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EFFECT OF SULPHUR ON THE UTILIZATION EFFICIENCY OF NITROGEN BY WHEAT ON SANDY SOILS OF SAUDI ARABIA

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ABSTRACT

Two field experiments were conducted during winter seasons of 2000–2001 and 2001– 2002 to examine the effect of elemental sulphur applied at the rates of 0, 500 and 1000 Kg ha^{-1} on the utilization efficiency of nitrogen fertilizer as urea at the rates of 0, 100, 200 and 300 Kg N ha^{-1} by wheat grown on sandy soils using sprinkler irrigation system under the arid conditions in the central region of Saudi Arabia (Al–Qassim region).

The obtained results indicated that the straw and grain yields of wheat were significantly increased as the nitrogen dose increased and more pronounced increases were producd with applying nitrogen with sulphur as compared to the application of nitrogen alone. The optimum economic level of nitrogen with sulphur at the rate of 500 or 1000 Kg ha^{-1} was 200 Kg N ha^{-1}. The protein content of wheat grains increased significantly with increasing nitrogen and sulphur application rates when they were applied either alone or in combination and it was significantly correlated with the nitrogen content in wheat grains. N , P and K contents of wheat straw and grains were significantly increased with increasing nitrogen and sulphur application rates when they were applied either alone or in combination .

Soil salinity (ECe) was increased significantly due to the application of 300 Kg N and 1000 Kg sulphur ha^{-1}, while soil pH was significantly decreased. Available soil N and P increased significantly with increasing nitrogen and sulphur application rates during the two seasons, while Available soil K was significantly increased with increasing sulphur levels in the first season and with nitrogen at the rates of 200 and 300 Kg N ha^{-1} in the second season. It can be concluded that application of sulphur has apparently promoted the utilization efficiency of nitrogen fertilizer as urea in sandy soils under arid environment.

Keywords: Sulphur. nitrogen fertilizer, wheat, yield, protein content, nutrient content and uptake, soil chemical properties.

INTRODUCTION

The soils in the central region of Saudi Arabia are predominantly calcareous and sandy soils (Al–Omran and Shalaby,1992). These soils are poor not only in essential plant nutrients but also in organic matter content which is a storehouse for many nutrients especially nitrogen. Moreover, the less availability of nutrients to plants is common under these conditions (Awad,1998 and Koreish *et al.*,1998). Unfortunately, such prevailing conditions may stimulated the loss of nitrogen as ammonia from the surface of soil applied N fertilizers (Shahin *et al.*,1999). Hargrove (1988) and Watson (1990) found that most of the NH_3 volatilization occurred with calcareous and sandy soils Most of the reported work had been focused urea (Reddy *et*

2 ; Al-Kanani *et al.*,1990 and Grant *et al.*,1996). Several approaches been used to minimize NH_3 volatilization especially from urea applied to soils. One is to apply coatings of inert materials to urea granules (Prasad *et al.*, 1971). Bonding urea to acid anions which lower the pH in the vicinity of urea granules (Stumpe *et al.*,1984). A third approach is to use urease inhibitors (Abdel–Monem,1991 and Abdel–Sabour *et al.*,1993). The application of elemental sulphur to soils due to its favourable effects in promoting nutrient availability in soils (Mostafa *et al.*,1990 and El–Fakhrani,1995,1996 and 2001). Boswell and Friesen (1993) reported that elemental sulphur is currently used to coat urea granules to increase its use efficiency by plants. The blending of N fertilizers with elemental sulphur slowed down their transformation and NH_3 volatilization was reduced by 30% of their corresponding original values (Shahin *et al.*,1999).

The objective of this study is to examine the effect of elemental sulphur on the utilization efficiency of N fertilizer as urea applied to wheat grown on a sandy soil under arid conditions in the central region of Saudi Arabia (Al–Qassim region).

MATERIALS AND METHODS

Two field experiments were carried out during the two successive winter seasons viz. 2000– 2001 and 2001–2002 under sprinkler irrigation system at the Experimental Station of the College of Agriculture and Veterinary Medicine, King Saud University, Al–Qassim Branch, Saudi Arabia. Data of Table 1 show some characteristics of the soil of the experimental site as determined according to Page *et al.*,(1982). Twelve treatments were examined during both seasons resulted from the combination of four N fertilizer rates (0, 100, 200 and 300 Kg N ha^{-1}) and three sulphur levels (0, 100, 200 and 300 Kg N ha^{-1}). Treatments were arranged according to the completely randomized block design in three replicates. Plot area for each treatment was 3 x 2 m^2. Wheat seeds (*Triticum aestivum* , CV. Yeccra Rojo) at the rate of 120 Kg ha^{-1} were sown in 23th of November 2000 and 2001 for the first and second seasons, respectively and irrigated immediately. Wheat was drilled in the dry soil in rows 20 cm apart. One week before sowing, the treatment materials of sulphur and phosphorus fertilizer as triple superphosphate (20% P) at the rate of 60 Kg P ha^{-1} were applied and mixed with the top 10 cm of the soil surface. Then the plots were lightly irrigated to encourage oxidation of sulphur to sulphate ions ($SO_4^{=}$). The chemical composition of water used for irrigation is shown in Table 2. Nitrogen fertilizer as urea (46% N) was added to soil in three equal doses, while potassium fertilizer as potassium sulphate (40% K) was added to soil at the rate of 80 Kg K ha^{-1} in two equal doses during the growth period. Four weeks after sowing, the first dose of both N and K fertilizers was applied. The second dose of both N and K fertilizers was applied at the tillering stage (one month after the first dose) and the third dose of N was added at the headind stage (one month after the second dose).

Table 1: Some characteristics of the experimental soil

Particle size Distribution (%)			Tex-Tural class	pH*	ECe* (dS m^{-1})	Ion concentration* (meq l^{-1})						$CaCO_3$ (%)	Organic Matter (%)	Soil available Nutrients (mg Kg^{-1} soil)		
Sand	Silt	Clay				HCO_3^-	Cl^-	$SO_4^=$	Ca^{2+}	Mg^{2+}	Na^+			N	P	K
90.6	5.4	4.0	Sand	8.55	2.56	2.70	13.5	9.35	9.82	3.50	12.2	4.21	0.32	17.4	20.1	90.0

* Measured in saturation paste extract.

Table 2: Chemical analysis of water used for irrigation

PH	ECe (dS m^{-1})	Ion concentration (meql^{-1})							SAR
		HCO_3^-	Cl^-	$SO_4^=$	Ca^{2+}	Mg^{2+}	Na^+	K^+	
6.92	1.39	1.95	5.75	6.18	4.17	1.73	7.78	0.19	4.53

At maturity, approximately 5 months (153 days) after sowing the straw and grain yields per hectar of wheat crop were recorded in both seasons. Straw and grain samples were taken from each treatment and analyzed for N, P and K according to Chapman and Pratt (1961). The protein content in grains was calculated by multiplying N% x 6.25. Disturbed surface soil samples (0 – 30cm) were collected from all treatments after harvesting to determine the pH, electrical conductivity (ECe) and available macronutrients of N, P and K according to Page *et al.*, (1982).

RESULTS AND DISCUSSION

Straw and grain yields

The results presented in Table 3 show the effect of nitrogen and sulphur applications on straw and grain yields of wheat in the two seasons. Apparently, the straw and grain yields of wheat were significantly increased with increasing N application rate from 0 to 300 Kg N ha^{-1} in both seasons. This increase may be attributed to that N increased photosynthetic area and consequently increased photosynthates (Abd El-Gawad *et al.*,1997). These findings are in agreement with those reported by Ibrahim *et al.* (1987), Omran *et al.* (1991) and El-Fakhrani (1999) who stated that N fertilization promoted the growth and yield of plants. The highest yields of straw and grain at the two seasons were obtained by using 200 Kg N ha^{-1} during both seasons. The results in Table 3 indicate also that sulphur application at the rate of 1000 Kg ha^{-1} caused significant increases in the straw and grain yields in the first season and only in the straw yield in the second season as compared to the control. This may be due to the influence of sulphur on lowering soil pH and consequently increasing the availability of plant nutrients (Shahin *et al.*,1999 and El-Fakhrani, 2001). Similar results were obtained by Sotiriov and Kick (1983) and El-Fakhrani (1996) with wheat and El-Fakhrani (2001) with sugar beet.

Concerning the interaction effect between nitrogen and sulphur, data in Table 3 reveal more pronounced increase in the straw and grain yields in the two studied seasons due to the interaction of nitrogen and sulphur than that of each of them applied alone. It can be concluded that application of sulphur with nitrogen fertilizer has apparently promoted the utilization efficiency of nitrogen fertilizer and consequently wheat yield. Shahin *et al.*(1999) reported that addition of sulphur to sandy soils increased N fertilizer efficiency and reduced NH_3 volatilization. This reflects the relative beneficial effects of sulphur on soil properties as well as on nutrient availability. The maximum straw and grain yields were obtained by using 1000 Kg sulphur and 200 Kg N ha^{-1} in both seasons.

Table 3 : Straw and grain yields (t ha^{-1}) of wheat as affected by nitrogen and sulphur applications in the two seasons.

Nitrogen Levels (Kg ha^{-1})	Sulphur levels (Kg ha^{-1})							
	0	500	1000	mean	0	500	1000	mean
	Straw				Grains			
First season								
0	4.61	4.82	4.91	4.78	4.60	4.69	4.78	4.69
100	5.24	5.43	5.58	5.42	5.01	5.20	5.33	5.18
200	5.86	6.14	6.39	6.13	5.73	5.93	6.13	5.93
300	5.67	5.88	6.28	5.94	5.37	5.74	6.03	5.71
mean	5.35	5.57	5.79		5.18	5.39	5.57	
Second season								
0	4.94	5.06	5.08	5.03	4.79	4.94	5.04	4.92
100	5.38	5.67	5.75	5.60	5.30	5.63	5.72	5.55
200	5.62	5.87	6.04	5.84	5.51	5.71	5.90	5.71
300	5.33	5.45	5.71	5.50	5.21	5.39	5.64	5.41
mean	5.32	5.51	5.65		5.20	5.42	5.58	

LSD ($p = 0.05$) :	First season Straw	First season Grains	Second season Straw	Second season Grains
Nitrogen effect :	0.45	0.34	0.36	0.48
Sulphur effect :	0.39	0.29	0.31	0.42
Interaction :	0.78	0.58	0.62	0.84

Nutrient content

The nutrient contents (%) of wheat straw and grains as affected by nitrogen and sulphur applications during both seasons are shown depicted in Tables 4, 5 and 6. Contents of N and P in grains were greater than that in straw. Conversely, content of K in straw was higher than that in grains. Moreover, the N content in straw and grains in the second season was greater than that in straw and grains in the first season (Table 4). The results presented in Table 4 show that the addition of N at the rates of 200 and 300 Kg N ha^{-1} caused a significant increase in the N content in straw in the two seasons. While the N content in grains was significantly increased with increasing N application rate from 0 to 300 Kg N ha^{-1} in the first season and at the rate of 300 Kg N ha^{-1} in the second season. These results are in agreement with those obtained by Ibrahim *et al.*,(1987); Omran *et al.*,(1991) and El-Fakhrani (1999 and 2000) who reported that the application of N to soil increased N content in wheat plants.

Table 4 : Nitrogen content (%) in straw and grains of wheat as affected bynitrogen and sulphur applications in the two seasons.

Nitrogen Levels (Kg ha^{-1})	Sulphur levels (Kg ha^{-1})							
	0	500	1000	mean	0	500	1000	mean
	Straw				Grains			
	First season							
0	0.38	0.52	0.64	0.51	2.27	2.42	2.44	2.38
100	0.47	0.77	0.84	0.69	2.51	2.71	3.00	2.74
200	0.50	0.81	0.89	0.73	2.53	2.72	3.03	2.76
300	0.53	0.87	0.96	0.79	2.66	3.22	3.53	3.14
mean	0.47	0.74	0.87		2.49	2.77	3.00	
	Second season							
0	0.69	0.76	0.89	0.78	2.40	3.12	3.61	3.04
100	0.78	0.83	1.02	0.88	2.77	3.50	3.68	3.32
200	0.86	0.90	1.03	0.93	3.03	3.64	3.78	3.48
300	1.04	1.05	1.06	1.05	3.16	4.01	4.70	3.96
mean	0.84	0.89	1.00		2.84	3.57	3.94	

	First season		Second season	
LSD (p = 0.05) :	Straw	Grains	Straw	Grains
Nitrogen effect :	0.20	0.35	0.12	0.86
Sulphur effect :	0.18	0.31	0.11	0.75
Interaction :	0.35	0.61	0.21	1.49

Concerning the effect of sulphur application on the N content in straw and grains of wheat, results in Table 4 reveal that the N content in straw and grains significantly increased as a result of increasing sulphur levels from 0 to 1000 Kg ha^{-1} in the first season and at the sulphur level of 1000 Kg ha^{-1} in the *second season. This reflects* the role of sulphur in improving chemical properties and fertility status of the studied soil (Tables 11 and 12). These results are in agreement with those obtained by El-Fakhrani (1996 and 2001). Regarding the interaction effect of nitrogen and sulphur on the N *content of straw* and grains, the obtained results(Table 4) indicate that there are significant interactions between nitrogen and sulphur in increasing N content in straw and grains in the two seasons.

With respect to the effect of nitrogen and sulphur applications on P content of wheat straw and grains in the two seasons, the obtained results (Table 5) show that P contents in straw and grains were significantly increased due to the highest levels of nitrogen and sulphur compared to the control in both seasons.This may be due to increasing the solubility and availability of P in soil as a result of reducing soil pH (Table 11). Similar results were obtained by El-Gala *et al.* (1989); Faiyad *et al.* (1991); El-Maghraby *et al.*,(1996) and El-Fakhrani (1995, 1996, 1999 and 2001). In addition, the results in Table 5 show that P contents of straw and grains were affected significantly by nitrogen fertilization when interacted with sulphur at the highest levels of nitrogen and sulphur in both seasons.

Table 5 : Phosphorus content (%) in straw and grains of wheat as affected by nitrogen and sulphur applications in the two season

Nitrogen Levels (Kg ha^{-1})	Sulphur levels (Kg ha^{-1})							
	0	500	1000	mean	0	500	1000	mean
	Straw				Grains			
First season								
0	0.08	0.08	0.08	0.08	0.16	0.16	0.17	0.16
100	0.08	0.08	0.09	0.08	0.16	0.17	0.18	0.17
200	0.08	0.09	0.10	0.09	0.16	0.18	0.18	0.17
300	0.08	0.11	0.12	0.10	0.17	0.19	0.19	0.18
mean	0.08	0.09	0.10		0.16	0.18	0.18	
Second season								
0	0.06	0.06	0.07	0.06	0.19	0.19	0.20	0.19
100	0 06	0.07	0.07	0.07	0.19	0.20	0.21	0.20
200	0.07	0.08	0.08	0.08	0.20	0.21	0.21	0.21
300	0.09	0.09	0.09	0.09	0.21	0.21	0.22	0.21
mean	0.07	0.08	0.08		0.20	0.20	0.21	

	First season		Second season	
LSD (p = 0.05) :	Straw	Grains	Straw	Grains
Nitrogen effect :	0.017	0.013	0.013	0.011
Sulphur effect :	0.015	0.012	0.011	0.010
Interaction :	0.030	0.023	0.022	0.020

Regarding the effect of nitrogen and sulphur applications on K content of straw and grains of wheat in both seasons, results in Table 6 indicate that K contents in straw and grains were increased as nitrogen and sulphur application levels were increased, and the effect was particularly significant with the highest nitrogen and sulphur levels. These results are in good agreement with those obtained by El–Gala *et al.* (1989); Faiyad *et al.* (1991); El–Maghraby *et al.* (1996); El–Fakhrani and Abdel Magid,(1997) and El–Fakhrani (2001) who reported that application of nitrogen and sulphur increased K content in plants. With respect to K content as functions of nitrogen and sulphur interaction, the obtained results in Table 6 indicate that there were significant interactions between nitrogen and sulphur at the highest levels on the K content.

Nutrient uptake

The results presented in Tables 7, 8 and 9 show the effect of nitrogen and sulphur applications on the uptake of N, P and K by straw and grains of wheat during both seasons. Uptake of N and P by grains was higher than that of straw. Conversely, uptake of K in straw was greater than that in grains. This may be attributed to the increase in N and P contents of grains and in K content of straw (Tables 4, 5 and 6). The results obtained indicate that there were significant increases in N, P and K uptake by straw and grains in both seasons caused by nitrogen and sulphur applications. This is in line with the results obtained for straw and grain yields and NPK contents (Tables 3, 4, 5 and 6).Moreover, the combination of nitrogen fertilizer with elemental sulphur resulted in significant increases in N, P and K uptake by straw and grains as compared to the application of nitrogen fertilizer and elemental sulphur alone.

Table 6 : Potassium content (%) in straw and grains of wheat as affected by nitrogen and sulphur applications in the two seasons.

Nitrogen Levels (Kg ha^{-1})	Sulphur levels (Kg ha^{-1})							
	0	500	1000	mean	0	500	1000	mean
	Straw				Grains			
First season								
0	0.81	0.85	0.92	0.86	0.26	0.27	0.30	0.28
100	0.92	0.99	1.00	0.97	0.26	0.28	0.31	0.28
200	1.06	1.06	1.07	1.06	0.28	0.28	0.32	0.29
300	1.07	1.12	1.18	1.12	0.28	0.29	0.35	0.31
mean	0.97	1.01	1.04		0.27	0.28	0.32	
Second season								
0	0.74	0.76	0.78	0.76	0.25	0.25	0.26	0.25
100	0.86	0.94	0.96	0.92	0.26	0.27	0.28	0.27
200	0.95	0.95	0.97	0.96	0.27	0.27	0.28	0.27
300	1.01	1.03	1.04	1.03	0.28	0.30	0.31	0.30
mean	0.89	0.92	0.94		0.27	0.27	0.28	

	First season		Second season	
LSD (p = 0.05) :	Straw	Grains	Straw	Grains
Nitrogen effect :	0.13	0.04	0.13	0.02
Sulphur effect :	0.11	0.03	0.11	0.02
Interaction :	0.23	0.06	0.22	0.03

Table 7 : Nitrogen uptake (Kg ha^{-1}) by straw and grains of wheat affected by nitrogen and sulphur applications in the two seasons.

Nitrogen Levels (Kg ha^{-1})	Sulphur levels (Kg ha^{-1})							
	0	500	1000	mean	0	500	1000	mean
	Straw				Grains			
First season								
0	17.4	25.2	31.7	24.8	105	113	116	111
100	24.8	41.9	47.0	37.9	126	142	159	142
200	29.0	49.8	56.9	45.2	146	162	186	165
300	30.4	51.0	60.2	47.2	143	185	213	180
mean	25.4	42.0	49.0		130	151	169	
Second season								
0	33.9	38.2	45.6	39.2	116	153	182	150
100	41.2	47.1	58.9	49.1	146	198	211	185
200	48.1	53.2	62.4	54.6	167	209	223	200
300	55.3	57.4	60.5	57.7	165	218	265	218
mean	44.6	49.0	56.9		149	195	220	

	First season		Second season	
LSD (p = 0.05) :	Straw	Grains	Straw	Grains
Nitrogen effect :	13.1	26	7.6	44
Sulphur effect :	11.4	22	6.6	38
Interaction :	22.7	45	13.1	76

Table 8 : Phosphorus uptake (Kg ha^{-1}) by straw and grains of wheat as affected by nitrogen and sulphur applications in the two seasons.

Nitrogen Levels (Kg ha^{-1})	Sulphur levels (Kg ha^{-1})							
	0	500	1000	mean	0	500	1000	mean
	Straw				Grains			
First season								
0	3.47	3.84	3.96	3.76	7.22	7.64	7.98	7.61
100	4.01	4.54	5.21	4.59	7 83	9.02	9.39	8.75
200	4.51	5.55	6.37	5.48	9.31	10.5	10.8	10.2
300	4.63	6.64	7.73	6.33	9.11	10.9	11.5	10.5
mean	4.16	5.14	5.82		8.37	9.52	9.92	
Second season								
0	2.94	3.23	3.57	3.25	9.13	9.39	10.1	9.54
100	3.07	3.77	4.04	3.63	10.2	11.3	12.1	11.2
200	3.75	4.68	5.03	4.49	11.0	12.0	12.6	11.9
300	4.62	5.09	4.95	4.89	10.8	11.5	12.2	11.5
mean	3.60	4.19	4.40		10.3	11.1	11.8	

	First season		Second season	
LSD (p = 0.05) :	Straw	Grains	Straw	Grains
Nitrogen effect :	1.18	1.02	0.80	1.36
Sulphur effect :	1.03	0.88	0.69	1.18
Interaction :	2.05	1.76	1.39	2.35

Table 9 : Potassium uptake (Kg ha^{-1}) by straw and grains of wheat as affected by nitrogen and sulphur applications in the two seasons.

Nitrogen Levels (Kg ha^{-1})	Sulphur levels (Kg ha^{-1})							
	0	500	1000	mean	0	500	1000	mean
	Straw				Grains			
First season								
0	37.2	41.4	45.1	41.2	11.8	12.7	14.3	12.9
100	48.4	54.0	56.1	52.8	13.0	14.4	16.5	14.6
200	62.9	65.4	68.7	65.7	15.9	16.6	19.6	17.4
300	60.6	66.3	74.0	67.0	14.8	16.5	21.3	17.5
mean	52.3	56.8	61.0		13.9	15.1	17.9	
Second season								
0	36.1	38.1	39.5	37.9	12.0	12.5	13.3	12.6
100	47.6	53.0	55.3	52.0	13.6	15.1	16.1	14.9
200	53.9	55.9	58.5	56.1	14.9	15.4	16.4	15.6
300	53.9	56.2	59.4	56.5	14.6	16.4	17.7	16.2
mean	47.9	50.8	53.2		13.8	14.9	15.9	

	First season		Second season	
LSD (p = 0.05) :	Straw	Grains	Straw	Grains
Nitrogen effect :	10.0	2.6	7.2	2.0
Sulphur effect :	8.7	2.3	6.2	1.7
Interaction :	17.4	4.5	12.5	3.4

This shows that application of elemental sulphur promoted the uptake of N, P and K by wheat. These findings are in conformity with those reported by other investigators using various plant species (Ibrahim *et al.*,1987; El–

Gala *et al.*,1989; El–Maghraby *et al.*,1996 and El–Fakhrani,1996,1999 and 2001) who stated that application of nitrogen fertilizer and elemental sulphur caused increases in N, P and K uptake by plants. The favourable effects of sulphur may be due to increasing availability of nutrients (Table 12).

Protein content of grains

The results presented in Table 10 indicate that the protein content of wheat grains in both seasons increased significantly with increasing level of both N and sulphur applied as compared to the control. The increase is more pronounced at 300 Kg N and 1000 Kg sulphur ha^{-1} as compared with other nitrogen and sulphur levels. These results are in conformity with those obtained by El–Fakhrani (2000). The combination of nitrogen fertilizer and elemental sulphur resulted in a significant increase in protein content of wheat grains as compared to application of nitrogen fertilizer and elemental sulphur alone. This reflects the improvement effect of sulphur on the protein content in wheat grains. The results obtained show also that the addition of nitrogen fertilizer at the highest level (300 Kg N ha-1) in combination with elemental sulphur at the highest level (1000 Kg ha^{-1}) gave higher protein content in wheat grains than nitrogen fertilizer and elemental sulphur alone in both seasons (Table 10). The protein content of wheat grains was significantly correlated with the nitrogen content in grains (Figure 1) since protein content is equal nitrogen content x 6.25 (Abdel Magid,1992).

Table 10 : Protein content (%) in wheat grains as affected by nitrogen and sulphur applications in the two seasons.

Nitrogen Levels (Kg N ha^{-1})	Sulphur levels (Kg ha^{-1})							
	0	500	1000	mean	0	500	1000	mean
	First season				Second season			
0	14.2	15.1	15.3	14.9	15.0	19.5	22.6	19.0
100	15.7	17.1	18.8	17.2	17.3	21.9	23.1	20.8
200	15.8	17.0	18.9	17.2	18.9	22.7	23.6	21.7
300	16.6	20.1	22.0	19.6	19.8	25.1	29.4	24.8
mean	15.6	17.3	18.8		17.8	22.3	24.7	

LSD (p = 0.05) :	First season	Second season
Nitrogen effect :	2.2	4.1
Sulphur effect :	1.9	3.6
Interaction :	3.8	7.1

Soil reaction and soil salinity

The effect of nitrogen and sulphur applications on the pH and electrical conductivity (ECe) of the experimental soil after wheat harvest in the two seasons is shown in Table 11. Soil pH values in the second season were lower than that in the first season. This may be attributed to the residual effect of sulphur at the second season. Conversely, ECe values in the second season were higher than that in the first season. This may be due to the continuous salt accumulation in soil. The results presented in Table 11 demonstrate that soil pH values were significantly decreased with increasing sulphur application rates as compared with control in the two seasons.

Table 11 : Soil pH and ECe (dS m^{-1}) after harvest of wheat In the two seasons.

Nitrogen Levels (Kg ha^{-1})	Sulphur levels (Kg ha^{-1})							
	0	500	1000	mean	0	500	1000	mean
	pH				ECe			
First season								
0	8.06	7.85	7.76	7.89	1.33	1.58	2.11	1.67
100	8.01	7.80	7.75	7.65	1.42	1.63	2.16	1.74
200	7.97	7.79	7.73	7.83	1.45	1.85	2.35	1.88
300	7.93	7.74	7.68	7.78	1.64	1.92	2.47	2.01
mean	7.99	7.80	7.73		1.46	1.75	2.27	
Second season								
0	7.95	7.53	7.24	7.57	1.43	1.68	2.14	1.75
100	7.90	7.51	7.17	7.53	1.55	1.82	2.33	1.90
200	7.73	7.42	7.12	7.42	1.62	1.95	2.60	2.06
300	7.55	7.30	7.06	7.30	1.78	2.12	2.89	2.26
mean	7.78	7.44	7.15		1.60	1.89	2.49	

LSD (p = 0.05) :	First season pH	First season ECe	Second season pH	Second season ECe
Nitrogen effect :	0.19	0.43	0.35	0.47
Sulphur effect :	0.17	0.37	0.30	0.41
Interaction :	0.33	0.76	0.61	0.81

Similar results were obtained by Shahin *et al.*,1999 and El–Fakhrani (2001) who reported that application of elemental sulphur to the soil decreased the soil pH. On the other hand, Table 11 show significant increases in ECe values due to the sulphur application rate at 1000 Kg ha^{-1} in *the two seasons. These findings are in agreement with those reported* by Mostafa *et al.*,(1990); El–Fakhrani(1995,1996 and 2001) and Shahin *et al.*,(1999). The increase in salinity could be rendered to the oxidation of sulphur into sulphates which may be confirmed by the significant increase in soluble sulphate ion ($SO_4^{=}$) in all the investigated treatments (Shahin *et al.*,1999). The results indicate also that the soil pH values were decreased with increasing nitrogen application rates. while the ECe values were increased as a result of increasing nitrogen level as compared with control in the two seasons. However most differences were did not reach the level of significance. These results are in conformity *with those obtained by Feigin* (1985) who reported that excessive application of nitrogen fertilizers may result in a salinity buildup in the soil due to their high solubility and osmotic effect. Moreover, El–Fakhrani (1999) found that the addition of nitrogen *fertilizer as urea decreased* the soil pH values, while ECe values increased . Concerning the interaction effect between nitrogen and sulphur application rates on ECe and soil pH values, the obtained results (Table 11) reveal that there are significant interactions between nitrogen and sulphur at the highest levels in decreasing soil pH and increasing ECe values.

Available macronutrients

The results presented in Table 12 show the effect of nitrogen and sulphur application rates on the available soil N, P and K at harvest stage of wheat plants in the two growing seasons. It is evident that available soil N in the first season was more higher than that in the second season. This may be attributed to the increases in N content and uptake of straw and grains in the second season (Tables 4 and 7). In addition, Table 12 indicates that available soil N was significantly increased with increasing N application rate from 0 to 300 Kg N ha^{-1} in the first season and at 300 Kg N ha^{-1} in the second season as compared to the control. These results are in good agreement with those obtained by El-Sherbieny *et al.*, (1989) and El-Fakhrani (1999) who reported that application of urea fertilizer to soil led to raising the available soil N in the soil. Table 12 reveals also that available soil N was significantly increased with increasing sulphur application level as compared to the control in the two sesons. These findings are in conformity with those obtained by Shahin *et al.*, (1999) and El-Fakhrani (2001) who found that application of elemental sulphur promoted availability of soil N. Combination of nitrogen fertilizer with sulphur resulted in a significant increase in available soil N as compared to the application of nitrogen fertilizer or sulphur alone. This indicates that sulphur must have promoted utilization efficiency of nitrogen fertilizer in sandy soils. Concerning the effect of nitrogen and sulphur application rates on the availability of soil P, Table 12 indicates that available soil P was significantly increased with increasing nitrogen and sulphur application rates as compared to the control in the two sesons. These results are in good agreement with those obtained by other investigators (Abdel-Aziz *et al.*,1996; El-Maghraby *et al.*,1996 and El-Fakhrani,2001). Combination of nitrogen fertilizer with sulphur resulted in a significant increase in available soil P as compared to the application of nitrogen fertilizer alone. This may be due to increasing the solubility of P in soil as a result of reducing soil pH (Table 11). The results presented in Table 12 show the effect of nitrogen and sulphur application rates on the availability of soil K. It is evident that available soil K in the second season was greater than that in the first season. This may be due to an increase in K content and uptake of straw and grains in the first season (Tables 6 and 9). Generally, available soil K was increased with increasing nitrogen and sulphur application rates as compared to the control. Available soil K was significantly increased at highest levels of nitrogen fertilizer (200 and 300 Kg N ha^{-1}) with sulphur at the rates of 500 and 1000 Kg ha^{-1} as compared to the other treatments in the two seasons. These results are in harmony with those obtained by El-Fakhrani, with sugar beet (2001) who reported that available K in soil increased as a result of application of elemental sulphur .

Table 12 : Available N, P and K (mg Kg^{-1}) in the experimental soil after harvest of wheat in the two seasons.

Nitrogen Levels (Kg ha^{-1})	Sulphur levels (Kg ha^{-1})											
	0	500	1000	mean	0	500	1000	mean	0	500	1000	mean
	N				P				K			
First season												
0	41.3	52.4	64.7	52.8	17.3	23.1	26.5	22.3	67	87	87	80
100	62.7	79.5	84.3	75.5	17.9	25.8	27.3	23.7	68	90	93	83
200	66.1	85.9	92.4	81.5	18.1	31.4	31.8	27.1	70	92	100	87
300	77.5	86.7	98.0	87.4	23.8	31.8	32.2	29.3	81	97	100	93
mean	61.9	76.1	84.9		19.3	29.0	29.5		72	91	95	
Second season												
0	4.8	7.8	7.9	6.9	16.0	18.1	27.7	20.6	120	121	117	119
100	5.2	9.1	9.5	8.0	21.7	26.7	29.1	25.8	129	129	127	128
200	6.5	9.8	9.9	8 7	25.1	30.4	31.4	29.0	131	134	131	132
300	9.3	11.6	12.1	11.0	29.5	32.0	35.5	32.3	140	139	139	139
mean	6.5	9.6	9.9		23.1	26.8	30.9		130	131	129	

First season	N	P	K	Second season N	P	K
LSD (p = 0.05) :	N	P	K	N	P	K
Nitrogen effect :	15.4	6.2	14	2.2	4.5	9
Sulphur effect :	13.4	5.4	12	1.9	3.9	8
Interaction :	26.7	10.7	25	3.8	7.9	15

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تأثير الكبريت على كفاءة الاستفادة من النيتروجين بواسطة القمح فـــي الأراضـــي الرملية بالمملكة العربية السعودية

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أجريت تجربتان حقليتان خـــلال شـــتاء موســمي ٢٠٠٠ – ٢٠٠١ و ٢٠٠١ – ٢٠٠٢ لاختبار تأثير الكبريت عند معدلات صفر ، ٥٠٠ و ١٠٠٠ كجم / هكتـــار علـــى كفاءة الاستفادة من اليوريا عند معدلات صفر ، ١٠٠ ، ٢٠٠ و٣٠٠ كجـــم نيـــتروجين / هكتار بواسطة القمح النامي على الاراضي الرملية باستخدام نظام الـــري بـــالرش تحـــت الظروف الجافة في المنطقة الوسطى (منطقة القصيم) من المملكة العربية السعودية.
أوضحت النتائج أن محصول القش والحبوب للقمح ازداد زيادة معنوية مع زيادة التســـميد النيتروجيني ، وقد ازداد بدرجة أعلى عند إضافة السماد النيتروجيني مع الكبريت بالمقارنة مع إضافة السماد النيتروجيني منفردا . وتشير النتائج إن المســـتوى الاقتصـــادي الأمثـــل للسماد النيتروجيني مع إضافة الكبريت بمعدل ٥٠٠ أو ١٠٠٠ كجم / هكتـــار كـــان ٢٠٠ كجم نيتروجين / هكتار . وأوضحت النتائج أن محتوى البروتين في حبوب القمـــح ازداد زيادة معنوية مع زيادة معدلات النيتروجين والكبريت عند إضافتهما في حالـــة منفـــردة أو مجتمعة معا ، وقد ارتبط بروتين الحبوب ارتباطا معنويـــا بمحتـــوى النيـــتروجين فـــي الحبوب.ولقد أظهرت النتائج أن امتصاص عناصر النيتروجين ، الفوســـفور والبوتاســـيوم بواسطة القش والحبوب ازدادت زيادة معنوية مع زيادة معدلات النيتروجين والكبريت عنـــد إضافتهما في حالة منفردة أو مجتمعة معا .
ازدادت ملوحة التربة (ECe) معنويا عند إضافة النيتروجين بمعدل ٣٠٠ كجـــم نيتروجين / هكتار والكبريت بمعدل ١٠٠٠ كجم / هكتار ، بينما رقم pH التربة انخفـــض معنويا . وأظهرت النتائج أيضا أن النيتروجين والفوسفور الميسر في التربة بعد الحصـــاد ازداد زيادة معنوية مع زيادة معدلات إضافة النيتروجين والكبريت في الموسمين ، بينمـــا البوتاسيوم الميسر في التربة ازداد معنويا مع زيادة مستويات الكبريت في الموســـم الأول ومع النيتروجين عند معدلات ٢٠٠ و٣٠٠ كجم نيتروجين / هكتار في الموســـم الثـــاني .
ومن النتائج المتحصل عليها يمكن استنتاج أن إضافة الكبريت يعزز كفاءة الاســـتفادة مـــن السماد النيتروجيني مثل اليوريا تحت ظروف البيئة الجافة .