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COTTON RESPONSE TO ELEMENTAL SULPHUR AND PHOSPHORUS APPLICATIONS UNDER DIFFERENT SOIL MOISTURE DEPLETION LEVELS AT NORTH NILE DELTA

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ABSTRACT

Two field experiments were conducted at Sakha Agric. Res. Station during two successive seasons 2000 and 2001 to investigate the response of cotton crop to the levels of soil moisture depletion, applications of the elemental sulphur and phosphorus at North Nile Delta. The soil of the experiment was clayey in texture, non saline and non alkaline. The design of the experiment was split-split plot during the two growing seasons. Depletion levels 40% (D_1), 55% (D_2) and 70% (D_3) of available soil moisture were conducted to the main plots. Elemental sulphur rates, zero (S_1), 50 (S_2) and 100 (S_3) kg S fed.$^{-1}$ were assigned to sub-plots. Phosphorus fertilizer rates zero (P_1), 15 (P_2) and 30 (P_3) kg P_2O_5 fed.$^{-1}$ were allocated to sub-sub-plots. The most important results could be summarized as follows:

- Irrigation of cotton at 55% depletion (D_2) produced the highest seed cotton yield (10.92 and 10.51 kentar fed.$^{-1}$) in the 1st and 2nd season, respectively. Also, plant height, fruit branches/plant, bolls/plant and boll weight were higher under treatment D_2.
- Irrigation at low soil moisture depletion (D_1) resulted in the highest values of water applied (3666.3 and 3451.7 m^3 fed.$^{-1}$), water consumptive use (2993.8 and 2760.2 m^3 fed.$^{-1}$) in the 1st and 2nd seasons, respectively, but decreased water utilization and water use efficiencies.
- Decreasing soil moisture depletion increased P, Fe and Mn concentrations in cotton leaves and its availability in the soil, while Zn took the opposite trend.
- Application of S resulted in a significant increase in seed cotton yield, yield components, water utilization, and water use efficiency, soil available P, Zn, Fe and Mn and their content in cotton leaves.
- Application of phosphate fertilizer resulted in a significant increase in seed cotton yield, yield components, water utilization, water use efficiency, soil available P, Fe and Mn and the concentrations of P and Mn in cotton leaves.
- The combination between 100 kg S and 30 kg P_2O_5 fed.$^{-1}$ and irrigation at 55% depletion produced the highest seed cotton yield in the two studied seasons.
- An antagonistic relationship was found between P and Zn & Fe and a synergetic between P and Mn in cotton leaves.

Keywords: sulfur and phosphorus applications, soil moisture depletion, nutrient interaction, cotton yield

INTRODUCTION

Cotton is the main cash crop being raized in Egypt for its fibers and oil. It is also the export crop and an important source in the national income. The proper available soil moisture in the effective root zone, phosphorus and sulphur fertilization are very important factors that affect the productivity of cotton crop at north Nile Delta soils.

Simishi and Marani (1971) stated that seed cotton yield, plant height and number of bolls were decreased when cotton plants were subjected to soil moisture stress at the start of flowering. Ballator *et al.* (1974) reported that irrigation at 30% depletion of available water increased cotton water consumptive use but did not affect the yield significantly. Mahrous (1977) showed that seasonal water consumptive use by cotton for wet, medium and dry regimes were 25.7, 24.3 and 20.9 inches , respectively. Bharambe and Varade (1982) found that the reduction in leaf water potential beyond-15 bar decreased seed cotton yield due to the reduction in boll numbers and their size. Mohamed *et al.* (1995) and El-Naggar *et al.* (1999) stated that increasing available soil moisture increased significantly the seasonal water consumptive use by cotton plants. Eid and Hosny (1995a, b) reported that increasing water amounts from 73.5 to 136.5 cm resulted in shorter periods to the first flower and first open boll, while 94.5 cm increased number of open bolls/plant and seed cotton yield $feddan^{-1}$. Mahrous *et al.* (1984) used 20, 40, 60 and 80% depletion from available soil moisture on cotton at Sakha. They obtained the highest seed cotton yield from 60% depletion treatment. Khater and Eid (1997) revealed that irrigation cotton using 2 inches diameter siphon at 15 days interval increased boll weight and seed cotton yield. Water consumptive use was found to be 56.6 cm. Husman *et al.* (1998) concluded that irrigation of cotton at 30 and 50% soil moisture depletion resulted in the highest mean cotton lint yields (1374 and 1438 lbs lint $acre^{-1}$), respectively. While irrigation at 65 and 80% depletion produced the lowest mean cotton lint yields (1123 and 248 lbs lint $acre^{-1}$, respectively). While irrigation at 65 and 80% depletion produced the lowest mean cotton lint yields (1123 and 248 lbs lint $acre^{-1}$, respectively). Ebada (1998) found that termination of irrigation after 165, 150 and 135 days from sowing cotton resulted in decreasing water consumptive use from 83.77 to 78.37 and 75.8 cm, respectively. The opposite trend was recorded for water utilization efficiency 0.26, 0.28 and 0.30 kg seed cotton m^{-3} applied water, respectively) and also for water consumptive use 0.28, 0.29 and 0.30 kg seed cotton m^{-3} water consumed, respectively) with the studied terminations.

Elemental sulphur added to the soil as a soil amendment and as a plant nutrient. It is oxidized by soil microorganisms to sulphuric acid which lowers soil pH and increases availability of P, Zn, Fe and Mn (Mostafa *et al.*, 1990). Nasseem *et al.* (1986) pointed out that addition of sulphur to the soil increased cotton lint yield and increased leaves content of Zn, Fe, Mn, Cu, Mo and Pb. Dubey *et al.* (2000) showed that cotton seed yield, dry matter and boll weight were increased with increasing sulphur application rate. Chatterjee *et al.* (2000) found that the yields of cotton fibre and seed were significantly decreased by sulphur deficiency, as well as quality of cotton seeds. Singh and Karion (2001) concluded that the highest cotton seed yield was recorded with 30 kg S ha^{-1}. They also concluded that application of sulphur more than 30 kg ha^{-1} decreased phosphorus content in cotton seeds and reduced P content in the soil at the second year. Shinde *et al.* (2001) found that S fertilizer inoculated with S oxidizing bacteria and fungi recorded the highest values for plant height, picked bolls per plant, seed yield and S uptake.

Cakmak and Marschner (1986) found that increasing P supply resulted in severe Zn deficiency while Zn deficiency markedly increased the uptake and translocation rates of P. Gill *et al.* (1985) revealed that increasing P fertilizer rate to sandy loam soil from zero to 100 kg P_2O_5 ha^{-1} increased cotton seed yield from 565 to 785 kg ha^{-1}, bolls $plant^{-1}$ from 7 to 11 and lint percentage from 33.2 to 33.9. Hamid and Sarwar (1983) pointed out that yield of cotton was increased significantly with 20 kg P ha^{-1} and application of P increased P concentration in leaves. They added that 90 days after sowing was the best time for better measure of fertilizer utilization. Shrivastava *et al.* (1999) showed that P fertilizer increased cotton seed yield, but amounts varied between years. Sawan *et al.* (1997) revealed that cotton yield, open bolls $plant^{-1}$, boll weight, and uptake of P, Ca and Zn were increased with increasing P, Zn and Ca fertilizers. Mahmoud *et al.* (1985) found that the highest dry matter of cotton was obtained with application of 15 kg P + 10 kg Zn or 30 kg P + 10 kg Zn $feddan^{-1}$.

MATERIALS AND METHODS

Two field experiments were carried out at the Farm of Sakha Agricultural Res. Station during two successive seasons 2000 and 2001 to evaluate the role of elemental sulphur and phosphorus fertilization under different soil moisture depletion levels and their effect on cotton yield and its water relations.

The soil of the experimental field was clayey in texture, non saline, non alkaline with water table depth 115 cm. Soil samples were taken before planting and after harvesting cotton. The main soil characteristics and the level of some nutrients are shown in Table (1).

Table 1: Average values of some physical and chemical properties of the soil before the experiment.

Soil depth, cm	Particle size distribution, %				Bulk density, gm/cm^3	Soil moisture characteristics			Total carbonate %	EC dS m^{-1} at 25°C	Soil pH 1:2.5	O.M %	Available nutrients, ppm			
	Sand	Silt	Clay	Textural class		F.C.	W.P.	A.S.M.					P	Zn	Fe	Mn
0-30	17.96	32.53	49.55	Clayey	1.14	42.85	23.13	19.72	2.48	1.86	7.83	1.74	6.25	0.78	35.68	7.54
30-60	15.11	3.33	51.66	Clayey	1.24	39.76	22.64	17.12	2.58	1.94	7.98	1.62	5.63	0.655	32.37	6.78
60-90	13.77	37.55	48.68	Clayey	1.29	38.57	21.56	17.01	2.96	2.45	8.36	1.25	4.48	0.46	30.85	5.65

Split-split plot design with four replicates was used. Each sub-sub plot was 6 x 7 m (42 m^2) and constituted of 8 ridges. Depletion levels, elemental sulphur and phosphorus rates distributed in the experimental field as follows.

Main plots:

D_1 = Irrigation at 40% depletion of available soil moisture.
D_2 = Irrigation at 55% depletion of available soil moisture.
D_3 = Irrigation at 70% depletion of available soil moisture.

Sub-plots:

S_1 = Without sulphur application.
S_2 = Application of 50 kg S $feddan^{-1}$.
S_3 = Application of 100 kg S $feddan^{-1}$.

Sub-sub-plots:

P_1 = Without phosphorus application.
P_2 = Application of 15 kg P_2O_5 $feddan^{-1}$.

P_3 = Application of 30 kg P_2O_5 feddan^{-1}.

Elemental sulphur was added and mixed with soil surface layer before planting cotton seeds.

Phosphorus fertilizer levels as superphosphate (15.5% P_2O_5) were applied and mixed with the soil surface before planting.

Nitrogen fertilizer as urea 46.5% N was used with the recommended rate for the region (60 kg N feddan^{-1}) in two equal doses at the 1st and 2nd irrigations.

Giza 89 cotton seeds were sown in April 4, 2001 and picked in Oct. 7, 2001. While in the 2nd season 2002 the sowing date was April 6 and picking was in Oct. 10.

Application of irrigation water was controlled by Cutthroat flume 30 x 90 cm according to Skogerboe *et al.* (1973). Irrigation water was applied after depletion of 40%, 55% and 70% of available soil moisture. The amount of each irrigation to keep soil moisture content at field capacity was calculated as follows:

$$WA\ (depth)_i = \sum_{i=1}^{i=n} \frac{FC - PW}{100} \times Db \times Z$$

Where:

WA = Applied water (cm).
FC = Field capacity for the soil (%).
PW = Soil moisture content before irrigation (%).
Db = Bulk density of the soil (gm cm^{-3}).
Z = Thickness of the layer (0-60 cm).

Actual water consumptive use was determined as soil moisture depletion (SMD) according to Israelsen *et al.* (1979) as follows:

$$SMD = \sum_{i=1}^{i=n} \frac{PW_2 - PW_1}{100} \times Db_i \times Di$$

Where:

SMD = Soil moisture depletion (cm) in the effective root zone (0-60 cm).
PW_2 = Percentage of soil moisture content 48 hours after irrigation.
PW_1 = Percentage of soil moisture content before the next irrigation.
Db_i = Bulk density of the specified layer (gm cm^{-3}).
Di = Depth of soil layer (cm).

Water use efficiency (W.U.E.) was calculated according to Doorenbos and Pruitt (1979) as follows:

$$W.U.E. = \frac{\text{Cotton seed yield (kg fed.}^{-1})}{\text{Water consumptive use (m}^3\text{ fed.}^{-1})}\ kg\ m^{-3}$$

Water utilization efficiency (W.UT.E.) was calculated according to Doorenbos and Pruitt (1979) as follows:

$$W.UT.E. = \frac{\text{Cotton seed yield (kg fed.}^{-1})}{\text{Water applied (m}^3\text{ fed.}^{-1})}\ kg\ m^{-3}$$

Soil field capacity and wilting point were determined using pressure membrane apparatus according to Klute (1986). Samples of cotton leaves after 90 days at bolling stage were collected, dried, milled and wet digested according to Page (1982) for determination of P, Zn, Fe and Mn. Soil available Zn, Fe and Mn were extracted by DTPA solution according to Lindsay and Norvell (1978). The elements Zn, Fe and Mn were determined by the Atomic Absorption Spectrophotometers. Soil available P was extracted by $NaHCO_3$ 0.5 N and determined according to Murphy and Riley (1962). Data were statistically analyzed according to Snedecor and Cochran (1974).

RESULTS AND DISCUSSIONS

1. Cotton yield and its components:

The obtained results in Table 2 show that soil moisture depletion, elemental sulphur and phosphorus treatments had highly significant effects on cotton seed yield, plant height, fruit branches plant^{-1}, boll numbers plant^{-1} and boll weight in the two studied seasons. Irrigation at 55% depletion of soil available water (D_2) was the best treatment which resulted in the highest average values cotton seed yield (10.92 kentar fed^{-1}), plant height (146.63 cm), fruit branches plant (11.97), bolls/plant (23.53) and boll weight (2.99 gm) in the first season (2000). The corresponding average values in the second season (2001) were 10.51, 150.82, 11.47, 21.5 and 3.06, respectively. While irrigation of cotton at 40% or 70% depletion of available water (D_1 or D_3) resulted in a significant decrease in cotton yield and yield components compared to irrigation at 55% depletion of available water. These results are coincide with those of Baltator *et al.* (1974), Bharambe and Varade (1982) and Husman *et al.* (1998).

Increasing the rate of elemental sulphur resulted in a significant increase in cotton seed yield and yield components in the two studied seasons as shown in Table 2. Application of 100 kg S fed^{-1} (S_3) in the first season (2000) gave the highest cotton seed yield (11.18 kentar fed^{-1}), plant height (147.3 cm), fruit branches/plant (10.47), bolls/plant (22.5) and boll weight (2.99 gm). In the second season (2001) the corresponding average values were 10.83 kentar fed^{-1}, 147.54 cm for plant height, 10.64 fruit branches/plant, 21.14 bolls/plant and 3.09 gm for boll weight. The increase of cotton yield resulted from sulphur application may be due to the increasing of soil available P, Zn, Fe and Mn. These results are agreement with those of Nassem *et al.* (1986), Mostafa *et al* (1990), Dubey *et al.* (2000) and Singh and Karion (2001).

With respect to phosphorus fertilizer data in Table (2) revealed that increasing the rate of P fertilizer resulted in a significant increase in cotton seed yield and growth parameters during growing seasons. The treatment P_2 (30 kg P_2O_5 fed^{-1}) gave the highest average values of the studied parameters (11.97 and 11.36 kentar fed^{-1} for cotton seed yield, 145.69 and 146.38 cm for plant height, 10.97 and 11.19 fruit branches/plant, 23.92 and 22.94 bolls/plant and 3.01 and 3.07 gm for boll weight in the 1st and 2nd seasons, respectively). These results are agreement with those of Gill *et al.* (1985), Hamid and Sarwar (1983) and Sawan *et al.* (1997).

Table 2: Cotton seed yield and yield components as affected by soil moisture depletion, sulphur and phosphorus.

Treatments		First season, 2000					Second season, 2001				
		Cotton seed yield kentar/fed.$^{-1}$	Plant height cm	Number of fruit branches/ plant	Number of bolls/plant	Boll weight gm	Cotton seed yield kentar/fed.	Plant height cm	Number of fruit branches/plant	Number of bolls/plant	Boll weight gm
Depletion											
D_1		9.83	136.43	8.86	19.64	2.7	9.65	135.41	9.28	18.33	2.72
D_2		10.92	146.83	11.97	23.53	2.99	10.51	160.82	11.47	21.5	3.06
D_3		10.5	138.63	9.22	20.39	2.84	10.2	139.73	9.69	20.81	2.93
F-test		**	**	**	**	**	**	**	**	**	**
L.S.D.	0.05	0.57	1.72	0.37	0.78	0.06	0.2	1.42	0.45	0.9	0.04
	0.01	0.76	2.29	0.47	1.04	0.08	0.27	1.89	0.6	1.2	0.06
Sulphur											
S_1		9.36	134.93	9.81	19.61	2.72	9.34	135.05	9.86	19.72	2.76
S_2		10.45	139.46	9.97	21.44	2.82	10.15	143.37	9.94	19.78	2.86
S_3		11.18	147.3	10.47	22.5	2.99	10.83	147.54	10.64	21.14	3.09
F-test		**	**	**	**	**	**	**	**	**	**
L.S.D.	0.05	0.45	2.17	0.37	0.7	0.05	0.21	1.49	0.42	0.7	0.06
	0.01	0.77	2.97	0.5	0.96	0.07	0.29	2.04	0.58	0.96	0.08
Phosphorus											
P_1		9.28	135.44	9.31	18.58	2.71	8.95	137.96	9.28	17.22	2.74
P_2		10.35	140.56	9.78	21.06	2.82	10.04	141.81	9.97	20.47	2.9
P_3		11.97	145.69	10.97	23.92	3.01	11.36	148.38	11.19	22.94	3.07
F-test		**	**	**	**	**	**	**	**	**	**
L.S.D.	0.05	0.66	1.93	0.35	0.74	.07	0.24	1.53	0.55	0.98	0.09
	0.01	0.98	2.92	0.53	1.12	0.1	0.37	2.32	0.83	1.49	0.14
Interactions											
D * S		**	**	ns	**	ns	**	**	*	ns	ns
D * P		*	**	**	**	**	**	**	*	**	**
S * P		*	**	**	**	**	**	**	**	ns	**
D * S * P		ns	**	ns	ns	*	**	**	**	ns	**

* = Significant
** = Highly significant
ns = Not significant

The interaction D * S had significant effects on cotton seed yield and plant height in the two growing seasons. The interaction D * S had a significant effect on number of bolls/plant in the 1[st] season but had no significant effect in the 2[nd] season. Cotton seed yield and growth parameters were significantly affected by the interactions D * P and S * P except the number of bolls/plant in the 2[nd] season. Data also revealed that plant height and bolls weight were significantly affected by the interaction of D * S * P in the 1[st] season while in the 2[nd] season all yield and growth parameters were significantly affected except for number of bolls plant^{-1} in the 2[nd] season.

2. Water relations:

2.1. Seasonal water applied (Wa):

Data of the seasonal water applied (m^3 feddan^{-1}) during the two growing seasons are shown in Table (3). The obtained results reveal that the seasonal water applied to cotton plants was decreased with increasing the depletion of soil moisture content. The treatment D_1 which irrigated at 40%

depletion of soil available water received the highest average values (3666.3 and 3451.7 m^3 $feddan^{-1}$) of irrigation water in the 1^{st} and 2^{nd} seasons, respectively. The lowest average values of water applied (3163.6 and 3015.6 m^3 $feddan^{-1}$) in the 1^{st} and 2^{nd} seasons, respectively were recorded under the driest treatment (D_3) which irrigated at 70% depletion of available water.

These results are in agreement with those of Ballator *et al.* (1974); Mahrous *et al.* (1984); Mohamed *et al.* (1995); El-Naggar *et al.* (1999) and Eid and Hosny (1995a, b).

2.2. Seasonal water consumptive use (ETa):

The obtained results of seasonal water consumptive use (Table 3) indicated that (ETa) was decreased from D_1 treatment (irrigation at 40% depletion) to D_3 (irrigation at 70% depletion). The highest average values of ETa (2993.8 and 27.60. 2 m^3 $feddan^{-1}$ in the 1^{st} and 2^{nd} seasons, respectively) were achieved under D_1 treatment. While the lowest average values of ETa (2494.8 and 2384.9 m^3 $feddan^{-1}$ in the first and second seasons, respectively), were obtained under D_3 treatment. It could be concluded that irrigation at 55% depletion of available soil moisture (D_2) is the best treatment which produced the highest cotton seed yield. This finding is supported by Ballator *et al.* (1974), Mahrous *et al.* (1984), Mohamed *et al.* (1995); El-Naggar *et al.* (1999) and Ebada (1998).

2.3. Water utilization efficiency (W.UT.E.):

Data in Table 3 indicate that W.UT.E. values were increased with increasing the soil moisture depletion. Increasing sulphur application rate from 0.0 to 100 kg $feddan^{-1}$ led to marked increase in W.UT.E. during the two growing seasons. Application of 50 kg S $feddan^{-1}$ (S_2) had a little effect in increasing W.UT.E. Data also show that increasing the rate of P fertilizer increased the values of W.UT.E. comparing with control (P_1). The highest W.UT.E. values (0.63 and 0.64 kg seed cotton m^{-3} applied water in the 1^{st} and 2^{nd} seasons, respectively) were obtained from application of 100 kg S $feddan^{-1}$ + 30 kg P_2O_5 $feddan^{-1}$ under irrigation at 70% (D_3) depletion of available water. These results are agreement with those of Mahrous (1977), Mahrous *et al.* (1984), El-Naggar *et al.* (1999), Khater and Eid (1997) and Ebada (1998).

2.4. Water use efficiency (W.U.E.):

Data in Table 3 indicate that W.U.E. increased with increasing soil moisture depletion under the different rates of sulphur and phosphorus in the two growing seasons. These findings are in agreement with those of Mohamed *et al.* (1995) and El-Naggar *et al.* (1999). Application of sulphur up to 100 kg $fed.^{-1}$ increased W.U.E. over the control. Also, increasing the rate of P fertilizer increased W.U.E. in comparison with control. The interaction of sulphur with phosphorus fertilizer has a marked effect in increasing W.U.E. The highest values of W.U.E. in the 1^{st} and 2^{nd} season (0.79 and 0.81 kg seed cotton m^{-3} water consumed by cotton, respectively were obtained with application 100 kg S+ 30 kg P_2O_5 $fed.^{-1}$ under irrigation at 70% depletion of available soil moisture (D_3). The obtained results are in accordance with those of Mahrous (1977) and Ebada (1998).

Table 3: Seasonal water applied (m^3 fed^{-1}), seasonal water consumptive use (m^3 $fed.^{-1}$), water utilization efficiency and water use efficiency (kg m^{-3}) of cotton as affected by soil moisture depletion, sulphur and phosphorus.

Soil moisture depletion	Seasonal water applied (m^3/fed.)	Seasonal water consumptive use (m^3/fed.)	Water utilization efficiency									Water use efficiency								
			S_1			S_2			S_3			S_1			S_2			S_3		
			P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
First season (2000)																				
D_1	3666.3	2993.8	0.37	0.39	0.47	0.37	0.42	0.49	0.4	0.42	0.53	0.46	0.47	0.57	0.46	0.52	0.6	0.49	0.52	0.65
D_2	3424.8	2739.8	0.42	0.42	0.53	43	0.52	0.55	0.46	0.56	0.59	0.52	0.53	0.66	0.54	0.65	0.69	0.57	0.7	0.74
D_3	3163.6	2494.8	0.44	0.46	0.51	0.43	0.54	0.56	0.51	0.58	0.63	0.56	0.59	0.65	0.55	0.69	0.71	0.65	0.74	0.79
Second season (2001)																				
D_1	3451.7	2760.2	0.38	0.4	0.48	0.38	0.43	0.51	0.4	0.43	0.55	0.48	0.5	0.6	0.48	0.53	0.63	0.5	0.54	0.68
D_2	3219.3	2775.2	0.43	0.44	0.55	0.45	0.54	0.58	0.47	0.58	0.61	0.5	0.51	0.64	0.52	0.63	0.67	0.54	0.67	0.71
D_3	3015.4	2384.9	0.45	0.47	0.52	0.47	0.55	0.57	0.52	0.6	0.64	0.57	0.59	0.66	0.59	0.7	0.72	0.66	0.75	0.81

3. Elemental contents in cotton leaves:

Table 4 show the values of P, Zn, Fe and Mn in leaves of cotton as affected by different depletion levels and different rates of sulphur and phosphorus applications. It is clear from data that decreasing the depletion of soil moisture increased the concentrations of P, Fe and Mn in leaves but Zn was decreased. The highest mean values of P, Fe and Mn in the 1st season (0.27%, 1914.22 and 194.44 ppm, respectively,) and in the second season (0.25%, 1818.51 and 184.72 ppm), respectively were recorded under treatment D_1 which was irrigated at 40% depletion of available soil moisture. While the highest concentration of Zn in leaves (53.06 and 50.4 ppm, respectively) were obtained under the most dry treatment (D_3).

Table 4: Cotton leaves content of P (%), Zn, Fe and Mn (ppm) as affected by soil moisture depletion, elemental sulphur and phosphorus applications.

Treatments	Sulphur	Phosphorus	First season, 2000				Second season, 2001			
			P, %	Zn, ppm	Fe, ppm	Mn, ppm	P, %	Zn, ppm	Fe, ppm	Mn, ppm
D_1	S_1	P_1	0.20	50.00	1260.00	180.00	0.19	47.50	1197.00	171.00
		P_2	0.22	47.50	1077.00	187.50	0.21	45.13	1023.15	178.13
		P_3	0.32	25.00	988.00	192.50	0.30	23.75	938.60	182.88
	S_1 mean		0.25	40.83	1108.33	186.67	0.23	38.79	1052.92	177.33
	S_2	P_1	0.19	55.00	2481.00	185.00	0.18	52.25	2356.95	175.75
		P_2	0.22	42.50	2309.00	195.00	0.21	40.38	2193.55	185.25
		P_3	0.36	35.00	1482.00	202.50	0.34	33.25	1407.90	192.38
	S_2 mean		0.26	44.17	2090.67	194.17	0.24	41.96	1986.13	184.46
	S_2	P_1	0.23	55.00	3108.00	195.00	0.22	52.25	2952.60	185.25
		P_2	0.28	52.50	2968.00	205.00	0.27	49.88	2819.60	194.75
		P_3	0.38	45.00	1556.00	207.50	0.36	42.75	1477.25	197.13
	S_3 mean		0.30	50.83	2543.67	202.50	0.28	48.29	2416.48	192.38
D_1 mean			0.27	45.28	1914.22	194.44	0.25	43.01	1818.51	184.72
D_2	S_1	P_1	0.18	32.50	2006.00	160.00	0.17	30.88	1905.70	152.00
		P_2	0.21	55.00	1744.00	175.00	0.20	52.25	1656.80	166.25
		P_3	0.24	40.00	904.00	185.00	0.23	38.00	858.80	175.75
	S_1 mean		0.21	42.50	1551.33	173.33	0.20	40.38	1473.77	164.67
	S_2	P_1	0.22	60.00	2210.00	150.00	0.21	57.00	2099.50	142.50
		P_2	0.23	47.50	1953.00	182.50	0.22	45.13	1855.35	173.38
		P_3	0.26	52.50	746.00	205.50	0.25	49.88	708.70	195.23
	S_3 mean		0.24	53.33	1636.33	179.33	0.22	50.67	1554.52	170.37
	S_2	P_1	0.28	80.00	2912.00	152.00	0.27	76.00	2766.40	144.40
		P_2	0.30	45.00	2435.00	192.50	0.29	42.75	2313.25	182.88
		P_3	0.35	55.00	1286.00	203.40	0.33	52.25	1221.70	193.23
	S_3 mean		0.31	60.00	2211.00	182.63	0.29	57.00	2100.45	173.50
D_2 mean			0.25	51.94	1799.56	178.43	0.24	49.35	1709.58	169.51
D_3	S_1	P_1	0.12	42.50	1548.00	102.50	0.11	40.38	1565.60	97.38
		P_2	0.16	30.00	1251.00	115.00	0.15	28.50	1188.45	109.25
		P_3	0.20	65.00	951.00	117.50	0.19	61.75	903.45	111.63
	S_1 mean		0.16	45.83	1283.33	111.67	0.15	43.54	1219.17	106.08
	S_2	P_1	0.17	80.00	1496.00	107.50	0.16	76.00	1421.20	102.13
		P_2	0.18	37.50	1452.00	120.00	0.17	35.63	1379.40	114.00
		P_3	0.19	37.50	1247.00	167.50	0.18	35.63	1184.65	159.13
	S_2 mean		0.18	51.67	1398.33	131.67	0.17	49.08	1328.42	125.06
	S_2	P_1	0.16	95.00	1913.00	127.50	0.15	90.25	1817.35	121.13
		P_2	0.19	42.50	1884.00	132.00	0.18	40.38	1789.80	125.40
		P_3	0.32	47.50	1256.00	150.00	0.30	45.13	1193.20	142.50
	S_3 mean		0.22	61.67	1684.33	136.50	0.21	58.58	1600.12	129.68
D_3 mean			0.19	53.06	1455.33	128.61	0.18	50.40	1382.57	120.28

Data also reveale that application of S increased the concentrations of P, Zn, Fe and Mn in cotton leaves under the different levels of soil moisture depletion. In this connection Nasseem *et al.* (1986), Mostafa *et al.* (1990) and El-Fayoumy and El-Gamal (1998) found that application of sulphur to the soil increased plant content of P and micronutrients. The highest mean values of P, Fe and Mn in the 1st seasons (0.30%, 2543.67 and 202.5 ppm, respectively) were obtained with application of 100 kg S fed.$^{-1}$ (S_3) under irrigation at 40% depletion of available water (D_1). The corresponding values in the 2nd season were 0.28%, 2416.48 and 192.38 ppm for P, Fe and Mn, respectively. The highest mean values of Zn in the 1st and 2nd seasons (61.47 and 58.58 ppm, respectively) were resulted with application of 100 kg S fed.$^{-1}$ under treatment D_3. With respect to the effect of P fertilizer the obtained results showed that concentrations of Zn and Fe were decreased while Mn was increased with increasing the rate of P fertilizer. However, Fawzi (1981) observed the sergonism between P and Mn. Abou Zied *et al.* (1997) found that increasing P rates decreased Zn but increased P and Mn in corn plants. Hassan *et al.* (1997) observed the antagonistic relationship between P and Fe in broad bean. The highest values P and Mn in the 1st season (0.38% and 207.5 ppm, respectively), and (0.36% and 197.13 ppm, respectively) in the 2nd season were obtained under the highest rate of P and S (30 kg P_2O_5 + 100 kg S fed.$^{-1}$) and irrigation at 40% depletion (D_1). The highest concentration of Fe in leaves in the 1st and 2nd seasons (3108 and 2952.5 ppm, respectively) were resulted without P fertilizer and application of 100 kg S fed.$^{-1}$ under treatment D_1. The interaction between depletion 70% and application of 100 kg S fed.$^{-1}$ without P achieved resulted in the highest values of leaves Zn content in the 1st and 2nd seasons (95.0 and 90.25 ppm, respectively).

4. Soil elemental content:

Table 5 show the values of soil available P and DTPA extractable Zn, Fe and Mn as influenced by different depletion levels and different rates of sulphur and phosphorus applications. It is clear from the obtained data that the availability of P, Fe and Mn were increased with decreasing the depletion of soil moisture while Zn was decreased. This increases in DTPA extractable Fe and Mn were ascribed to the enhanced fall in redox potential (Eh) and pH of the soil with increasing water content, which change Fe^{+3} and Mn^{+4} to Fe^{+2} and Mn^{+2} (Olomu *et al.*, 1973; Sims & Patrick, 1978; Linsay, 1979 and Mohammed *et al.*, 1996). Increasing the breakdown of ferric and manganic oxides can provide surfaces of high adsorptive capacity on which Zn and Cu ions may be adsorbed and thus their extractability was decreased (Mackenzie, 1980 and Iu *et al.*, 1981).

Table 5: Soil available P, Zn, Fe and Mn (ppm) as affected by soil moisture depletion, elemental sulphur and phosphorus applications.

Treatments	Sulphur	Phosphorus	First season, 2000				Second season, 2001			
			P, %	Zn, ppm	Fe, ppm	Mn, ppm	P, %	Zn, ppm	Fe, ppm	Mn, ppm
D_1	S_1	P_1	6.30	0.77	43.80	6.95	6.05	0.74	41.61	6.67
		P_2	19.90	0.64	47.20	8.06	19.10	0.61	44.84	7.73
		P_3	21.10	0.46	53.80	8.25	20.26	0.44	51.11	7.92
	S_1 mean		15.77	0.62	48.27	7.75	15.14	0.60	45.85	7.44
	S_2	P_1	18.90	0.81	44.30	7.26	18.14	0.78	42.09	6.97
		P_2	19.10	0.63	48.70	8.15	18.34	0.60	46.27	7.82
		P_3	22.10	0.50	55.50	8.55	21.22	0.48	52.73	8.21
	S_1 mean		20.03	0.65	49.50	7.99	19.23	0.62	47.03	7.67
	S_2	P_1	18.90	0.83	48.10	7.26	18.14	0.80	45.70	6.97
		P_2	22.10	0.78	49.30	8.35	21.22	0.75	46.84	8.02
		P_3	26.50	0.55	56.90	8.96	25.44	0.53	53.11	8.59
	S_3 mean		22.50	0.72	51.10	8.19	21.60	0.69	48.55	7.86
D_1 mean			19.43	0.66	49.62	7.97	18.66	0.64	47.14	7.66
D_2	S_1	P_1	6.50	0.73	38.20	7.35	6.24	0.72	36.29	7.06
		P_2	18.30	0.60	45.90	7.55	17.57	0.58	43.61	7.25
		P_3	22.10	0.52	51.20	7.95	21.22	0.50	48.64	7.63
	S_1 mean		15.63	0.62	45.10	7.62	15.01	0.60	42.85	7.31
	S_2	P_1	11.80	.83	40.60	7.35	11.33	0.80	38.57	7.06
		P_2	20.40	0.68	44.60	7.65	19.58	0.65	42.37	7.34
		P_3	24.50	0.56	53.50	8.15	23.52	0.54	50.83	7.82
	S_2 mean		18.90	0.69	46.23	7.72	18.14	0.66	43.92	7.41
	S_2	P_1	11.50	0.93	41.30	7.75	11.04	0.89	39.24	7.44
		P_2	21.20	0.74	46.50	7.85	20.35	0.71	44.18	7.54
		P_3	26.50	0.55	55.40	8.45	25.44	0.53	52.63	8.11
	S_3 mean		19.73	0.74	47.73	8.02	18.94	0.71	45.35	7.70
D_2 mean			18.09	0.68	46.36	7.78	17.37	0.66	44.04	7.47
D_3	S_1	P_1	5.70	0.80	36.50	7.27	5.47	0.77	34.68	6.98
		P_2	12.50	0.60	40.30	7.49	12.00	0.58	38.29	7.19
		P_3	20.30	0.50	49.70	7.78	19.49	0.48	47.22	7.45
	S_1 mean		12.83	0.63	42.17	7.51	12.32	0.61	40.06	7.21
	S_2	P_1	6.40	0.85	38.10	7.33	6.14	0.82	36.20	7.04
		P_2	17.90	0.63	42.20	7.72	17.18	0.60	40.09	7.41
		P_3	21.60	0.55	50.10	8.14	20.74	0.53	47.60	7.81
	S_2 mean		15.30	0.68	43.47	7.73	14.69	0.65	41.29	7.42
	S_2	P_1	7.90	0.92	39.70	7.37	7.58	0.88	37.72	7.08
		P_2	18.60	0.75	42.50	7.95	17.86	0.72	40.38	7.63
		P_3	22.80	0.60	54.40	8.08	21.89	0.58	51.68	7.78
	S_3 mean		16.43	0.76	45.53	7.80	15.78	0.73	43.26	7.49
D_3 mean			14.86	0.69	43.72	7.68	14.26	0.66	41.54	7.37

On the other hand, increasing the availability of P under the higher soil moisture content generally attributed to the less contact of P with soil colloids due to dilution and solubility action (Vyas and Motiramani, 1971; Turner and Gilliam, 1976; Sah and Mikelsen, 1986 and Mohammed *et al.*, 1996). Concerning the effect of sulphur, data indicated that application of sulphur had a marked effect in increasing the availability of P and DTPA extractable Zn, Fe and Mn in the two studied seasons. The combination between S_3 (100 kg S fed.$^{-1}$) and (D_1 irrigation at 40% depletion of available water) recorded the highest mean values of P, Fe and Mn, in the first season (22.50, 51.10 and 8.19 ppm). The same trend was observed in the second season and the corresponding mean values were 21.6, 48.55 and 7.86 ppm.

respectively. These results are supported by Hilal *et al.* (1990b), Abd El-Fattah *et al.* (1990); Nasern *et al.* (1986); El-Raies *et al.* (1997) and El-Fayoumy and Gamal (1998) who found increasing in the availability of P and DTPA extractable micronutrients with sulphur application. Data also showed that increasing the rate of P fertilizer increased the available P and DTPA extractable Fe and Mn while Zn was decreased. The antagonism between Zn and extractable P, Fe and Mn was observed by Cakmak and Marschner (1986); Fawzi (1981); Abou Zied *et al.* (1997) and Hassan *et al.* (1997). The combination between (S_3), (P_3) and (D_1) recorded the highest concentrations of P, Fe and Mn, (26.50, 55.9 and 8.95 ppm, respectively) in the first season. The corresponding values in the 2nd season were 25.44, 53.11 and 8.59 ppm, respectively. The highest concentrations of Zn in both seasons (0.92 and 0.88 ppm, respectively) were recorded with adding 100 kg S fed.$^{-1}$ (S_3) without P fertilizer and irrigation at 70% (D_3) depletion of available soil moisture.

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استجابة محصول القطن إلى إضافات الكبريت العنصري والفوسفور تحت مستويات مختلفة من استنفاذ الرطوبة الأرضية بشمال الدلتا

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أقيمت تجربتان حقليتان خلال موسمين متتابعين ٢٠٠٠، ٢٠٠١م بمحطة البحوث الزراعية بسخا لبحث استجابة محصول القطن إلى إضافات الكبريت العنصري والفوسفور تحت مستويات مختلفة من استنفاذ الرطوبة الأرضية بشمال الدلتا. صممت التجربة في قطع منشقة مرتين خلال موسمي الدراسة. كانت مستويات استنفاذ الرطوبة الأرضية هي ٤٠% (D_1)، ٥٥% (D_2)، ٧٠% (D_3) من الماء الميسر بالتربة وقد تم توزيعها في القطع الرئيسية. معدلات إضافة الكبريت العنصري هي صفر (S_1)، ٥٠ (S_2)، ١٠٠ (S_3) كجم/فدان وتم توزيعها في القطع المنشقة الأولى. معدلات إضافة السماد الفوسفاتي هي صفر (P_1)، ١٥ (P_2)، ٣٠ (P_3) كجم فو٢أ٥/فدان وقد وزعت في القطع المنشقة الثانية.

ويمكن تلخيص أهم النتائج المتحصل عليها كما يلي:

- ري نباتات القطن عند استنفاذ ٥٥% من الرطوبة الميسرة بالتربة (D_1) أدى إلى أعلى إنتاج لمحصول القطن الزهر (١٠,٩٢، ١٠,٥١ قنطار/فدان) في الموسم الأول والثاني على التوالي. أيضا فإن الري عند استنفاذ ٥٥% من الرطوبة الميسرة قد أعطى أعلى تقيم لطول النباتات، عدد الأفرع الثمرية/نبات، عدد اللوز/نبات ووزن اللوزة.
- ري القطن عند مستوى منخفض من استنفاذ الري أدى إلى قيم عالية للماء المضاف (٣٦٦٦,٣ و ٣٤٥١,٧ م٣/فدان)، الاستهلاك المائي (٢٩٩٣,٨ و ٢٧٦٠,٢ م٣/فدان في الموسم الأول والثاني على التوالي)، ولكنه أدى إلى قيم أقل بالنسبة لكفاءة التطبيق وكفاءة استخدام مياه الري.
- ري القطن عند مستوى منخفض من استنفاذ الرطوبة الميسرة بالتربه قد أدى زيادة بميسر P, Zn, Fe, Mn بالتربه وكذلك تركيزاتها بأوراق القطن بينما عنصر Zn قد أخذ الاتجاه العكسي.
- إضافة الكبريت العنصري للتربه أدى الى زيادة معنوية في محصول القطن الزهر، مكونات المحصول، الكفاءة التطبيقية، الكفاءة الاستخدامية لمياه الري، بميسر P، Zn، Fe، Mn بالتربه وكذلك تركيزاتها بأوراق القطن.
- إضافة السماد الفوسفاتي للتربه أدى إلى زيادة معنوية في محصول القطن الزهر، مكونات المحصول، ميسر Mn, Fe, P وكذلك تركيز Mn, P بأوراق القطن.
- إضافة ١٠٠كجم كبريت + ٣٠كجم فو٢أ٥/فدان مع الري عند استنفاذ ٥٥% من الرطوبة الميسرة بالتربه قد أدى إلى الحصول على أعلى محصول للقطن الزهر خلال موسمي الدراسة.
- وجدت علاقة تضاد بين الفوسفور والزنك والحديد في أوراق القطن وعلاقة تشجيع بين الفوسفور والمنجنيز.