nutrients severely limit flower initiation and development (Steer and Hocking 1983) and viability of pollen grains (Sharma *et al.* 1991). The concentration of mineral nutrients in the soil solution, i.e. the available nutrient concentration, varies over a wide range, depending on many factors such as pH, soil organic matter and fertilizer application (Marschner 1986). High pH and low organic matter characterize soils of arid and semi-arid areas. Such properties reduce the availability of the mineral nutrients to crop plants.

Potassium (K) is an essential macronutrient for all living organisms required in large amounts for normal plant growth and development (Marschner 1986). Potassium deficiencies can limit the accumulation of crop biomass. This is attributed to the fact that K increases the photosynthetic rates of crop leaves, CO_2 assimilation, and facilitates carbon movement (Sangakkara *et al.* 2000). Also, K nutrition has pronounced effects on carbohydrate partitioning by affecting either phloem export of photosynthates (sucrose) or growth rate of sink and/or source organs (Cakmak *et al.* 1994). Furthermore, K has an important role in the translocation of photosynthesis from sources to sinks (Cakmak *et al.* 1994). Pettigrew (1999) stated that the elevated carbohydrate concentrations remaining in source tissue, such as leaves, appear to be part of the overall effect of K deficiency in reducing the amount of photosynthate available for reproductive sinks, which produced changes in lint yield and fiber quality seen in cotton. Potassium plays a particularly important role in cotton fiber development and a shortage will result in poorer fiber quality and lowered yields (Cassman *et al.* 1990). Potassium is a major solute in the fiber (single cells) involved in providing the turgor pressure necessary for fiber elongation. If K is in limited supply during active fiber growth, there will be a reduction in the turgor pressure of the fiber resulting in less cell elongation and shorter fibers at maturity (Oosterhuis 1994). Notable improvements in cotton yield and quality resulting from K input were reported by Gormus (2002) when applying K_2O at the rates of 80, 160 and 240 kg K_2O ha^{-1} (with cv. 'Cukurova 1518'), Aneela *et al.* (2003a) with increasing K_2O levels and was highest at 200 kg K_2O ha^{-1} (with cvs. 'CIM443', 'CIM109' and 'CIM443'), Pervez *et al.* (2004) at 62.5, 125, 250 kg K ha^{-1} (with cvs. 'S-12', 'NIAB-Karishma', 'CIM-1100', 'CIM-448'), Pettigrew *et al.* (2005) under K fertilizer 112 kg ha^{-1} (with genotypes 'DPL 32B', 'FiberMax 832', 'MD 51 ne', 'PayMaster 1218BR', 'Phytogen PSC 355', 'RGC 9811', 'Stv. BXN 47', 'Stv. La 887', 'SureGrow 747') and Sharma and

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Sundar (2007) by foliar application of 2% K_2O at 5 kg ha^{-1} (with cv. 'H-6').

Crop yields are often limited by low soil levels of mineral micronutrients such as zinc (Zn), especially in calcareous soils of arid and semiarid regions (Cakmak *et al.* 1999). Zinc is an essential mineral nutrient and a cofactor of over 300 enzymes and proteins involved in cell division, nucleic acid metabolism, and protein synthesis (Marschner 1986). Cakmak (2000) speculated that Zn deficiency stress may inhibit the activities of a number of antioxidant enzymes, resulting in extensive oxidative damage to membrane lipids, proteins, chlorophyll, and nucleic acids. Zinc can affect carbohydrate metabolism at various levels. The activity of the Zn-containing enzyme carbonic anhydrase sharply declines with Zn deficiency. Carbonic anhydrase is localized in the cytoplasm and chloroplasts, and may facilitate the transfer of CO_2/HCO_3^- for photosynthetic CO_2 fixation (Sharma *et al.* 1982). Further, Zn is required in the biosynthesis of tryptophan, a precursor of the auxin indole-3-acetic acid (IAA), which is the major hormone inhibiting abscission of squares and bolls (Oosterhuis *et al.* 1991). Zinc deficiency symptoms include small leaves, shortened internodes giving the plant a stunted appearance, reduced boll set and small bolls size (Oosterhuis *et al.* 1991). Zinc deficiency is observed in cotton growing on high pH soils, particularly where the topsoil has been removed to alter the field slope for irrigation, exposing the Zn-deficient subsoil. In addition, Zn deficiencies have occurred where high concentrations of phosphorus are applied (Oosterhuis *et al.* 1991). Li *et al.* (2004) found that when summer cotton (*Gossypium hirsutum*) was sprayed with 0.2% zinc sulfate at the seedling stage, the activity of nitrate reductase in roots and leaves, chlorophyll content and photosynthetic rates of leaves increased significantly. They also found that the boll number $plant^{-1}$ increased by 17.3% and the lint cotton yield increased by 18.5% compared with the untreated control.

Phosphorus (P) has been found to be the life-limiting element in natural ecosystems because it is often bound in highly insoluble compounds and hence it becomes unavailable for plant uptake or utilization (Ozanne 1980). Phosphorus is an essential nutrient and an integral component of several important compounds in plant cells. These compounds include the sugar-phosphates involved in respiration, photosynthesis and the phospholipids of plant membranes, the nucleotides used in plant energy metabolism and in molecules of DNA and RNA (Taiz and Zeiger 1991). Phosphorus is also a necessary nutrient for the biosynthesis of chlorophyll, where P as pyridoxal phosphate must be present for the biosynthesis of chlorophyll (Ambrose and Easty 1977). Phosphorus as a constituent of the cell nucleus is essential for cell division and development of meristematic tissue (Russell 1973). Phosphorus deficiencies lead to a reduction in the rate of leaf expansion and photosynthesis per unit leaf area (Rodriguez *et al.* 1998). The high soil pH (>7.6) and the high quantities of $CaCO_3$ result in precipitation of P, which reduces the soluble P supply. Improvements in cotton yield resulting from P application were reported by Stewart *et al.* (2005) and Singh *et al.* (2006).

The objectives of the present study were to evaluate the effects of addition of K-fertilizer and foliar spraying of chelated Zn and P, during square initiation and boll setting stage, on yield and fiber properties of cotton. The aim was to identify fertilizer doses that may improve yield and quality. We tested the hypothesis that applying K-fertilizer and foliar application of Zn and P will stimulate and impact on growth, yield and fiber properties of Egyptian cotton (*G. barbadense*) grown on alluvial soil. An improved understanding of K, Zn and P nutrition in cotton would help producers better manage their inputs for optimal yield and fiber quality.

Table 1 Physical and chemical analysis of the soil used in seasons I and II.

Season	I	II
Physical analysis (soil fraction)[a]		
Clay (%)	43.00	46.46
Silt (%)	28.40	26.38
Fine sand (%)	19.33	20.69
Coarse sand (%)	4.31	1.69
Soil texture	Clay loam	Clay loam
Chemical analysis[b]		
Organic matter (%)	1.83	1.92
Calcium carbonate (%)	3.00	2.73
Total soluble salts (%)	0.13	0.13
pH (1:2.5)	8.10	8.08
Total nitrogen (%)	0.12	0.12
Available nitrogen (mg/kg soil)	50.00	57.50
Available phosphorus (mg/kg soil)	15.66	14.19
Available potassium (mg/kg soil)	370.00	385.00
Available zinc (mg/kg soil)	1.30	1.90
Calcium (meq/100 g)	0.20	0.20

[a] According to Kilmer and Alexander (1940).
[b] According to Chapman and Pratt (1961). Note: The field was divided into uniform soil areas; eight soil samples to plow depth of 30 cm were collected at random over the field and mixed to give a composite sample.

MATERIALS AND METHODS

A three-factor experiment was conducted at the Agricultural Research Center, Ministry of Agriculture in Giza (30°N, 31° 28′E at an altitude of 19 m), Egypt using the cotton cultivar 'Giza 86' (*Gossypium barbadense* L.) in the two seasons I and II. The factors studied were i.e. K-fertilization, foliar application of Zn and P concentrations. The experiment was arranged according to a randomized complete block design with four replications. The soil in both seasons was clay loamy. In each season, the experimental field was divided into uniform soil areas; eight soil samples to plow depth 30 cm were collected at random over the field and mixed to give a composite sample to measure its physical chemical properties. Average physical analysis and chemical characteristics (Chapman and Pratt 1961) for soil in both seasons is provided in **Table 1**. Range and mean values of the climatic factors recorded during the growing seasons are presented in **Table 2**. All the climatic factors were measured according to the methodological directions adapted by the World Meteorology Organization (WMO). The source of the climatic data was the Agricultural Meteorological Station of the Agricultural Research Station, Agricultural Research Center, Giza, Egypt. No rainfall occurred during the two growing seasons. Each experiment included 16 treatments, which were the combinations of two potassium rates (0.0 and 47.4 kg K ha^{-1}), two zinc rates (0.0 or 57.6 g Zn ha^{-1}) and four phosphorus rates (0.0, 576, 1152 and 1728 g P ha^{-1}). Potassium was applied as potassium sulfate (K_2SO_4, "48% K_2O"), eight weeks after sowing (as a concentrated band close to the seed ridge), and the applica-

Table 2 Range and mean values of the climatic factors recorded during the growing seasons.

Climatic factors	Season I		Season II		Overall date (Two seasons)	
	Range	Mean	Range	Mean	Range	Mean
Max Temp [°C]	20.8-44.0	32.6	24.6-43.4	32.7	20.8-44.0	32.6
Min Temp [°C]	10.4-24.5	19.4	12.0-24.3	19.3	10.4-24.5	19.3
Max-Min Temp [°C]	4.7-23.6	13.2	8.5-26.8	13.4	4.7-26.8	13.3
Sunshine [h d^{-1}]	0.3-12.9	11.1	1.9-13.1	11.2	0.3-13.1	11.1
Max Hum [%]	48-96	79.5	46-94	74.7	46-96	77.2
Min Hum [%]	6-48	30.1	8-50	33.0	6-50	31.5
Wind speed [m s^{-1}]	0.9-11.1	5.2	1.3-11.1	5.0	0.9-11.1	5.1

Table 3 A summary of all treatments K, Zn and P rate study in seasons I and II, Agricultural Research Center, Ministry of Agriculture, Giza, Egypt.

K rate (kg ha^{-1})	Zn rate (g ha^{-1})	P rate (g ha^{-1})	Treatment №
0.0	0.0	0.0	1
		576	2
		1152	3
		1728	4
	57.6	0.0	5
		576	6
		1152	7
		1728	8
47.4	0.0	0.0	9
		576	10
		1152	11
		1728	12
	57.6	0.0	13
		576	14
		1152	15
		1728	16

tion was followed immediately by irrigation. Zinc was applied to the foliage, in chelated form [ethylenediaminetetraacetic acid (EDTA)], two times (70 and 85 days after sowing) during the square initiation and boll setting stage. Phosphorus rates were foliar applied as calcium superphosphate (15% P_2O_5), two times (80 and 95 days after sowing). Zinc and P were applied to the leaves with uniform coverage in a solution volume of 960 L ha^{-1} using a knapsack sprayer. The pressure was 0.4 kg/cm^2 that resulted in a nozzle output of 1.43 L/min. The applications were carried out between 0900 and 1100 h. A summary of all treatments is shown in **Table 3**.

Experiments were planted on the 3rd and 20th April (seasons I and II, respectively) in a randomized complete block design with four replications. The plot size was 1.95 m × 4 m and contained three ridges (beds). Hills were spaced 25 cm apart on one side of the ridge, with seedlings thinned to two plants per hill at six weeks after planting. This provided a plant density of 123,000 plants ha^{-1}. Total irrigation during the growing season (surface irrigation) was about 6,000 m^3 ha^{-1}. Irrigation was first applied 3 weeks after planting and again 3 weeks later. Thereafter, the plots were irrigated every 2 weeks until the end of the season (11th October for season I and 17th October for season II) in a total of nine irrigations. On the basis of soil test results, N fertilizer was applied at a rate of 144 kg N ha^{-1} as ammonium nitrate with lime at two equal doses; the first one was applied after thinning just before the second irrigation and the other one was applied before the third irrigation (the recommended level for semi-fertile soil). Pest and weed management were conducted as needed during the growing season, according to local practice performed at the experimental station.

Ten days after the last spray of phosphorus in season II (105 days after planting), five plant samples (shoots) were randomly chosen from the first and the third ridges, transferred to the laboratory and oven-dried at 70°C for 24 hours to determine the dry matter yield (g plant^{-1}). Total potassium, zinc and phosphorus were determined by using the wet-digestion method (Chapman and Pratt 1961). Micronutrients were determined by atomic absorption spectrophotometer. Chlorophyll *a* and *b* were also determined in the 4th fresh leaves at the top plant as the method described by Ranganna (1972).

In both years, 10 plants were randomly chosen from the center ridge of each plot to determine number of open bolls per plant, boll weight (grams of seed cotton per boll), and seed cotton yield per plant in grams. Earliness was calculated as the percentage of first harvest. First hand picking took place on the 20th and 26th September and final picking on the 11th and 17th October in seasons I and II, respectively. Total seed cotton yield of each plot (including 10 plant sub samples) was ginned to determine seed cotton and lint yield (kg ha^{-1}), lint percentage, seed index (g 100 seed^{-1}) and lint index (g lint 100 seed^{-1}). Fiber tests were conducted at a relative humidity of 65 ± 2% and a temperature of 20 ± 1°C to determine fiber length in terms of 2.5 and 50% span length (mm) and uniformity ratio as measured by a digital fibrograph (ASTM 1998a). Micronaire reading, including combined measure of fiber fineness and maturity, was measured by a micronaire instrument (ASTM 1998b), and flat bundle strength was measured by stelometer at 1/8-inch gauge length (ASTM 1998c).

Statistical analysis

Data for the studied characters observed in each year were analyzed separately using a linear model for a factorial experiment arranged in a randomized complete block (RCB) design following the procedure outlined by Snedecor and Cochran (1980). The least significant difference (L.S.D.) test ($P = 0.05$) was used to examine differences among treatment means and the interactions, if significant, to determine the optimum factorial combination of K, Zn and P.

RESULTS AND DISCUSSION

Results from the analysis of variance for yield components, yield, yield earliness and fiber properties are presented in **Tables 4-6**.

Effects of interactions among treatments

There were no significant interactions among K, Zn and P with respect to quantitative and qualitative characters under investigation, except for the interaction effects between K and Zn for dry matter yield of cotton plants (shoots) at 105 days after sowing, as well as K, Zn and P content (**Table 7**, between K and P for total chlorophyll concentration, as well as K, and Zn content (**Table 8**), between Zn and P for K and Zn content (**Table 9**), and between K, Zn and P for total chlorophyll concentration, as well as Zn content (**Table 10**). Application of K combined with Zn and or P application increased Dry matter yield of cotton plants (shoots) at 105 days after sowing, as well as K, Zn and P content as well as total chlorophyll concentration, over that obtained with K or Zn and or P alone. With the exception of lint percentage, which tended to decrease, favorable effects on cotton productivity and quality accompanied the application of K, Zn, and P.

Table 4 Mean squares from analysis of variance of yield components of cotton.

Source	d.f.	№ of opened bolls plant^{-1}		Boll weight (g)		Lint percentage (%)		Seed index (g)		Lint index (g)	
		I	II	I	II	I	II	I	II	I	II
Replicates	3	2.66*	2.41	0.1240**	0.0655	0.5203*	0.5004	0.1100*	0.0844*	0.0006	0.0033
K	1	20.84**	12.32**	0.2128**	0.2116**	0.2413	0.5852	0.4692**	0.3460**	0.0704**	0.0163*
Zn	1	9.86**	5.41*	0.1165*	0.1351*	0.1016	0.1482	0.1936*	0.1016*	0.0260*	0.0063
P	3	3.87**	3.31*	0.1029**	0.0910*	0.0667	0.0766	0.1354**	0.0921*	0.0199**	0.0101*
K × Zn	1	2.77	0.03	0.0005	0.0008	0.0017	0.0663	0.0068	0.0118	0.0012	0.00002
K × P	3	0.57	0.34	0.0002	0.0054	0.0078	0.0020	0.0065	0.0023	0.0010	0.0005
Zn × P	3	0.29	0.31	0.0008	0.0054	0.0017	0.0031	0.0038	0.0082	0.0011	0.0025
K × Zn × P	3	1.73	0.23	0.0028	0.0045	0.0003	0.0029	0.0091	0.0013	0.0022	0.0007
Error	45	0.71	0.99	0.0201	0.0262	0.1573	0.1968	0.0310	0.0247	0.0042	0.0025

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

Table 5 Mean squares from analysis of variance of on yield and yield earliness in cotton.

Source	d.f.	Seed cotton yield ($g\ plant^{-1}$)		Seed cotton yield ($kg\ ha^{-1}$)		Lint yield ($kg\ ha^{-1}$)		Yield earliness (%)	
		I	II	I	II	I	II	I	II
Replicates	3	66.98**	47.20*	756173**	509163*	108828**	64747*	1.84	2.62
K	1	297.44**	207.54**	2789902**	2009802**	330036**	218416**	31.92*	7.49
Zn	1	147.41**	99.03*	1356992**	915801*	159490**	103427*	25.76*	0.93
P	3	77.22**	61.75*	727295**	573270*	86177**	64616*	13.72*	1.99
K × Zn	1	16.37	0.07	137456	225	17493	107	0.49	1.08
K × P	3	12.24	4.25	41951	40039	5530	4562	0.12	0.32
Zn × P	3	1.65	1.72	17837	19422	2299	2355	0.33	0.14
K × Zn × P	3	9.99	3.36	98995	29314	12504	3700	0.93	0.13
Error	45	11.99	15.29	134585	145893	16066	17937	4.80	5.61

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

Table 6 Mean squares from analysis of variance of fiber properties of cotton.

Source	d.f.	2.5% span length (mm)		50% span length (mm)		Uniformity ratio (%)		Micronaire reading		Flat bundle strength ($g\ tex^{-1}$)	
		I	II	I	II	I	II	I	II	I	II
Replicates	3	0.0981	0.5769	0.0183	0.0689	0.067	0.198	0.0331	0.0073	0.091	0.219
K	1	0.2889	0.3906	0.2025	0.3452	0.303	0.759*	0.1702*	0.0900	3.915*	3.629
Zn	1	0.0452	0.1600	0.0306	0.0977	0.044	0.122	0.0977	0.0400	1.142	0.833
P	3	0.0193	0.1490	0.0242	0.1852	0.068	0.597*	0.0689*	0.0102	0.875	0.631
K × Zn	1	0.0002	0.0025	0.0006	0.0077	0.003	0.108	0.0014	0.0156	0.044	0.018
K × P	3	0.0027	0.0040	0.0033	0.0252	0.017	0.188	0.0017	0.0021	0.085	0.041
Zn × P	3	0.0006	0.0050	0.0023	0.0027	0.030	0.007	0.0014	0.0004	0.020	0.006
K × Zn × P	3	0.0006	0.0042	0.0006	0.0018	0.002	0.041	0.0027	0.0019	0.005	0.023
Error	45	0.1025	0.3571	0.0558	0.1141	0.163	0.152	0.0243	0.0237	0.920	0.939

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

Table 7 Effect of interaction between K rate and foliar application of Zn on dry matter yield and uptake of K, Zn and P by cotton plants (season II, sampled 105 days after planting).

Character	Dry matter yield ($g\ plant^{-1}$)		K Uptake (µg/plant)		Zn Uptake (µg/plant)		P Uptake (µg/plant)	
Zn rate ($kg\ ha^{-1}$) / K rate ($g\ ha^{-1}$)	0.0 (control)	57.6	0.0 (control)	57.6	0.0 (control)	57.6	0.0 (control)	57.6
0.0 (control)	26.51	35.90	1442.4	1705.2	1381	2191	94.44	98.81
47.4	33.18	46.33	1686.6	2307.7	2052	2109	102.88	138.56
LSD (0.05)	1.649		245.8		503		23.72	

Values followed by the same letter in columns under every character head are not significantly different from each other at $P = 0.05$.

Table 8 Effect of interaction between K rate and foliar application of P on chlorophyll and uptake of K and Zn and by cotton plants (season II, sampled 105 days after planting).

Character	Chlorophyll (µg/L)		K uptake (µg/plant)		Zn uptake (µg/plant)	
K rate ($g\ ha^{-1}$) / P rate ($g\ ha^{-1}$)	0.0 (control)	47.4	0.0 (control)	47.4	0.0 (control)	47.4
0.0 (control)	3.859	4.389	1533.6	1687.6	1828	1402
576	5.002	5.120	1485.9	1551.0	1668	1970
1152	6.386	7.002	2003.8	1820.5	2120	2505
1728	7.355	7.839	2050.5	2151.5	1989	1984
LSD (0.05)	0.450		245.8		503	

Values followed by the same letter in columns under every character head are not significantly different from each other at $P = 0.05$.

Plant growth and mineral content

Dry matter yield of cotton plants (shoots) at 105 days after sowing; total chlorophyll concentration, as well as K, Zn and P content was determined to study the effect of applied potassium and foliar application of Zn and P on plant growth and mineral uptake (**Table 11**).

A higher response was obtained by applied potassium and foliar application of zinc and phosphorus. In this connection, Hiremath and Hunsigi (1995) found that K content in petioles, and total dry matter production increased by applied K to cotton plants. Furthermore, Fan *et al.* (1999) found that K content in petioles, and total dry matter production increased by applied K to cotton plants. Gormus (2002) indicated that the 0 kg K_2O ha^{-1} plots (untreated control) had lower leaf K concentrations, compared with the other plots, when applying K_2O at the rates of 80, 160 and 240 kg K_2O ha^{-1}. Aneela *et al.* (2003b) indicated that the K content significantly increased with increasing K_2O levels and was highest at 200 kg K_2O ha^{-1}. The P content increased significantly with potash application and was highest at 100 K_2O ha^{-1}. Kassem and Ahmed (2005) found that the application of K fertilizer at 48 kg ha^{-1} exhibited a significant increase in P and K content in leaves of cv. 'Giza 83'. Makhdum *et al.* (2007) stuied the effect of K supply (0, 62.5, 125, and 250 kg K ha^{-1}) on dry matter accumulation of cotton cvs. 'CIM-448', 'CIM-1100', 'Karishma', and 'S-12', and found that the maximum total dry weight was obtained when crops received 250 kg K ha^{-1}. According to the K-status in the experimental soil (**Table 1**), it is classified as medium fertile for K.

Foliar application of Zn improved dry matter yield, total chlorophyll concentration, as well as P, and Zn uptake. This stimulation is due to a decrease in Zn concentration in the soil (**Table 1**). Because the pH value of the soil site was higher than 6, Zn almost certainly would give a profitable response (Benton *et al.* 1991). Cakmak (2000) has speculated that Zn deficiency stress may inhibit the activities of a

Table 9 Effect of interaction between Zn rate and foliar application of P on uptake of K and Zn by cotton plants (season II, sampled 105 days after planting).

Character	K uptake (μg/plant)		Zn uptake (μg/plant)	
Zn rate (g ha^{-1}) / P rate (g ha^{-1})	0.0 (control)	57.6	0.0 (control)	57.6
0.0 (control)	1658.4	1879.0	2188	1551
576	1613.1	1895.0	1760	2139
1152	1495.1	2041.3	1836	1569
1728	1528.6	2173.4	2020	2402
LSD (0.05)	245.8		503	

Values followed by the same letter in columns under every character head are not significantly different from each other at $P = 0.05$.

Table 10 Effect of interactions between K rate, foliar application of Zn and P on chlorophyll and uptake of Zn by cotton plants (season II, sampled 105 days after planting).

Treatment			Chlorophyll (μg/L)	Zn uptake (μg/plant)
K rate (kg ha^{-1})	Zn rate (g ha^{-1})	P rate (g ha^{-1})		
0.0 (control)	0.0 (control)	0.0 (control)	3.163	1488
		576	3.965	1253
		1152	4.543	1124
		1728	4.652	1661
	57.6	0.0 (control)	4.555	2168
		576	4.813	1550
		1152	5.461	2212
		1728	5.588	2279
47.4	0.0 (control)	0.0 (control)	5.950	2888
		576	6.550	2419
		1152	6.812	1978
		1728	6.650	1478
	57.6	0.0 (control)	6.823	1353
		576	7.454	2591
		1152	7.899	2000
		1728	9.027	2490
LSD (0.05)			0.636	251

Means followed by the same letter in a column are not significantly different from each other at $P = 0.05$.

Table 11 Mean effects of K and foliar application of Zn and P on dry matter yield, chlorophyll and uptake of K, Zn and P by cotton plants (season II, sampled 105 days after planting).

Treatments	Dry matter yield (g plant^{-1})	Chloro phyll (μg/L)	K Uptake (μg/plant)	Zn Uptake (μg/plant)	P Uptake (μg/plant)
K rate (kg ha^{-1})					
0.0 (control)	29.85	4.593	1564.5	1717	98.66
47.4	41.12	7.146	2006.4	2150	119.19
LSD ($p = 0.05$)	1.166	0.225	122.91	251	11.86
Zn rate (g ha^{-1})					
0.0 (control)	31.21	5.286	1573.8	1786	97.13
57.6	39.76	6.453	1997.2	2081	120.72
LSD ($p = 0.05$)	1.166	0.225	122.91	251	11.86
P rate (g ha^{-1})					
0.0 (control)	33.50	5.123	1768.7	1974	91.50
576	34.56	5.696	1754.1	1954	108.56
1152	36.27	6.178	1768.1	1829	116.19
1728	37.59	6.479	1851.0	1977	119.44
LSD ($p = 0.05$)	1.649	0.318	n.s.	n.s.	16.77

* Significant at 5% level; n.s.: not significant.

number of antioxidant enzymes, resulting in extensive oxidative damage to membrane lipids, proteins, chlorophyll, and nucleic acids. Li *et al*. (2004) found that when summer cotton was sprayed with 0.2% zinc sulfate at the seedling stage, the chlorophyll content of leaves increased significantly.

Applied P at different concentrations significantly enhanced growth, N and K uptake as well as total chlorophyll concentration, of cotton plants. The most increase in dry matter yield was obtained from the high P concentration (1728 g ha^{-1}). In this respect, the importance of P and Zn nutrition for Egyptian cotton was also confirmed by Mahmoud *et al*. (1985) who found a significant relationship between Zn uptake and P uptake by plants. This reflects the positive relationship that exists between the two elements in the nutrition of cotton plants. These results can be interpreted that both K and Zn are necessary for the biosynthesis of chlorophyll (Amberger 1974). Therefore the factors making the tissues become green (NPK and minor-elements) are themselves stimulators for chlorophyll biosynthesis. Data also reveal that the uptake of P by cotton plants increased significantly by the application of K, Zn and P treatments, individually. Malik *et al*. (1992) indicated that manurial value of P was higher on medium fertile soil, as indicated by a higher pH resulting from P fixation. More and Agale (1993) indicated that when P was applied to cotton plants at 25-75 kg P_2O_5 ha^{-1}, plant uptake increased with increasing P fertilization, while dry matter yield increased with increasing P levels up to 50 kg P_2O_5 ha^{-1}. Deshpande and Lakhdive (1994) found that P application (25-50 kg P_2O_5 ha^{-1}) increased P uptake and content in stem, leaf, reproductive parts and seed. Ahmad *et al*. (2000) pointed out that P deficiency reduced biomass. Dorahy *et al*. (2004) indicated that seventeen field experiments were conducted on alkaline soils in eastern Australian to evaluate irrigated cotton response to P fertilizer application, and found that only 3 experiments demonstrated significant increase in crop P uptake when P was applied at 20-40 kg P ha^{-1}.

Yield components

***Number of opened bolls plant^{-1}*:** Application of K (47.4 kg ha^{-1}) increased the number of opened bolls plant^{-1} significantly, as compared to the untreated plants in both seasons (**Table 12**). Guinn (1985) suggested that growth, flowering, and boll retention decrease when the demand for photosynthate increases and exceeds the supply. This means that an increase in photosynthesis should permit more bolls to be set before cutout. The role of K suggests that it affects abscission. Zeng (1996a) indicated that K fertilizer reduced boll shedding. Similar results were obtained by Coker *et al*. (2000), Gormus (2002) and Pervez *et al*. (2004). Kassem and Ahmed (2005) found that the application of K fertilizer at 48 kg ha^{-1} exhibited a significant increase in the number of opened bolls plant^{-1}. Sharma and Sundar (2007), using cv. 'H-6' by foliar application of 2% K_2O at 5 kg ha^{-1} resulted in an increase in the number of opened bolls plant^{-1}.

Application of Zn significantly increased number of opened bolls plant^{-1}, over the untreated control in the two seasons. Zinc is required in the synthesis of tryptophan, a precursor of IAA synthesis (Oosterhuis *et al*. 1991), which is the major hormone that inhibits abscission of squares and bolls. These results agree with those previously reported by Sawan *et al*. (1997), Rathinavel *et al*. (2000), by soil application of $ZnSO_4$ at 50 kg ha^{-1}, and Li *et al*. (2004) when cotton was sprayed with 0.2% zinc sulfate at seedling stage.

Application the three P concentrations (576, 1152 and 1728 g ha^{-1}) increased the number of opened bolls plant^{-1} as compared with the untreated control in both seasons (but not significantly different from each other). This increase was significant for all P concentrations in the first season and for P at 1152 and 1728 g ha^{-1} in the second season. Spraying plants with P at 1728 g ha^{-1} (high concentration) produced (numerically) the highest number of opened bolls plant^{-1}. Phosphorus is essential for cell division and for development of meristematic tissue, causing a stimulating effect on the number of flower buds and bolls plant^{-1} (Russell 1973). Results for boll numbers as a result of P application in this study were similar to those obtained by Malewar *et al*. (2000), who applied P_2O_5 at 25-62.5 kg ha^{-1}, Katkar *et al*. (2002), who applied diammonium phosphate (DAP) at 2% and Liang *et al*. (2007) with *G. hirsutum*.

Table 12 Mean effects of K and foliar application of Zn and P on yield components of cotton.

Treatments	Number of opened bolls plant^{-1}		Boll weight (g)		Lint percentage (%)		Seed index (g)		Lint index (g)	
	I	II	I	II	I	II	I	II	I	II
K rate (kg ha^{-1})										
0.0 (control)	11.97	11.50	2.468	2.433	35.43	34.67	10.12	9.89	5.554	5.249
47.4	13.11*	12.38*	2.583*	2.548*	35.31	34.48	10.29*	10.04*	5.621*	5.281*
LSD (p = 0.05)	0.42	0.50	0.071	0.081	n.s.	n.s.	0.09	0.08	0.033	0.025
Zn rate (g ha^{-1})										
0.0 (control)	12.15	11.65	2.483	2.445	35.41	34.62	10.15	9.92	5.568	5.255
57.6	12.93*	12.23*	2.568*	2.536*	35.33	34.53	10.26*	10.00*	5.608*	5.275
LSD (p = 0.05)	0.42	0.50	0.071	0.081	n.s.	n.s.	0.09	0.08	0.033	n.s.
P rate (g ha^{-1})										
0.0 (control)	11.87	11.39	2.410	2.385	35.46	34.67	10.08	9.86	5.538	5.234
576	12.56*	11.80	2.532*	2.488	35.37	34.57	10.21*	9.95	5.590*	5.258
1152	12.68*	12.15*	2.576*	2.550*	35.33	34.54	10.26*	10.00*	5.604*	5.276*
1728	13.05*	12.44*	2.584*	2.539*	35.32	34.52	10.29*	10.04*	5.619*	5.292*
LSD (p = 0.05)	0.60	0.71	0.101	0.115	n.s.	n.s.	0.13	0.11	0.046	0.036

* Significant at 5% level; n.s.: not significant.

Boll weight: Boll weight was significantly increased by K application relative to the control in both seasons (**Table 12**). Applying a high K concentration resulted in the highest boll weight. Potassium increases the photosynthetic rates of crop leaves (Bednarz and Oosterhuis 1999; Ma *et al.* 2007) and CO_2 assimilation (Wolf *et al.* 1976). The obtained results of total chlorophyll (*a* and *b*) confirmed these findings (**Table 11**). Thereby K deficiency affected the reduction in the amount of photosynthate available for reproductive sinks and this produced changes in boll weight. The increase in boll weight by K application in our study confirms the findings of Gormus (2002), Aneela *et al.* (2003a) and Pervez *et al.* (2004). Pettigrew *et al.* (2005) indicated that K fertilization produced minimal (1%) but statistically significant increases in boll mass relative to the untreated control. Kassem and Ahmed (2005) found that the application of K fertilizer at 48 kg ha^{-1} exhibited a significant increase in boll weight. Sharma and Sundar (2007), using cv. 'H-6' by foliar application of 2% K_2O at 5 kg ha^{-1} could increase boll weight.

Application of Zn significantly increased boll weight, compared with the untreated control in both seasons. This could be attributed to the favorable effect of this nutrient on carbohydrate metabolism, where the activity of the Zn-containing enzyme carbonic anhydrase sharply declines with Zn deficiency. Carbonic anhydrase (which plays a role in photosynthesis) is localized in the cytoplasm and chloroplasts, and may facilitate the transfer of CO_2/HCO_3^- for photosynthetic CO_2 fixation (Sharma *et al.* 1982). Similar results to this study were obtained by Hai *et al.* (1999), and Rathinavel *et al.* (2000).

Phosphorus also significantly increased boll weight in both seasons, as compared to untreated plants as the treatment rate was increased up to 1728 g ha^{-1}, with one exception in season I, where the application of a low P concentration (576 g ha^{-1}) increased boll weight numerically only. Boll weights were greatest from the highest P concentration applied (1728 g ha^{-1}). Guidi *et al.* (1994) stated that photosynthetic activity and stomatal conductance were reduced and quantum yield of CO_2 uptake at 345 ppm CO_2 decreased with P deficiency. Similar results were obtained by Sawan *et al.* (1997) when cotton was supplied 44 or 74 kg of P_2O_5 ha^{-1}, and Vieira *et al.* (1998), when cotton was supplied 30-120 kg P ha^{-1}.

Lint percentage: Applied K did not significantly affected lint percentage as compared with the control in both seasons (**Table 12**). Gormus (2002) found that applying K_2O at 80 kg ha^{-1} gave the same mean lint turnout as the untreated control in the first season, while applications of 160 and 240 kg K_2O ha^{-1} increased lint turnouts (by 0.6 and 0.9%, respectively). Lint turnout in the second season was not affected by any K treatment. These results confirmed the present findings.

Neither phosphorus rate nor application of Zn caused significant differences in lint percentage in either season, although the higher P rate (1728 g ha^{-1}) and application of Zn (57.6 g ha^{-1}) resulted in a slight reduction in lint percentage. Shrivastava and Singh (1988) and Sawan *et al.* (1997) for Zn, and El-Debaby *et al.* (1995), and Sawan *et al.* (1997) for P did not observe any significant response of lint percentage when Zn was applied.

Lint index: Application of K significantly increased lint index compared to the untreated control in both seasons (**Table 12**). Result obtained here confirmed those of Pettigrew and Meredith (1997), when cotton received 112 kg K ha^{-1} before sowing. Kassem and Ahmed (2005) found that the application of K fertilizer at 48 kg ha^{-1} exhibited a significant increase in lint index.

Application of Zn increased numerically lint index over the control in both seasons, but this increase was statistically significant only in the second season. A similar result was obtained by Sawan *et al.* (1997), who, by applying Zn increased lint index 1.1% more than the control.

Lint index was significantly increased by raising P rate up to 1728 g ha^{-1} in both seasons, as compared to untreated plants, with one exception in the second season, where application of a low P concentration (576 g ha^{-1}) increased lint index numerically only. Lint index was greatest in the highest P-concentration applied (1728 g ha^{-1}). These results were in agreement with those reported by Sawan *et al.* (1997) who applied P at 74 P_2O_5 ha^{-1} and increased lint index 1.6% more than the control (44 P_2O_5 ha^{-1}); this could be due to nutrient response and availability leading to initiation and development of greater number of fibers seed^{-1}.

Seed index: Seed index significantly increased with the application of K in both years (**Table 12**). Zhao *et al.* (2001) indicated that K deficiency during squaring dramatically reduced leaf area and dry matter accumulation, and affected assimilate partitioning among plant tissues. In a related study, Sabino *et al.* (1999) indicated that the application of K fertilizer resulted in an increase in seed index. Kassem and Ahmed (2005) found that the application of K fertilizer at 48 kg ha^{-1} exhibited a significant increase in seed index.

Application of Zn significantly increased seed index coincidence with increased total chlorophyll (*a* and *b*, **Table 11**) compared to the control in both seasons. This might be due to its favorable effect on photosynthetic activity, which improves mobilization of photosynthesis and directly influences boll weight that coincides with increased seed index (Sharma 1982). Our results confirmed those obtained by Hai *et al.* (1999), and Rathinavel *et al.* (2000).

Applying the three P concentrations (576, 1152 and 1728 g ha^{-1}) increased the seed index more than the untreated control in both seasons. This increase was significant for all P concentrations in the first season and for P at

Table 13 Mean effects of K and foliar application of Zn and P on yield and yield earliness in cotton.

Treatments	Seed cotton yield ($g\ plant^{-1}$)		Seed cotton yield ($kg\ ha^{-1}$)		Lint yield ($kg\ ha^{-1}$)		Yield earliness (%)	
	I	II	I	II	I	II	I	II
K rate ($kg\ ha^{-1}$)								
0.0 (control)	29.66	28.08	2893.2	2736.8	1025.1	949.0	62.97	70.04
47.4	33.98*	31.69*	3310.8*	3091.2*	1168.7*	1065.8*	64.38*	70.72
LSD (p = 0.05)	1.74	1.97	184.7	192.3	63.8	67.4	1.10	n.s.
Zn rate ($g\ ha^{-1}$)								
0.0 (control)	30.30	28.64	2956.4	2794.4	1047.0	967.2	63.04	70.26
57.6	33.34*	31.13*	3247.5*	3033.7*	1146.8*	1047.6*	64.31*	70.50
LSD (p = 0.05)	1.74	1.97	184.7	192.3	63.8	67.4	1.10	n.s.
P rate ($g\ ha^{-1}$)								
0.0 (control)	28.74	27.28	2806.0	2664.4	995.1	923.7	62.63	69.93
576	31.92*	29.83	3105.6*	2874.6	1098.0*	993.6	63.44	70.28
1152	32.80*	31.10*	3193.5*	3028.5*	1128.1*	1046.5*	63.74	70.61
1728	33.83*	31.33*	3303.0*	3088.7*	1166.4*	1065.7*	64.87*	70.70
LSD (p = 0.05)	2.47	2.78	261.2	272.0	90.3	95.4	1.56	n.s.

* Significant at 5% level; n.s.: not significant.

1152 and 1728 g ha^{-1} in the second season. Spraying plants with P_2O_5 at 1728 g ha^{-1} (high concentration) produced the highest numerical seed index. This may be due in part to enhanced photosynthetic activity, as phosphorus is necessary for the biosynthesis of chlorophyll, as pyridoxal phosphate must be present for its biosynthesis (Ambrose and Easty 1977), which improves mobilization of photosynthates and directly influences boll weight that coincides with increased seed index. Plesnicar *et al.* (1994) stated that photosynthetic CO_2 fixation decreased in plants suffering from P deficiency. This indicates that treated cotton bolls had larger photosynthetically supplied sinks for carbohydrates and other metabolites than untreated bolls. Similar results were obtained by Sharma *et al.* (1991), Sawan *et al.* (2001) where seed index increased 2.1% more than the control, and Singh *et al.* (2006) when Zn was applied.

Yield

Seed cotton yield plant^{-1}, as well as seed cotton and lint yield ha^{-1}, increased significantly (by as much as 14.57, 12.86; 14.43, 12.95; 14.01, 12.31%, for seasons I and II, respectively) when K was applied at 57.1 kg K_2O ha^{-1} in both seasons (**Table 13**). A positive response to the addition of K fertilizer could be due to the favorable effects of this nutrient on several yield components, viz. the number of opened bolls plant^{-1}, boll weight, or both, leading to higher cotton yield (Zheng 1996a). Potassium deficiencies can limit the accumulation of crop biomass. This is attributed to (i) a reduction in the partitioning of assimilate to the formation of leaf area, or (ii) a decrease of the efficiency with which the intercepted radiation is used for the production of above-ground biomass (Colomb *et al.* 1995). Furthermore, K has an important role in the translocation of photosynthates from sources to sinks (Cakmak *et al.* 1994). These mean that K deficiency during the reproductive period markedly changes the structure of fruit-bearing organs and decreases yield. Pettigrew (1999) indicated that the elevated carbohydrate concentrations remaining in source tissue, such as leaves, appear to be part of the overall effect of K deficiency in reducing the amount of photosynthate available for reproductive sinks and thereby producing changes in lint yield seen in cotton. Results obtained here confirmed those of Gormus (2002) when applying K_2O at the rates of 80, 160 and 240 kg K_2O ha^{-1}, Aneela *et al.* (2003a) when applying 200 kg K_2O ha^{-1}, Pervez *et al.* (2004) under 62.5, 125, 250 kg K ha^{-1}, Pettigrew *et al.* (2005) under K fertilizer (112 kg ha^{-1}) and Makhdum *et al.* (2007) when applying K at the rates of 62.5, 125, and 250 kg K ha^{-1}.

Application of Zn significantly increased seed cotton yield plant^{-1}; seed cotton and lint yield ha^{-1} (by 9.93, 8.69; 9.85, 8.56; 9.53, 8.31%, for seasons I and II, respectively), as compared with the untreated control in the two seasons. Zinc could have a favorable effect on photosynthetic activity of leaves (Ohki 1976), which improves mobilization of photosynthesis coincidence the increases total chlorophyll (*a* and *b*) as shown in **Table 11** and directly influences boll weight. Also, there would be some favorable effects for this nutrient on carbohydrate metabolism, where the activity of the Zn-containing enzyme carbonic anhydrase sharply declines with Zn deficiency. Carbonic anhydrase (which plays a role in photosynthesis) is localized in the cytoplasm and chloroplasts, and may facilitate the transfer of CO_2/HCO_3^- for photosynthetic CO_2 fixation (Sharma *et al.* 1982). Further, Zn 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. Thus number of retained bolls plant^{-1} and consequently seed yields plant^{-1} and plot^{-1} would be increased. Thus the number of retained bolls plant^{-1} and consequently cottonseed yield ha^{-1} would be increased. These results were in good accordance with those obtained by Rathinavel *et al.* (2000), when $ZnSO_4$ was applied to the soil at 50 kg ha^{-1}, Sawan *et al.* (2001), when Zn was applied as foliar application at 48 g ha^{-1}, and Li *et al.* (2004) when cotton was sprayed with 0.2% zinc sulfate at the seedling stage.

Phosphorus also significantly increased seed cotton yield plant^{-1} and seed cotton and lint yield ha^{-1} in both seasons (by 11.06-17.71, 9.35-14.85; 10.68-17.17, 7.89-15.92; 10.34-17.21, 7.57-15.37%, for seasons I and II, respectively), as compared to the untreated plants, when treatment rate was increased up to 1728 g ha^{-1}. There was one exception in season II where the low P concentration (576 g ha^{-1}) increased seed cotton yield plant^{-1} and seed cotton and ha^{-1} was the greatest when the highest P-concentration lint yields ha^{-1} numerically. Generally, seed cotton yield plant^{-1} and seed cotton and lint yield (1728 g ha^{-1}) was applied compared with the other two concentrations (576 and 1152 g ha^{-1}). Such results reflect the pronounced improvement in yield components due to the application of P, which is possibly ascribed to its involvement in photosynthesis, and translocation of carbohydrates to young bolls. Phosphorus is a constituent of the cell nucleus is also essential for cell division and development of meristematic tissue, and hence it would have a stimulating effect on increasing the number of flowers and bolls per plant (Russell 1973). Results obtained here were in good agreement with those of Malewar *et al.* (2000), Katkar *et al.* (2002) and Stewart *et al.* (2005). Dorahy *et al.* (2004) indicated that seventeen field experiments were conducted on alkaline soils in eastern Australian to evaluate irrigated cotton response to P fertilizer application, and found that only 3 experiments demonstrated significant increase in lint yield with P application (20-40 kg P ha^{-1}).

Table 14 Mean effects of K and foliar application of Zn and P on fiber properties of cotton.

Treatments	2.5% span length (mm)		50% span length (mm)		Uniformity ratio (%)		Micronaire reading		Flat bundle strength (g tex^{-1})	
	I	II	I	II	I	II	I	II	I	II
K rate (kg ha^{-1})										
0.0 (control)	32.75	32.27	16.36	15.94	49.94	49.40	3.66	3.81	32.13	30.97
47.4	32.88	32.43	16.47	16.09	50.08	49.62*	3.76*	3.88	32.62*	31.45
LSD (p = 0.05)	n.s.	n.s.	n.s.	n.s.	n.s.	0.20	0.08	n.s.	0.48	n.s.
Zn rate (g ha^{-1})										
0.0 (control)	32.79	32.30	16.39	15.98	49.98	49.46	3.67	3.82	32.24	31.10
57.6	32.84	32.40	16.43	16.05	50.04	49.55	3.75	3.87	32.51	31.32
LSD (p = 0.05)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
P rate (g ha^{-1})										
0.0 (control)	32.78	32.21	16.37	15.86	49.94	49.24	3.63	3.81	32.09	30.96
576	32.81	32.35	16.39	16.01	49.97	49.50	3.69	3.84	32.28	31.16
1152	32.83	32.39	16.43	16.09	50.05	49.69*	3.74	3.86	32.51	31.29
1728	32.86	32.44	16.46	16.09	50.08	49.59*	3.78*	3.87	32.61	31.43
LSD (p = 0.05)	n.s.	n.s.	n.s.	n.s.	n.s.	0.28	0.11	n.s.	n.s.	n.s.

* Significant at 5% level; n.s.: not significant.

Yield earliness

Yield earliness (% of yield obtained in the first picking) increased numerically with K application over the control in both seasons (**Table 13**), but was statistically significant only in the first season. Howard *et al*. (2000) indicated that, foliar K solution (4.1 kg K ha^{-1}) buffered to pH 4-increased first-harvest. Previously, a similar result had been reported by Gormis (2002) when applying K_2O at 80, 160 and 240 kg K_2O ha^{-1}, yield earliness increased by 4.7, 3.3, and 2.3%, compared with 0, the control.

Yield earliness tended to increase with Zn application, but was statistically significant only in the first season, as compared with the control. Supporting this fact, Zeng (1996b) found that the squaring and boll-setting growth stages were earlier, and that cotton ripened early by the application of Zn to cotton on calcareous soil.

Applying the three P_2O_5 concentrations increased yield earliness numerically, compared to the untreated control in both seasons. This increase was significant in the first season, when P was applied at 1728 g ha^{-1}. The promotive effect of increased phosphorus rate on earliness percentage may be through an alteration of the nitrogen balance of the cotton plant as illustrated by the earlier maturation of cotton plants. This result agreed with that of Chiles and Chiles (1991), and Sawan *et al*. (1997) where lint index increased 2% more than the control when Zn was applied.

Fiber properties

Few fiber quality traits were significantly affected by K fertility treatment. Application of K did not cause any significant effect on the fiber properties tested (which increased numerically) in either season, with three exceptions, for micronaire reading and flat bundle strength in the first season, and uniformity ratio in the second season, where the mean values of these characters were significantly increased over the untreated control by applying K (**Table 14**). Pettigrew (1999) indicated that the elevated carbohydrate concentrations remaining in source tissue, such as leaves, appear to be part of the overall effect of K deficiency in reducing the amount of photosynthetic available for reproductive sinks and thereby producing changes in fiber quality seen in cotton. In this respect, Oosterhuis (1994) found that fiber quality was improved by foliar-applied KNO_3, with the increase occurring primarily in fiber length, uniformity and strength. Micronaire was also increased in certain years. He also found that application of KNO_3 either as foliar treatment alone, or in combination with supplemental soil KCl, effectively improved uniformity and strength. do Nascimento and Athayde (1999) studied the effect of potassium chlorate (applied at 30-150 kg ha^{-1}) on cotton, and found that K improved micronaire index and the uniformity. Li *et al*. (1999) reported that cellulose synthesis and dry matter accumulation were increased by K application. The response of fiber length to varying K concentrations was in agreement with the findings of Gormis (2002). Pettigrew *et al*. (2005) indicated that a 1% increase in fiber micronaire and 3% in fiber elongation produced by K fertilization relative to the untreated control were statistically significant. None of the other fiber traits were affected by K fertilization.

Application of Zn did not affect fiber properties in either season. All fiber properties tended to improve numerically with the application of Zn compared with the control. Livingston *et al*. (1991) indicated that fiber strength is reported to be one of the most stable fiber quality features and its expression is attributed to genetic to a larger degree than to environmental conditions. Zeng (1996b) found that fiber quality was improved by applying Zn to cotton on calcareous soil. Similar results were obtained by Sawan *et al*. (1997) where all fiber properties tended to improve numerically with the application of Zn.

The three P concentrations had no significant effect on the fiber properties tested (however, for the three P treatments the values of all fiber properties were numerically higher than the control) in either season, with two exceptions, i.e. for the micronaire reading in the first season (when applying P at 1728 g ha^{-1}) and uniformity ratio in the second season (when applying P at 1152 and 1728 g ha^{-1}), where the mean values of these characters were significantly higher than the untreated control when applying P. This may be due to the essential effect of phosphorus on photosynthesis and carbohydrate metabolism (Taiz and Zeiger 1991). Other fiber characters did not respond to phosphorus rate. Mehetre *et al*. (1990) found that fiber bundle strength was highest with phosphorus fertilizer, while mean fiber length, uniformity ratio, fineness and maturity coefficient did not change. Malik *et al*. (1992) observed that phosphorus had no consistent effect on fiber properties, which is in general agreement with our present findings. Sharma *et al*. (1991) stated that P application improved fiber quality. Vieira *et al*. (1998) found that fiber length was increased by P application. On the other hand Tewolde and Fernandez (2003) indicated that the important fiber properties – length, strength, or micronaire were not significantly affected when Pima cotton (*Gossypium barbadens*) cv. 'S-7' was treated with 44 kg P ha^{-1}.

CONCLUSION

During the two growing seasons no significant interactions were found between the variables in the present study (K-fertilizer and foliar application of Zn and the P) on quantitative and qualitative characters under investigation. The interactions numerically indicated that, the favorable effects accompanied the application of K, spraying of cotton plants with Zn and also P were more obvious by applying K-fertilizer at 47.4 kg ha^{-1} combined with spraying cotton plants with Zn at 57.6 g ha^{-1} and also with P at 1728 g ha^{-1}.

From the findings of the present study, it seems rational to recommend the addition of K at 47.4 kg ha^{-1} combined with spraying cotton plants with zinc at 57.6 g ha^{-1} and also with P at 1728 g ha^{-1}. These combinations appeared to be the most beneficial treatments, which have the most beneficial effects of treatments examined, affecting not only the growth and nutrient content of cotton plants (105 days after sowing) but also affecting cotton productivity and quality. In comparison with the ordinary cultural practices adopted by Egyptian cotton producers, it is quite apparent that applications of such treatments could bring about better impact on cotton productivity and quality.

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