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ASSIMILATION OF SULPHATE-SULPHUR AS INFLUENCED BY POTASSIUM NUTRITION IN COTTON (*GOSSYPIUM HIRSUTUM* L.)

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Abstract
A field experiment was conducted to study absorption of sulphate-sulphur (SO^{2-}_4) under varying levels of potassium (K) fertilizer in cotton (*Gossypium hirsutum* L.) plant. Treatments consisted of four cotton (*Gossypium hirsutum* L.) cultivars (CIM-448, CIM-1100, Karishma and S-12), four potassium fertilizer rates (0, 62.5, 125.0 and 250.0 kg K ha^{-1}) and two sources of potassium fertilizer [sulphate of potash (K_2SO_4) and muriate of potash (KCl)]. Studies were carried out on silt loam, Miani soil series (Calcaric cambisols, fine silty, mixed Hyperthermic Fluventic Haplocambids) under irrigated conditions. The sequential harvests were collected at five stages of growth, viz; first flower bud, first flower, peak flowering, first boll split and maturity. Plants were divided into leaves, stems, burs, seed and lint at each harvest and analyzed for Sulphate-sulphur content. Sulphate-sulphur content was the highest during early part of growth period and then declined with ontogeny. Cultivars varied greatly in utilizing SO^{2-}_4 in various organs. Cultivar CIM-448 accumulated greater quantity of SO^{2-}_4 compared to other cultivars. Sulphate-sulphur content increased with concurrent increasing levels of K-fertilizer added in the form of K_2SO_4. Crop maintained SO^{2-}_4 in different organs in sequence of leaves> seed> burs> lint> stems. These studies showed that synergistic phenomenon existed between K^+ and SO^{2-}_4 content in cotton plant.

Keywords: *Gossypium hirsutum* L., irrigated cotton, K-nutrition, potassium concentration, Sulphate-sulphur concentration, synergistic interaction; upland cotton.

INTRODUCTION
Arid and semi-arid zones are characterized as areas in which evaporation exceeds precipitation at least during more than six months of the year. Ascending soil water driven by capillary forces and evaporation carry soluble salt into rooting zone of the top soil [Jensen *et al*. 1990]. Additional accretion of salts

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can occur with irrigation water, unless leaching and removal of drainage water ensured, and with fertilizer application.

Salt accumulation in the rooting zone leads to decreasing soil water potential. With increasing water stress, physiological disorders may occur such as decreasing transpiration and assimilation in pepper and cotton [Shalhevet *et al*. 1986]. Salts accumulation close to roots also affects the selectivity in ion uptake. Other researchers reported that potassium deprived tomato roots failed to control sodium (Na^+) uptake even at low concentrations [Wrona and Epstein 1985]. Several researchers [Dibb and Thompson Jr. 1985, Mengel and Kirkby 1982] reported the existence of ionic interactions, both antagonistic and synergistic. Various researchers suggested that cation-anion interactions occur at both the membrane and in cellular processes after absorption. Potassium interactions with sulphur are less evident in the literature than those with some other nutrients [Hiatt and Leggett 1974].

Under conditions of sulphur deficiency, protein synthesis is inhibited [Marschner 1995]. The sulphate content is extremely low in deficient plants and increases markedly when the sulphate supply is sufficient for optimal growth. The sulphate content of plants is therefore, a more sensitive indicator of sulphur nutritional status than the total sulphur content [Marschner 1995]. A little work has been reported on sulphur nutrition in cotton in Pakistan. Cotton crop is cultivated on more than 3.12 million hectare with product of 13.6 million bolls of lint in the country. It is need of the hour to quantify the sulphur required in cotton crop. Therefore, the present study was undertaken to determine pattern of sulphate-sulphate absorption under varied levels of potassium nutrition by different parts of cotton (*Gossypium hirsutum* L.) plants under irrigated conditions.

MATERIALS AND METHODS

A field experiment was conducted on silt loam soil at Central Cotton Research Institute, Multan Pakistan. The soil samples were collected before imposition of fertilizer treatments at planting time. The analysis of soil samples was carried out according to the prescribed methods [Ryan *et al.* 2001]. Soil analytical data are given in Table 1. The soil is moderately calcareous, weakly structured and developed in an arid sub-tropical continental climate in the areas of sub-recent flood plains. The soil is alluvium of mixed mineralogy with smectites and mica being dominant clay minerals followed by kaolinites and chlorites with various degrees of weathering. The soil belongs to Miani soil series and classified as calcaric cambsoles and fine silty, mixed Hyperthermic Fluventic Haplocambids according to FAO [1990] and Soil Survey Staff [1998], respectively.

The treatments consisted of (a) four cultivars: (CIM-448, CIM-1100, Karishma and S-12) (b) four potassium fertilizer doses (0, 62.5, 125.0 and 250.0 kg K ha^{-1}) and (c) two potassium fertilizer sources [sulphate of potash (K_2SO_4) and muriate of potash (KCl)]. The design of the experiment was split plot (main: cultivars, sub-plot: K-doses and sub-sub plot: K-source) having four replications. Crop was planted at a spacing of 75.0 cm between rows and 30.0 cm between plants in the rows. Crop also received 22 kg P ha^{-1} as triple super-phosphate at planting and 150 kg N ha^{-1} as urea in three split doses, i.e., at planting, flowering and peak flowering. Total quantity of potassium and phosphorus was applied at the time of seedbed preparation and incorporated in the upper plough layer. Stomp-330E @

2.5 l ha^{-1} as pre-emergence herbicide was applied. Crop was kept free from insect pests attack through regular sprays of common pesticides. Crop received normal irrigation and standard production practices of the area throughout the season.

Table 1: Physical and chemical characteristics of experimental site before imposition of treatments.

Characteristics		Depth (cm)			
		0-30	30-60	60-90	90-120
a)	Organic matter (%)	0.67	0.61	0.38	0.21
b)	$CaCO_3$ (%)	4.8	4.8	4.9	2.5
c)	pH_s	8.3	8.4	8.4	8.4
d)	EC_e (dS m^{-1})	2.5	3.9	3.1	4.1
e)	CO_3^{2-} (meq L^{-1})	Nil	Nil	Nil	Nil
f)	HCO_3^{2-} (meq L^{-1})	2.38	3.64	2.56	2.16
g)	Cl^-(meq L^{-1})	4.9	5.3	5.3	5.4
h)	SO_4^{2-} (meq L^{-1})	15.5	20.4	21.9	24.3
i)	Ca^{2+} + Mg^{2+}($cmol^+$ kg^{-1})	0.20	0.24	0.40	0.17
j)	Na^+ ($cmol^+$ kg^{-1})	2.30	3.66	2.60	3.98
	Cation exchange capacity ($cmol^+$ kg^{-1})	5.20	4.80	4.40	4.30
	NO_3-N (mg kg^{-1})	6.8	5.3	4.1	3.8
	$NaHCO_3$-P (mg kg^{-1})	14.3	7.2	2.8	2.2
	NH_4OAc-K ($cmol^+$ kg^{-1})	0.38	0.24	0.23	0.22
Soil separates	Sand (%)	17	15	14	14
	Silt (%)	58	61	61	64
	Clay (%)	25	24	25	22
Textural class		Silt loam	Silt loam	Silt loam	Silt loam

The parameters from a to j were determined in the soil solution extract.

The whole plant samples were harvested sequentially by treatment at five stages of growth, viz. first flower bud at 28 days after planting (DAP), first flower (61 DAP), peak flowering (94 DAP), first boll split (125 DAP) and maturity (153 DAP). Each sample was collected from one square meter area. The whole plants were separated into leaves, stems and fruiting forms according to [Mullins and Burmester 1992]. Mature bolls were separated into lint, seed and burs. Flowers, squares, immature bolls and burs from mature bolls were included with the bur fraction. The material was dried in a forced draft oven at 70ºC to a constant weight. The plant material was digested in a 2:1 HNO_3 (70%), $HClO_4$ (70%) mixture and sulphate-sulphur (SO^{2-}_4) determined according to [Lisle *et al.* 1994]. Data were analyzed statistically according to [Montgomery 1997].

RESULTS AND DISCUSSION

Data for sulphate-sulphur concentration in leaf tissues differed significantly in different cultivars (cv), K-doses (D) and K sources (S) (Table 2). The significant interaction between CvxS and DxS depict that SO^{2-}_4 concentration was dependent upon K-does and K-sources at maturity. Sulphate-Sulphur content decreased gradually from first flower bud stage to maturity. Maximum concentration of SO^{2-}_4 was found at first flower bud stage and minimum at maturity. Cultivars CIM-448 and Karishma had the highest Sa^{2-}_4-S content (0.66 percent) compared to cv. S-12 containing (0.52 percent). Sulphate-sulphur increased concurrently with increase in K-rates. Crop receiving 250 kg ha^{-1} maintained 0.66 percent SO^{2-}_4 content compared to 53 percent at zero K-rate\plot. Application of K-fertilizer in the form of K_2SO_4 raised the level of SO^{2-}_4 by 25.9 percent over KCl addition. The maintenance of SO^{2}_4 by the leaf tissues of various cultivars was affected by K-source. Cultivars CIM-448 and Karishma maintained similar levels of SO^{2}_4 (0.72%) compared to cv. CIM-1100 and S-12. Crop receiving various K-rates in the form of K_2SO_4 and KCl produced differential response to absorption of SO^{2-}_4 by leaf tissues. Cultivars maintained the lowest SO^{2}_4 contents in leaf tissues of plants fertilized with KCl compared to K_2SO_4. Cultivars CIM-448 and Karishma maintained similar SO^{2-}_4 concentration of 0.60 and 0.72 percent by addition of K-fertilizer in the form of KCl and K_2SO_4, respectively. Moreover, the maximum SO^{2-}_4 concentration (0.55 and 0.78 percent) was found in crop receiving 250 kg K ha^{-1} in the form of KCl and K_2SO_4, respectively.

Data for SO^{2-}_4 content in stem tissues at maturity differed significantly due to cultivars, doses and sources (Table 3). Sulphate-sulphur content decreased gradually from first flower bud stage to maturity. Cultivars differed significantly in maintaining SO^{2-}_4 contents. Cultivar CIM-448 and CIM-1100 contained 0.06 percent SO^{2-}_4 compared to Karishma and S-12 having 0.05 percent. Crop receiving K-fertilizer improved SO^{2-}_4 content in stem tissues compared to zero-K rate. Sulphate-sulphur contents were higher in plots fertilized with K_2SO_4 compared to KCl. Concentration of SO^{2-}_4 was higher in CIM-448 and CIM-1100 having 0.04 and 0.05 percent, receiving K-fertilizer in the form of KCl and K_2SO_4, respectively.

Data for SO^{2-}_4 contents in bur tissues at maturity differed significantly due to cultivars, dose and sources (Table 4). There were significant interaction between (cultivars x K-doses and K-doses x sources) indicating that absorption of SO^{2-}_4 in cultivars were dependent upon doses and sources. Sulphate-sulphur content was maximum at first flower bud stage and declined with ontogeny. Cultivar CIM-448 contained higher SO^{2-}_4 (0.10%) content compared to cv. S-12 having 0.09 percent. Addition of varying levels of K-fertilizer caused concurrent increase in SO^{2-}_4 content. Averaged across the cultivars, values ranged from 0.06-0.09% in various treatments of maturity. Under K-stress treatment, crop maintained 0.06 percent than that of 0.09% at 250 kg K ha^{-1} treatment. Maximum SO^{2-}_4 content (0.10%) were found in crop fertilized with K_2SO_4 compared to minimum (0.06%) under KCl treatment. Cultivar CIM-448 was most efficient in maintaining the highest SO^{2-}_4 concentration (0.08 and 0.12%) under KCl and K_2SO_4 fertilized crop, respectively. Furthermore, addition of varying levels of K-fertilizer in the form of K_2SO_4 maintained two-third higher SO^{2-}_4 content compared to under KCl treated plots.

Table 2: Effect of potassium fertilization (kg K ha^{-1}) on SO^{2-}_4 concentration (%) in leaf tissues at various stages of growth.

Cultivar	KCl				K_2SO_4		
	0	62.5	125.0	250.0	62.5	125.0	250.0
			First Flower Bud				
CIM-448	1.15	1.15	1.16	1.16	1.21	1.24	1.26
CIM-1100	1.10	1.10	1.10	1.11	1.17	1.18	1.19
Karishma	1.13	1.14	1. 14	1.14	1.18	1.22	1.24
S-12	0.99	0.99	0.99	0.99	1.08	1.11	1.17
LSD	Cultivar (Cv.)		Dose (D)		Source (S)	Cv.xS	DxS
($p<0.05$)	0.016**		0.016**		0.009**	0.018**	0.015**
			First Flower				
CIM-448	0.99	1.00	0.98	0.98	1.11	1.13	1.16
CIM-1100	0.93	0.93	0.94	0.95	1.09	1.13	1.17
Karishma	0.98	0.98	0.98	0.98	1.10	1.11	1.14
S-12	0.88	0.88	0.89	0.89	0.99	1.01	1.03
LSD	Cv.	D	S	CvxD	CxS	DxS	
($p<0.05$)	0.019**	0.011**	0.010**	0.023**	0.02**	0.017**	
			Peak Flowering				
CIM-448	0.81	0.82	0.82	0.82	0.92	1.01	1.06
CIM-1100	0.78	0.79	0.79	0.80	0.92	1.00	1.02
Karishma	0.77	0.77	0.78	0.79	0.95	0.98	1.07
S-12	0.71	0.71	0.78	0.72	0.88	0.93	0.98
LSD ($p<0.05$)		Cv. 0.013**		D 0.015**	S 0.011**		DxS 0.019**
			First boll split				
CIM-448	0.70	0.70	0.70	0.70	0.85	0.88	0.92
CIM-1100	0.66	0.66	0.67	0.67	0.77	0.81	0.88
Karishma	0.67	0.68	0.68	0.69	0.85	0.92	0.94
S-12	0.59	0.59	0.59	0.59	0.75	0.79	0.83
LSD ($p<0.05$)	Cv. 0.011**		D 0.017**	S 0.011**	CxS 0.023**		DxS 0.021**
			Maturity				
CIM-448	0.59	0.60	0.62	0.60	0.71	0.76	0.81
CIM-1100	0.50	0.50	0.50	0.52	0.67	0.71	0.78
Karishma	0.62	0.52	0.63	0.63	0.73	0.75	0.77
S-12	0.41	0.42	0.42	0.42	0.60	0.67	0.75
LSD ($p<0.05$)	Cv. 0.031**		D 0.025**	S 0.016**	CxS 0.033**		DxS 0.029**

** = significant at the 0.01 level.

Data for SO^{2-}_4-S content in seed at maturity differed significantly due to cultivar, dose and source (Table 5). There were significant interaction between K-dose and K-sources at maturity. This depicted that SO^{2-}_4 content was influenced due to K-sources in seed tissues. Sulphate-sulphur increased from peak flowering to maturity. Crop maintained the highest SO^{2-}_4 concentration at maturity compared to other stages during crop season. Cultivar S-12 contained the highest concentration (0.23%) compared with Karishma having 0.19%. Sulphate-sulphur increased concurrently with increasing levels of K-fertilizer. Crop under zero K-rate maintained the lowest SO^{2-}_4 content (0.17%) than that of 0.23% under 250 kg K ha^{-1} treatment. Sulphate-sulphur content of 0.17 and 0.24% were found under KCl and K_2SO_4 treated crop, respectively. Application of varying levels of K-fertilizer in the form of K_2SO_4 caused significant improvement in SO^{2-}_4 compared to KCl. Crop fertilized with 250 kg K ha^{-1} in the form of KCl and K_2SO_4 maintained 0.17 and 0.28% SO^{2-}_4, respectively at maturity.

Table 3: Effect of potassium fertilization (kg K ha^{-1}) on SO^{2-}_4 concentration (%) in stem tissues at various stages of growth.

Cultivar	KCl				K_2SO_4		
	0	62.5	125.0	250.0	62.5	125.0	250.0
			First Flower Bud				
CIM-448	0.12	0.12	0.13	0.13	0.16	0.18	0.20
CIM-1100	0.10	0.10	0.10	0.10	0.14	0.15	0.19
Karishma	0.09	0.10	0.10	0.10	0.13	0.17	0.19
S-12	0.11	0.11	0.11	0.11	0.15	0.16	0.18
LSD (p<0.05)		Cv. 0.008**	D 0.007**		S 0.007**		DxS 0.012**
			First Flower				
CIM-448	0.09	0.09	0.09	0.10	0.12	0.13	0.17
CIM-1100	0.08	0.08	0.08	0.08	0.11	0.12	0.14
Karishma	0.08	0.08	0.08	0.09	0.11	0.13	0.14
S-12	0.08	0.08	0.08	0.08	0.12	0.15	0.15
LSD (p<0.05)		Cv. 0.006**		D 0.008**	S 0.006**		DxS 0.010**
			Peak Flowering				
CIM-448	0.07	0.07	0.08	0.07	0.09	0.12	0.14
CIM-1100	0.06	0.06	0.06	0.06	0.10	0.11	0.11
Karishma	0.06	0.06	0.06	0.06	0.10	0.10	0.11
S-12	0.07	0.07	0.07	0.07	0.09	0.11	0.12
LSD (p<0.05)		Cv. 0.007**		D 0.007**	S 0.005**		DxS 0.009**
			First boll split				
CIM-448	0.05	0.05	0.05	0.05	0.07	0.07	0.08
CIM-1100	0.05	0.05	0.05	0.05	0.08	0.10	0.11
Karishma	0.05	0.05	0.05	0.05	0.07	0.08	0.08
S-12	0.04	0.04	0.04	0.04	0.06	0.07	0.08
LSD (p<0.05)		Cv. 0.006**	D 0.005**	S 0.003**		DxS 0.006**	CxS 0.007**
			Maturity				
CIM-448	0.04	0.04	0.04	0.04	0.05	0.05	0.05
CIM-1100	0.04	0.04	0.04	0.04	0.05	0.06	0.06
Karishma	0.03	0.03	0.03	0.03	0.04	0.06	0.06
S-12	0.03	0.03	0.03	0.03	0.05	0.06	0.06
LSD (p<0.05)		Cv. 0.004**		D 0.004**	S 0.003**		CxS 0.006**

** = significant at the 0.01 level.

Sulphate-Sulphur in the lint tissues at maturity also differed due to cultivar, dose and source. There were non-significant difference in interaction terms CvxDxS, showing that SO^{2-}_4 content in lint tissues were independent of dose and source. Crop maintained almost similar content of SO^{2-}_4 in lint tissues from peak flowering to maturity. Cultivars CIM-448, Karishma and S-12 had higher concentration than that of CIM-1100. Addition of K-fertilizer caused increase in SO^{2-}_4 contents in lint tissues (Table 6). Crop fertilized with K_2SO_4 contained 37.5% higher SO^{2-}_4 than that of KCl treated plots.

There were positive correlation coefficient between K^+ and SO^{2-}_4 concentration due to addition of K-fertilizer in the form of KCl and K_2SO_4 in various parts of cotton plant. However, there were non-significant correlation between application of K-fertilizer in the form of KCl and SO^{2-}_4 concentration maintained by different parts of the plant. These data demonstrate the synergistic interaction between potassium and sulphate-sulphur nutrients (Table 7).

Table 4: Effect of potassium fertilization (kg K ha^{-1}) on SO^{2-}_4 concentration (%) in burs at different stages of growth Stage.

Cultivar	KCl				K_2SO_4		
	0	62.5	125.0	250.0	62.5	125.0	250.0
			First Flower Bud				
CIM-448	0.30	0.30	0.30	0.31	0.41	0.45	0.49
CIM-1100	0.26	0.26	0.27	0.27	0.37	0.44	0.52
Karishma	0.28	0.28	0.28	0.28	0.40	0.43	0.48
S-12	0.24	0.25	0.25	0.25	0.36	0.44	0.47
LSD (p<0.05)	Cv. 0.014**		D 0.015**		S 0.009**	DxS 0.016**	
			Peak Flowering				
CIM-448	0.28	0.28	0.28	0.28	0.38	0.43	0.44
CIM-1100	0.25	0.25	0.25	0.25	0.35	0.40	0.42
Karishma	0.25	0.25	0.25	0.25	0.34	0.38	0.40
S-12	0.20	0.20	0.20	0.21	0.31	0.37	0.40
LSD p<0.05)	Cv. 0.013**	D 0.012**		S 0.007**	DxS 0.013**		CxS 0.015**
			First boll split				
CIM-448	0.16	0.16	0.16	0.16	0.19	0.22	0.27
CIM-1100	0.14	0.14	0.14	0.14	0.23	0.34	0.38
Karishma	0.13	0.13	0.14	0.14	0.24	0.32	0.35
S-12	0.11	0.11	0.11	0.12	0.24	0.26	0.31
LSD (p<0.05)	C 0.013**	D 0.012**	S 0.008**	CvxD 0.024**	CvxS 0.016**		DxS 0.013**
			Maturity				
CIM-448	0.08	0.08	0.08	0.08	0.11	0.13	0.14
CIM-1100	0.06	0.06	0.06	0.06	0.10	0.13	0.14
Karishma	0.04	0.04	0.04	0.04	0.10	0.12	0.12
S-12	0.03	0.03	0.03	0.03	0.07	0.07	0.08
LSD (p<0.05)	Cv. 0.006**		D 0.006**	S 0.004**	Cv.xS 0.008**		DxS 0.007**

Table 5: Effect of potassium fertilization (kg K ha^{-1}) on SO^{2-}_4 concentration (%) in seed tissues at different stages of growth.

Cultivar	KCl				K_2SO_4		
	0	62.5	125.0	250.0	62.5	125.0	250.0
			Peak flowering				
CIM-448	0.14	0.14	0.14	0.14	0.20	0.22	0.23
CIM-1100	0.12	0.12	0.12	0.16	0.16	0.20	0.21
Karishma	0.11	0.11	0.11	0.11	0.17	0.19	0.21
S-12	0.16	0.16	0.16	0.16	0.20	0.22	0.23
LSD (p<0.05)		Cv. 0.011**		D 0.01**	S 0.006**		DxS 0.011**
			First boll split				
CIM-448	0.16	0.16	0.16	0.16	0.24	0.25	0.25
CIM-1100	0.14	0.14	0.14	0.14	0.20	0.24	0.24
Karishma	0.14	0.14	0.14	0.14	0.20	0.21	0.23
S-12	0.18	0.18	0.18	0.18	0.23	0.26	0.28
LSD (p<0.05)		Cv. 0.013**		D 0.009**	S 0.007**		DxS 0.013**
			Maturity				
CIM-448	0.17	0.17	0.17	0.18	0.25	0.26	0.28
CIM-1100	0.16	0.16	0.16	0.16	0.24	0.27	0.28
Karishma	0.16	0.16	0.16	0.16	0.22	0.23	0.25
S-12	0.19	0.19	0.19	0.19	0.25	0.28	0.29
LSD (p<0.05)		Cv. 0.008**		D 0.010**	S 0.008**		DxS 0.014**

** = significant at the 0.01 level.

Table 6: Effect of potassium fertilization (kg K ha^{-1}) on SO^{2-}_4 concentration (%) in lint tissues at various stages of growth.

Cultivar	KCl				K_2SO_4		
	0	62.5	125.0	250.0	62.5	125.0	250.0
				Peak Flowering			
CIM-448	0.07	0.07	0.07	0.07	0.09	0.10	0.10
CIM-1100	0.05	0.05	0.05	0.05	0.10	0.11	0.11
Karishma	0.06	0.06	0.06	0.06	0.10	0.10	0.11
S-12	0.06	0.06	0.06	0.07	0.11	0.11	0.12
LSD (p<0.05)	Cv. 0.005**		D 0.005**	S 0.005**	DxS 0.009**		CvxS 0.011**
				First boll split			
CIM-448	0.08	0.08	0.08	0.08	0.11	0.11	0.11
CIM-1100	0.06	0.06	0.06	0.06	0.11	0.11	0.11
Karishma	0.08	0.08	0.08	0.08	0.11	0.11	0.11
S-12	0.08	0.08	0.08	0.08	0.11	0.11	0.11
LSD (p<0.05)	Cv. 0.008**		D 0.005**		S 0.004**	DxS 0.009**	
				Maturity			
CIM-448	0.08	0.08	0.08	0.08	0.11	0.11	0.11
CIM-1100	0.06	0.06	0.06	0.06	0.11	0.11	0.11
Karishma	0.08	0.08	0.08	0.08	0.11	0.11	0.11
S-12	0.08	0.08	0.08	0.08	0.11	0.11	0.11
LSD (p<0.05)		Cv. 0.008**		D 0.007**		S 0.006**	

Table 7: Relationship between K^+ concentration (%) and SO^{2}_{-4} concentration (%) as influenced by the addition of K-fertilizer in the form of KCl and K_2SO_4 in various organs of cotton plant.

VARIABLES	REGRESSION EQUATION	CORRELATION CO-EFFICIENT
	KCl	
K+ conc. in leaves vs. SO2-4 conc. in leaves	Y = -0.004X+0.802	-0.084NS
K+ conc. in stems vs. SO2-4-S conc. in stems	Y = 0.006X+0.044	0.47NS
K+ conc. in burs vs. SO2-4 conc. in burs	Y = 0.005x+0.14	0.39NS
K+ conc. in seed vs. SO2-4 conc. in seed	Y = 0.018X+1.494	0.44NS
K+ conc. in lint vs. SO2-4 conc. in lint	Y = 0.051x+0.482	0.46NS
	K_2SO_4	
K+ conc. in leaves vs. SO2-4 conc. in leaves	$Y = 1.115X^2-5.95X+8.714$	0.81**
K+ conc. in stems vs. SO2-4 conc. in stems	$Y = 0.027X^2-0.066X+0.079$	0.92**
K+ conc. in burs vs. SO2-4 conc. in burs	$Y = 0.039X^2-0.085X+0.175$	0.97**
K+ conc. in seed vs. SO2-4 conc. in seed	$Y = 0.442X^2-1.243X+1.022$	0.92**
K+ conc. in lint vs. SO2-4 conc. in lint	$Y = -0.376X^2+1.125X-0.729$	0.84**

NS = non-significant at the 0.05 probability level.
** = significant at the 0.01 probability level.

The accompanying anion of potassium fertilizer can interfere also with the availability and efficiency of those nutrients fixed at high pH such as phosphorus and micro-nutrients. Plants fed with sulphate of potash [Roemheld 1983] have a substantially lower pH at the root surface than in the surrounding soil. The marked decrease in rhizospheric pH with K_2SO_4 is caused by differences in cation/anion uptake. K supplied as sulphate is absorbed more rapidly than the accompanying anion SO_4, which results in surplus of protons (H^+) extruded by roots in exchange for K^+. The rhizospheric pH remains fairly unchanged when muriate of potash is the source of K because both elements, the cation K^+ and the anion Cl^- are absorbed in equivalent quantities. An increase in rhizospheric pH can be expected when nitrate of potash is used in fertigation method, i.e. the injection of nutrients into the irrigation system. The nitrate uptake rates (in terms of mol per time unit) are much higher than K^+ uptake rates. Nitrate uptake increases the pH since it is taken up in proton-co-transport [Ullrich 1992] while K^+ uptake stimulates the release of H^+ [Mengel and Schubert 1985]. Lowering the rhizospheric pH with K_2SO_4 can improve the availability and thus, the efficiency of P and micro nutrients in particular, when fixed at high pH. The change in rhizospheric pH with the K source is also an important factor in determining the proper K source for future fertigation of permanent crops.
The secondary element sulphur has been reported to be deficient in soils of the cotton belt of the Punjab [Ahmed *et al.* 1992]. Soils had available SO^{2-}_4-S less than 10-15 mg kg^{-1} of soil. Various researchers [Makhdum *et al.* 2001] reported 7% increase in seed cotton yield by the addition of 125 kg gypsum ha^{-1} to meet the hidden hunger of cotton crop. Sulphate-sulphur content increased with increasing levels of K-fertilizer added in the form of K_2SO_4. Hiatt and Leggett [1974] advocated that cation and anion interaction occur at both the membrane and in cellular processes after absorption. These results are in agreement with those of Marschner [1995] who reported that sulphte content is extremely low in deficient plants and increases markedly when the sulphate supply is sufficient for optimal growth.

References

Ahamd, N., Saleem M., Rashid, M. and Jalil, A. (**1992**) “Sulphur status of Pakistan Soil”. NFDC Publication No. 4/92, Islamabad.

Dibb, D.W. and Thompson Jr., W.R. (**1985**) “Interaction of potassium with other nutrients”, In: R.D. Munson (Ed.), *Potassium in Agriculture*, ASA. CSSA. SSSA, Madison, WI, USA. pp. 515-533.

FAO (Food and Agriculture Organization) (**1990**) “Soil Map of the World”, FAO Soil Classification, Rome, Italy.

Hiatt, A.J. and Leggett, J.E. (**1974**) “Ionic interactions and antagonism in plants”, In: E.W. Carson (Ed.), *The Plant Root and its Environment*, University of Virginia Press, Charlottesville, USA, pp. 101-134.

Jensen, M.E., Rangeley, W.R. and Dieleman, P.J. (**1990**) “Irrigation trends in world agriculture”, In: B.A. Stewart and D.R. Nielsen (Eds.), *Irrigation of Agricultural Crops*, SSSA, Madison, WI, USA, pp. 32-67.

Lisle, L., Lefroy, R., Anderson, G. and Blair, G. (**1994**) "Methods for the measurement of sulphur in plants and soil", *Sulphur in Agriculture*, **18**, 45-54.

Makhdum, M.I., Malik, M.N.A., Chaudhry, F.I. and Shabab-ud-Din (**2001**) "Effects of gypsum as sulphur fertilizer in cotton (*Gossypium hirsutum* L.)", *Internat. J. Agric. & Biol*., **3**, 375-377.

Marschner, H. (**1995**) "Functions of mineral nutrients: macronutrients", In: *Mineral Nutrition of Higher Plants*, 2nd ed., Academic Press, London, pp. 195-268.

Mengel, K. and Kirkby, E.A. (**1982**) "Principles of Plant Nutrition". *Int. Potash Inst. Berne*, Switzerland, pp. 462-464.

Mengel, K. and Schubert, S. (**1985**) "Active extrusion of protons into deionized water by roots of intact maize plants", *Plant Physiol*., **79**, 344-348.

Montgomery, D.C. (**1997**) "Design and Analysis of Experiments", 4th ed., John Wiley and Sons, Inc., New York, p. 704.

Mullins, G.L. and Burmester, C.H. (**1992**) "Uptake of calcium and magnesium by cotton grown under dryland conditions", *Agron. J*., **84**, 564-569.

Roemheld, V. (**1983**) "pH-Veranderungen is der Rhizosphare in Abhangigkeit von Nahrstoffangebot", *Landw. Forschung*, **40**, 226-230.

Ryan, J., Estefan, G. and Rashid, A. (**2001**) "Soil and Plant Analysis Laboratory Manual", 2nd ed., Internat. Center for Agric. Res. in the Dry Area, Aleppo, Syria, p. 172.

Shalhevet, J., Vinten, A. and Meiri, A. (**1986**) "Irrigation interval as a factor in sweet corn response to salinity", *Agron. J*., **78**, 539-545.

Soil Survey Staff (**1998**) "Keys to Soil Taxonomy", 8th ed., United States Department of Agriculture, National Sources Conservation Service, Washington D.C.

Ullrich, W.R. (**1992**) "Transport of nitrate and ammonium through plant membranes", In: K. Mengel and D.J. Pilbeam (Eds.), *Nitrogen Metabolism in Plants*, Oxford University Press, pp. 121-137.

Wrona, A.F. and Epstein, E. (**1985**) "Potassium and sodium absorption kinetics in roots of two tomato species, *Lycopersicon esculentum* and *Lycopersicon cheesmanii*", *Plant Physiol*., **79**, 1064-1067.