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Influence of potassium fertilization and foliar application of zinc and phosphorus on growth, yield components, yield and fiber properties of Egyptian cotton (*Gossypium barbadense* L.)

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Abstract

Aims

Supplying optimal quantities of mineral nutrients to growing crop plants is one way to improve crop yields. Nutrients need to be used rationally in order to avoid a negative ecological impact and undesirable effects on the sustainability of agricultural production systems. Excessive application of nutrients also affects the farmer's economy. In order to calculate the amount of fertilizer to be applied to crops, it is necessary to develop recommendation programmers that adjust nutrient rates to crop requirements.

Methods

Experiments in two successive seasons were conducted to investigate the effect of K fertilization and foliar application of Zn and P on yield and fiber properties of cotton cv. Giza 86. Potassium (0.0 and 47.4 kg of K ha^{-1}) was soil applied, while chelated zinc (0.0 and 57.6 g of Zn ha^{-1}, applied twice at 70 and 85 days after sowing 'DAS') and phosphorus (0.0, 576, 1 152 and 1 728 g of P ha^{-1}, applied twice at 80 and 95 DAS) were applied to the foliage.

Important findings

Dry matter yield, total chlorophyll concentration, K, Zn and P uptake per plant, number of opened bolls per plant, boll weight, seed index, lint index, seed cotton yield per plant, seed cotton and lint yield ha^{-1} and earliness of harvest increased with the application of K, Zn and P. Treatments generally had no significant effect on lint percentage and fiber properties, with exceptions, for micronaire reading and flat bundle strength, and uniformity ratio, where the mean values of these characters were significantly increased over the untreated control by applying K, and for the micronaire reading in the first season, when applying P at 1 728 g ha^{-1}, and uniformity ratio in the second season, when applying P at 1 152 and 1 728 g ha^{-1}, where the mean values of these characters were significantly increased 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 1 728 g ha^{-1} improved growth and yield of Egyptian cotton.

Keywords: cotton • fiber properties • phosphorus • potassium • yield and yield components • zinc

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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 micronutrient doses to growing crop plants is one way to improve crop yields (Zubillaga *et al.* 2002). Mineral nutrients possess several roles in formation, partitioning and utilization 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 semiarid areas. Such properties reduce the availability of the mineral nutrients to crop plants.

Potassium (K) is the 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 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 photosynthates 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 a 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).

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) has 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, i.e. small leaves, shortened internodes giving the plant a stunted appearance, reduced boll set and small boll 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).

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 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.

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 growth, yield and fiber properties of Egyptian cotton (*Gossypium barbadense*) grown on alluvial soil. The aim was to identify fertilizer doses that may improve yield and quality. An improved understanding of K, Zn and P nutritions in cotton would help producers better manage their inputs for optimal yield and fiber quality.

MATERIALS AND METHODS

A three-factor experiment was conducted at the Agricultural Research Center, Ministry of Agriculture in Giza, Egypt (30°N, 31°: 28′E at an altitude 19 m), using the cotton cultivar Giza 86 (*G. barbadense* L.) in the two Seasons I and II. The factors studied were K fertilization, foliar application of Zn and P fertilizers. The experiment was arranged according to randomized complete block (RCB) design with four replications. The soil in both seasons was clay loam. 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 and chemical properties. Average physical analysis and chemical characteristics (Chapman and Pratt 1961) for soil in both seasons are 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. 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 (ordinary) and 47.4 kg K ha^{-1}), two zinc rates (0.0 (ordinary) or 57.6 g Zn ha^{-1}) and four phosphorus rates (0.0 (ordinary), 576, 1 152 and 1 728 g P ha^{-1}). Potassium was applied as potassium sulfate (K_2SO_4, 48% K_2O), 8 weeks after sowing (as a concentrated band close to the seed ridge), and the application was followed immediately by irrigation. Zinc was applied to the foliage, in chelated form (ethylenediaminetetraacetic acid), 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^{-1}. The applications were carried out between 0900 and 1100 h. A summary of all treatments is shown in Table 3.

Table 1: physical and chemical analysis of the soil used in 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 per kg soil)	50.00	57.50
Available phosphorus (mg per kg soil)	15.66	14.19
Available potassium (mg per kg soil)	370.00	385.00
Available zinc (mg per 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). The 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.

Experiments were planted on 3 April (I) and 20 April (II) in an RCB design with four replications. The plot size was 1.95 × 4 m and contained three ridges (after precaution of border effect was taken into consideration). Hills (beds) were spaced 25 cm apart on one side of the ridge, with seedlings thinned to two plants per hill at 6 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 (11 October, I; 17 October, II) for a total of nine irrigations. On the basis of soil test results, N fertilizer was applied at the 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 semifertile 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

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
Maximum temperature (°C)	20.8–44.0	32.6	24.6–43.4	32.7	20.8–44.0	32.6
Minimum temperature (°C)	10.4–24.5	19.4	12.0–24.3	19.3	10.4–24.5	19.3
Maximum–minimum temperature (°C)	4.7–23.6	13.2	8.5–26.8	13.4	4.7–26.8	13.3
Sunshine (h day^{-1})	0.3–12.9	11.1	1.9–13.1	11.2	0.3–13.1	11.1
Maximum humidity (%)	48–96	79.5	46–94	74.7	46–96	77.2
Minimum humidity (%)	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

to the laboratory and oven dried at 70°C for 24 hours to determine the dry matter yield (grams per plant). 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 fourth 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 20 and 26 September and final picking on 11 and 17 October in I and II, respectively. Total seed cotton yield of each plot (including 10 plant subsamples) was ginned to determine seed cotton and lint yield (kg ha^{-1}), lint percentage, seed index (g per 100 seed) and lint index (g lint per 100 seed). 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 an RCB design following the procedure outlined by Snedecor and Cochran (1980). The least significant difference (LSD) 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

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 4), between K and P for total chlorophyll concentration, as well as K and Zn content (Table 5), between Zn and P for K and Zn content (Table 6), and between K, Zn and P for total chlorophyll concentration, as well as Zn content (Table 7). Application of the high K rate 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 the high K rate or Zn and/or

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

Treatments				Treatments			
K rate (kg ha^{-1})	Zn rate (g ha^{-1})	P rate (g ha^{-1})	Treatment no.	K rate (kg ha^{-1})	Zn rate (g ha^{-1})	P rate (g ha^{-1})	Treatment no.
0.0	0.0	0.0	1	47.4	0.0	0.0	9
		576	2			576	10
		1 152	3			1 152	11
		1 728	4			1 728	12
	57.6	0.0	5		57.6	0.0	13
		576	6			576	14
		1 152	7			1 152	15
		1 728	8			1 728	16

Table 4: 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 (mg $plant^{-1}$)		Zn uptake (μg $plant^{-1}$)		P uptake (mg $plant^{-1}$)	
	Zn rate (g ha^{-1})							
K rate (kg 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	1 442.4	1 705.2	1 381	2 191	94.44	98.81
47.4	33.18	46.33	1 686.6	2 307.7	2 052	2 109	102.88	138.56
LSD ($p = 0.05$)	1.649		245.8		503		23.72	

Table 5: 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 (mg L^{-1})		K uptake (mg $plant^{-1}$)		Zn uptake (μg $plant^{-1}$)	
P rate (g ha^{-1})	K rate (kg ha^{-1})					
	0.0 (control)	47.4	0.0 (control)	47.4	0.0 (control)	47.4
0.0 (control)	3.859	4.389	1 533.6	1 687.6	1 828	1 402
576	5.002	5.120	1 485.9	1 551.0	1 668	1 970
1 152	6.386	7.002	2 003.8	1 820.5	2 120	2 505
1 728	7.355	7.839	2 050.5	2 151.5	1 989	1 984
LSD (p = 0.05)	0.450		245.8		503	

P alone. Favorable effects on cotton productivity and quality accompanied the application of high K rate, Zn and P.

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 were determined to study the effect of applied potassium and foliar application of Zn and P on plant growth and mineral uptake (Table 8).

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 applying K to cotton plants. In this connection, Fan *et al.* (1999) found that K content in petioles and total dry matter production increased by applying 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 the highest at 200 kg K_2O ha^{-1}. The P content increased significantly with potash application and was the highest at 100 K_2O ha^{-1}. According to the K status in the experimental soil (Table 1), it 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 low Zn content 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 number of antioxidant enzymes, resulting in extensive oxidative damage to membrane lipids, proteins, chlorophyll and nucleic acids.

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 (1 728 g ha^{-1}). In this connection, 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

Table 6: 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 (mg $plant^{-1}$)		Zn uptake (μg $plant^{-1}$)	
	Zn rate (g ha^{-1})			
P rate (g ha^{-1})	0.0 (control)	57.6	0.0 (control)	57.6
0.0 (control)	1 658.4	1 879.0	2 188	1 551
576	1 613.1	1 895.0	1 760	2 139
1 152	1 495.1	2 041.3	1 836	1 569
1 728	1 528.6	2 173.4	2 020	2 402
LSD (p = 0.05)	245.8		503	

Table 7: 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				
K rate (kg ha^{-1})	Zn rate (g ha^{-1})	P rate (g ha^{-1})	Chlorophyll (mg L^{-1})	Zn uptake (μg $plant^{-1}$)
0.0 (control)	0.0 (control)	0.0 (control)	3.163	1 488
		576	3.965	1 253
		1 152	4.543	1 124
		1 728	4.652	1 661
	57.6	0.0 (control)	4.555	2 168
		576	4.813	1 550
		1 152	5.461	2 212
		1 728	5.588	2 279
47.4	0.0 (control)	0.0 (control)	5.950	2 888
		576	6.550	2 419
		1 152	6.812	1 978
		1 728	6.650	1 478
	57.6	0.0 (control)	6.823	1 353
		576	7.454	2 591
		1 152	7.899	2 000
		1 728	9.027	2 490
LSD (p = 0.05)			0.636	251

Table 8: 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})	Chlorophyll (mg L^{-1})	K uptake (mg plant^{-1})	Zn uptake (μg plant^{-1})	P uptake (mg plant^{-1})
K rate (kg ha^{-1})					
0.0 (control)	29.85	4.593	1 564.5	1 717	98.66
47.4	41.12	7.146	2 006.4	2 150	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	1 573.8	1 786	97.13
57.6	39.76	6.453	1 997.2	2 081	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	1 768.7	1 974	91.50
576	34.56	5.696	1 754.1	1 954	108.56
1 152	36.27	6.178	1 768.1	1 829	116.19
1 728	37.59	6.479	1 851.0	1 977	119.44
LSD (P = 0.05)	1.649	0.318	n.s.	n.s.	16.77

n.s., not significant.

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 in P fixation. More and Agale (1993) indicated that when P 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. Ahmed *et al.* (2000) pointed that P deficiency reduced biomass

Yield components

Number of opened bolls per plant.

Application of K (47.4 kg ha^{-1}) increased number of opened bolls per plant significantly, as compared to the untreated plants in both seasons (Table 9). 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).

Application of Zn significantly increased number of opened bolls per plant, 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. This result confirms those of Sawan *et al.* (1997) and Rathinavel *et al.* (2000) by soil application of $ZnSO_4$ at 50 kg ha^{-1}.

Application of the three P concentrations (576, 1 152 and 1 728 g ha^{-1}) increased the number of opened bolls per plant 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 1 152 and 1 728 g ha^{-1} in the second season. Spraying plants with P at 1 728 g ha^{-1} (high concentration) produced (numerically) the highest number of opened bolls per plant. Phosphorus is essential for cell division and for development of meristematic tissue, causing a stimulating effect on the number of flower buds and bolls per plant (Russell 1973). These results agreed with those obtained by Malewar *et al.* (2000), when applied P_2O_5 at 25–62.5 kg ha^{-1}, and Katkar *et al.* (2002), when applied diammonium phosphate (DAP) at 2%.

Boll weight.

Boll weight was significantly increased by K application relative to the control in both seasons (Table 9). Potassium increases the photosynthetic rates of crop leaves (Bednarz and Oosterhuis 1999) and CO_2 assimilation (Wolf *et al.* 1976). The obtained results of total chlorophyll (a and b) confirmed these findings (Table 8). Thereby the K deficiency affecting in reducing the amount of photosynthate available for reproductive sinks and this producing changes in boll weight. The increase in boll weight by K application in this

Table 9: mean effects of K and foliar application of Zn and P on yield components of cotton

Treatments	Number of opened bolls per plant I	Number of opened bolls per plant II	Boll weight (g) I	Boll weight (g) II	Lint percentage (%) I	Lint percentage (%) II	Seed index (g) I	Seed index (g) II	Lint index (g) I	Lint index (g) 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
1 152	12.68	12.15	2.576	2.550	35.33	34.54	10.26	10.00	5.604	5.276
1 728	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

n.s., not significant.

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.

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 the 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). Results were similar to those 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 treatment rate was increased up to 1728 g ha^{-1}, with one exception in the first season, where applied the low P concentration (576 g ha^{-1}) increased boll weight numerically only. Boll weights were the greatest from the highest P concentration applied (1 728 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 given 44 or 74 kg of P_2O_5 ha^{-1}, and Vieira *et al.* (1998), when cotton was given 30–120 kg P ha^{-1}.

Lint percentage.

Applied K did not significantly affected lint percentage as compared with the control in the two seasons (Table 9). Gormus (2002) found that applying K_2O at the rate of 80 kg ha^{-1} gave the same mean of lint turnout as untreated control in the first season, while applications of 160 and 240 kg K_2O ha^{-1} increased lint turnouts. Lint turnout in the second season was not affected by any of K treatments. 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 (1 728 g ha^{-1}) and application of Zn (57.6 g ha^{-1}) resulted in a slight reduction in lint percentage. Similar results were obtained by Shrivastava and Singh (1988) and Sawan *et al.* (1997) for Zn and El-Debaby *et al.* (1995) and Sawan *et al.* (1997) for P.

Seed index.

Seed index significantly increased with applying K in both years (Table 9). 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 this connection, Sabino *et al.* (1999) and Ghourab *et al.* (2000) indicated that application of K fertilizer resulted in an increase in seed index.

Application of Zn significantly increased seed index coincidence with increased total chlorophyll (a and b, Table 8) 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 *et al.* 1982). Our results confirmed those obtained by Hai *et al.* (1999) and Rathinavel *et al.* (2000).

Applying the three P concentrations (576, 1 152, and 1 728 g ha^{-1}) increased the seed index as compared with the untreated control in both seasons. This increase was significant for all P concentrations in the first season and for P at 1 152 and 1 728 g ha^{-1} in the second season. Spraying plants with P_2O_5 at 1 728 g ha^{-1} (high concentration) produced the highest numerical seed index. This may in part be due 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) and Sawan *et al.* (2001).

Lint index.

Application of K significantly increased lint index compared to the untreated control in both seasons (Table 9). Results obtained here confirmed those of Pettigrew and Meredith (1997), when cotton received 112 kg K ha^{-1} before sowing. Application of Zn increased numerically lint index over the control in both seasons, but this increase was statistically significant only in the second season. Similar result was obtained by Sawan *et al.* (1997). Lint index was significantly increased by raising P rate up to 1 728 g ha^{-1} in both seasons, as compared to untreated plants, with one exception in the second season, where applied the low P concentration (576 g ha^{-1}) increased lint index numerically only. Lint index was the greatest from the highest P concentration applied (1 728 g ha^{-1}). These results were in agreement with those reported by Sawan *et al.* (1997), which could be due to nutrient response and availability leading to initiation and development of greater number of fibers per seed.

Yield

Seed cotton yield per plant, as well as seed cotton and lint yield ha^{-1}, significantly increased (by as much as14.57, 12.86; 14.43, 12.95; 14.01, 12.31%, respectively) when K was applied at the rate of 57.1 kg K_2O ha^{-1} in both seasons (Table 10). Positive response to addition of K fertilizer could be due to the favorable effects of this nutrient on the yield components of number of opened bolls per plant, boll weight, or both, leading to higher cotton yield (Zeng 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 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 a 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), Aneela *et al.* (2003a) and Pervez *et al.* (2004).

Application of Zn significantly increased seed cotton yield per plant; seed cotton and lint yield ha^{-1} (by 9.93, 8.69; 9.85, 8.56; 9.53, 8.31%, respectively), as compared with the untreated control in the two seasons. Zinc could have a favorable effect on photosynthetic activity of leaves (Ohki 1976),

Table 10: mean effects of K and foliar application of Zn and P on yield and yield earliness in cotton

	Seed cotton yield (g per plant)		Seed cotton yield (kg ha^{-1})		Lint yield (kg ha^{-1})		Yield earliness (%)	
Treatments	I	II	I	II	I	II	I	II
K rate (kg ha^{-1})								
0.0 (control)	29.66	28.08	2 893.2	2 736.8	1 025.1	949.0	62.97	70.04
47.4	33.98	31.69	3 310.8	3 091.2	1 168.7	1 065.8	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	2 956.4	2 794.4	1 047.0	967.2	63.04	70.26
57.6	33.34	31.13	3 247.5	3 033.7	1 146.8	1 047.6	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	2 806.0	2 664.4	995.1	923.7	62.63	69.93
576	31.92	29.83	3 105.6	2 874.6	1 098.0	993.6	63.44	70.28
1 152	32.80	31.10	3 193.5	3 028.5	1 128.1	1 046.5	63.74	70.61
1 728	33.83	31.33	3 303.0	3 088.7	1 166.4	1 065.7	64.87	70.70
LSD (*P* = 0.05)	2.47	2.78	261.2	272.0	90.3	95.4	1.56	n.s.

n.s., not significant.

which improves mobilization of photosynthesis coincidence that increases total chlorophyll (a and b) as shown in Table 3 and directly influences boll weight. Also, there would be some favorable effects for this nutrient on the 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, the number of retained bolls per plant and consequently seed cotton 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}, and Sawan *et al.* (2001), when Zn was applied as foliar application at 48 g ha^{-1}.

Phosphorus also significantly increased seed cotton yield per plant 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%, respectively), as compared to the untreated plants, when treatment rate was increased up to 1 728 g ha^{-1}. There was one exception in the second season, where the low P-concentration (576 g ha^{-1}) increased seed cotton yield $plant^{-1}$ and seed cotton and lint yields ha^{-1} numerically. Generally, seed cotton yield $plant^{-1}$ and seed cotton and lint yields ha^{-1} were the greatest when the highest P concentration (1728 g ha^{-1}) was applied compared with the other two concentrations (576 and 1 152 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 a constituent of 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) and Katkar *et al.* (2002).

Yield earliness

Yield earliness (% of yield obtained in the first picking) increased numerically with K application over the control in both seasons (Table 10), 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, similar result has been reported by Gormus (2002).

Yield earliness tended to increase with Zn application, but was statistically significant only in the first season, as compared with the control. In this connection, Zeng (1996b) found that, the squaring and boll setting growth stages were earlier, and cotton ripened early by the application of Zn to cotton on calcareous soil. Applying the three P_2O_5 concentrations increased yield earliness numerically, as compared with the untreated control in both seasons. This increase was significant in the first season, when applied P at 1 728 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).

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 11). Pettigrew (1999) indicated that the elevated carbohydrate concentrations remaining in source tissue, such as leaves, appear to be a part of the overall effect of K deficiency in reducing the amount of photosynthate 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. 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 Gormus (2002). Pettigrew *et al.* (2005) indicated that the 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 large 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).

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 1 728 g ha^{-1}) and uniformity ratio in the second season (when applying P at 1 152 and 1 728 g ha^{-1}), where the mean values

Table 11: mean effects of K and foliar application of Zn and P on fiber properties of cotton

	2.5% span length (mm)		50% span length (mm)		Uniformity ratio (%)		Micronaire reading		Flat bundle strength (g per tex)	
Treatments	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
1 152	32.83	32.39	16.43	16.09	50.05	49.69	3.74	3.86	32.51	31.29
1 728	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.

n.s., not significant.

of these characters were significantly increased over the untreated control by 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 the 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.

CONCLUSIONS

From the findings of the present study, it seems rational to recommend 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 1 728 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 the 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. The impact in cotton productivity and quality due to the application of K, Zn and P are believed to be sufficient enough to cover the cost of using those chemicals and to attain an economical profit.

The increases in cost ascribed to the addition of K at 47.4 kg ha^{-1}, and spraying cotton plants with Zn twice (at 57.6 g ha^{-1}) and application of P also twice (especially P concentration of 1 728 g ha^{-1}) in the present study are as follows: (i) applied K costs 140.0 L.E. ha^{-1}, (ii) Zn costs 100.0 L.E. ha^{-1} (for both the chemical material and its foliar spray twice), (iii) P costs 80.0 L.E. ha^{-1} (for both the chemical material and its foliar spray twice) and (iv) additional increases in costs of hand picking 240 L.E. ha^{-1}. Accordingly, the total cost of applying the three aforementioned chemicals and hand picking amounts to 560.0 L.E. ha^{-1}. However, it is worthy to mention that the attained increase in yield (lint and seed), which was about 40%, would secure an increase in revenue of as much as 3 500 L.E. ha^{-1}. Accordingly, the net revenue would be 2 940 L.E. ha^{-1}. This revenue was about 5-fold of the costs.

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