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Full Length Research Paper

Growth and nutrient uptake of maize plants as affected by elemental sulfur and nitrogen fertilizer in sandy calcareous soil

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This study was carried out to investigate the effect of elemental sulfur (S^0) combined with or without N fertilizer on the growth and nutrient uptake such as nitrogen (N), phosphorus (P), sulfur (S), iron (Fe), zinc (Zn) and manganese (Mn) by maize plants grown in sandy calcareous soils. Elemental S at rates of 0, 1, 5 and 10 t ha^{-1} were tested combined with or without N fertilizer at rates of 0 and 0.34 t ha^{-1} in pots using normal irrigation water (pH >7.5) under Al Zaid and Al Semaih soils in evaporative cooled greenhouse conditions. Electrical conductivity (EC) increased (2.50 to 2.95 dSm^{-1}) significantly and decreased (5.07 to 6.06 dSm^{-1}) with application of S^0 at rates of 5 and 10 t ha^{-1} combined with N fertilizer in both Al Zaid and Al Semaih soils, respectively. Soil acidity improved by decreasing soil pH (1.41 to1.52 unit) with application of S^0 at the rate of 10 t ha^{-1} combined with N fertilizer. Addition of S^0 at the rate of 5 t ha^{-1} combined with N fertilizer recorded superior total dry matter (TDM) and maximum uptake of all nutrients in both soils. Total dry matter accumulation and nutrient uptake had positive correlation, while soil pH showed negative correlation with TDM and uptake of all nutrients. Based on experimental findings, S^0 at the rate of 5 t ha^{-1} combined with N fertilizer is suitable for growth of maize in both soils. Collectively, the results indicate that Al Zaid soil is more favorable due to higher nutrient uptake and growth of maize than Al Semaih soil.

Key words: Elemental sulfur, nutrient uptake, maize, sandy calcareous soil.

INTRODUCTION

Most of the agricultural soils in United Arab Emirates (UAE) contain relatively high amounts of calcium trioxocarbonate (IV) $CaCO_3$ and extremely poor organic matter content with high pH value that showed marked influence on the nutrient availability for plant growth (Abdou, 2006). Numerous soil factors affect plant nutrient uptake from soil. Among them, high pH and $CaCO_3$ levels are predominantly responsible for low availability of plant nutrients (Kaya et al., 2009). Soil pH has an important role in the loss of N and or fixation of most nutrients and therefore different nutrient management practices are required for crop production in calcareous and non-calcareous soils. Calcareous soil has high $CaCO_3$ and alkaline pH that greatly reduce the solubility of Fe, Zn, Mn and Cu, thus characterized as deficient in these micro nutrients. Nitrogen, phosphorus (P) and potassium (K) are frequently the most limiting nutrients for plant growth in numerous ecosystems (Olivera et al., 2004). Intensive cropping systems requires important amounts of N, P, K and S fertilizers and among these N fertilizer plays significant role. Sulfur is accumulated in plants in low concentrations compared to N, but is an essential element as a constituent of proteins, cysteine-containing peptides such as glutathione, or numerous secondary metabolites (Scherer et al., 2008; Abdallah et al., 2010). Nitrogen and S are both involved in protein synthesis and

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play an important role in the protection of plants against nutrient stress and pests and synthesis of vitamins and chlorophyll in the cell (Kacar and Katkat, 2007).

Crop deficiencies of S have been reported with increasing frequency in the last decade, caused by decreasing anthropogenic S input and by the lack of input through S fertilization to compensate for exportation (Scherer, 2001). The severity of S deficiency is aggravated by higher rates of N application. Plants grown without N fertilizer showed no apparent S stress, whereas plant receiving N fertilizer particularly at higher rate without S, showed symptoms suggesting severe physiological disorder in N nutrition (Kopriva and Rennenberg, 2004). Increased application of N fertilizer increases S response thus leading to a reduction of protein-N and an increase in nitrate-N and other non-protein N fractions which may adversely affect crop quality (Jackson, 2000). Corn as an oilseed crop is highly responsive to S; making corn an ideal crop for S application in the forms of S^0 and ammonium sulfate or urea, especially in alkaline and calcareous soils (Ghosh et al., 2000). Sulfur fertilization is relatively inexpensive and its use leads to substantial benefits of yield and quality of crops.

The presence of $CaCO_3$ in soils also directly or indirectly affects the availability of N, P, Mg, and K (Brady and Weil, 2002). The biochemical oxidation of S^0 produces H_2SO_4 which decreases soil pH and solubilizes $CaCO_3$ in alkaline calcareous soils to make soil conditions more favorable for plants growth including the availability of plant nutrients (Abdou, 2006; El-Tarabily et al., 2006). Little is known about uptake pattern and metabolism of the S fertilizers applied to the soil regarding metabolic need for plant growth and in relation to the uptake of other nutrients. The interaction of nutrients is of great importance because decline of S supply from the atmosphere has already caused substantial losses of N from agro-ecosystems to the environment (Luit et al., 1999). Therefore, a strong focus on reducing N loads to arid environments and the interaction between N and S metabolism needs more clarification with view to improve environmentally friendly fertilizing techniques. Intensive and excessive use of chemical fertilizer may create environmental hazard and natural imbalance. Optimum fertilization is crucial to assess nutrient status of crop and soil to avoid alarming use of chemical fertilizer. The productivity and growth of plant is directly related with sulfur uptake and assimilation. In addition S plays significant role to the acquisition of N (Malagoli, 1999).

Based on these observations, sufficient supply of S is required to maintain the optimum growth and nutrient uptake ability of plants. For this purpose, the use of S fertilizer is gaining importance because besides the inhibitory actions on N, it contains high S concentration. Substantial information on N and S nutrition of plant is available (Fismes et al., 2000) but the data related to both N and S interaction with irrigation water are still insufficient, especially for maize cultivation in sandy calcareous soils of UAE. Accounting for the above observations, this research was undertaken to investigate the impact of S^0 fertilization combined with N fertilizer on the growth and nutrient uptake of maize grown in sandy calcareous soil with normal irrigation water.

MATERIALS AND METHODS

Greenhouse experiments were conducted at Al-Foah Agricultural Experiment Station (27°N and 22°S latitude and 51°W and 57°E longitude), UAE University in 2005. Elemental S at rates of 0, 1, 5 and 10 t ha^{-1} were tested combined with or without N fertilizer at rates of 0 and 0.34 t ha^{-1} in pots under evaporative cooled greenhouse conditions. The treatment arrangements were as follows: S 0 + N 0 (control), S 0 + N 0.34 t ha^{-1}, S 1 t ha^{-1} + N 0, S 1 t ha^{-1} + N 0.34 t ha^{-1}, S 5 t ha^{-1} + N 0, S 5 t ha^{-1} + N 0.34 t ha^{-1}, S 10 t ha^{-1} + N 0 and S 10 t ha^{-1} + N 0.34 t ha^{-1}. The experiment was laid out in a factorial completely randomized design with three replications. With same set of treatments, two experiments were carried out simultaneously using each with normal irrigated water in Al Zaid and Al Semaih soils. Sandy calcareous soil was collected from the areas of Al Zaid and Al Semaih in Abu Dhabi, UAE. A proportion of soil was separated and sieved through 1-mm stainless steel sieve and stored in plastic bags for physicochemical analysis.

Soil pH was determined from the prepared soil suspension (1:2.5 soil water ratios) by using combined pH meter model 900A (Thermo Orion, Ontario, Canada) (Thomas, 1996). Electrical conductivity was measured by the saturation extracts of soil samples using Orion model 120 microprocessor conductivity meters (Thermo Scientific, USA). Water soluble cations (Ca, Mg, Na, and K) and anions (Cl, HCO_3, CO_3 and SO_4) were determined as per the methods recommended in Page et al. (1982). Physicochemical properties of the soil are presented in Table 1. After harvesting maize plants, soil samples were also collected from each pot to determine Na, K, Cl, EC and pH. The analytical results are presented in Table 2.

Soils were air-dried before being used in the experimental pots. Free-draining polyethylene pots (height 25 cm x diameter 23 cm) were filled with 5 kg of sandy calcareous soil. Each pot was initially filled with 3.8 kg of soil. Prior to sowing each pot received extra 1.2 kg of soil mixed with P and K at the rates of 3.3 and 1.1 g pot^{-1} in the forms of single super-phosphate and potassium sulfate, respectively. Elemental S powder (particle size<150 µM) was collected from TAKREER Company, Abu Dhabi, UAE and applied as per treatment schedule. According to treatment schedule N was applied at rates of 1.49 g per pot (~0.34 t ha^{-1}) at 10 and 17 days after germination (DAG) on the soil surface and irrigated by normal water, respectively. Ten corn seeds [cv. Merit (Asgrow vegetable seeds, CA, USA)] were sown per pot at a depth of 5 mm into the soil. The pots were saturated with normal irrigation water up to field capacity for proper germination and growth of maize plants. After emergence all seedlings were kept until final harvest. Maize plants were selected at random and harvested after 35 DAG for nutrient analysis and total dry matter accumulation. Roots and shoots were washed in deionized water and oven dried at 72°C for 48 h and grounded to powder in a ball mill. The plant samples were then digested by the dry ashing method (Jones and Case, 1990) for the determination of total content of micronutrients (Fe, Mn and Zn) using atomic absorption spectrophotometer (Varian, model Spectra AA 220 FS). Sulfur content was measured using ICP-AES, Varain model Vista MPX. Phosphorus was determined colorimetrically according to the method described by Kuo (1996). The N concentration was measured by automatic distillation (FOSS, 2200 Kjeltic Auto Distillation) followed by acid titration (Munsinger and McKinney, 1982).

Table 1. Physicochemical properties of Al Zaid and Al Semaih soils.

Soil property	Al Zaid soil	AL Semaih soil
EC (d Sm^{-1})	3.36	18.27
pH	9.08	9.01
Total $CaCO_3$ (%)	38.98	68.17
Active $CaCO_3$ (%)	3.50	12.50
O.C. (%)	0.17	0.14
Texture		
Sand (%)	95.00	99.73
Silt + clay (%)	5.00	0.27
Soluble cations (meq L^{-1})		
Ca	1.60	28.60
Mg	1.40	12.60
Na	28.70	171.10
K	0.34	2.86
Soluble anions (meq L^{-1})		
Cl	33.00	169.00
SO_4	3.40	25.18
HCO_3	2.90	1.40
CO_3	1.00	0.00

Table 2. Chemical properties of soil as affected by S^0 and N fertilizer after harvesting of maize plants.

Treatment	EC (dSm^{-1})	pH	Na (cmol L^{-1})	K (cmol L^{-1})	Cl (cmol L^{-1})
Al Zaid soil					
S0N0	3.87	8.35	30.85	0.69	126.0
S0N*1	4.72	7.93	29.31	1.05	86.00
S1N0	4.74	7.95	24.02	1.62	76.00
S1N1	4.81	7.76	28.57	1.74	72.00
S5**N0	4.90	7.84	22.54	1.88	66.00
S5N1	5.89	7.64	23.97	2.05	56.00
S10***N0	5.76	7.66	18.99	1.91	70.00
S10N1	6.31	7.56	26.51	2.40	69.00
LSD (0.05)	0.42	0.14	3.65	0.40	12.5
Al Semaih soil					
S0N0	17.59	8.15	132.93	6.00	368.00
S0N1	17.31	8.12	134.97	6.39	363.00
S1[†]N0	16.17	7.96	146.23	5.42	456.00
S1N1	14.60	7.96	113.77	5.60	333.00
S5[††]N0	14.36	7.75	84.67	4.98	291.00
S5N1	13.30	7.74	106.83	6.35	341.00
S10[†††]N0	13.33	7.71	92.30	5.18	425.00
S10N1	12.21	7.60	140.07	6.54	328.00
LSD (0.05)	1.08	0.15	8.50	0.35	25.7

*N1 = N fertilizer 0.34 t ha^{-1}, [†]S1 = S fertilizer 1 t ha^{-1}, [††]S5 = S fertilizer 5 t ha^{-1}, [†††]S10 = S fertilizer 10 t ha^{-1}.

Statistical analysis was carried out by one-way ANOVA using general linear model to evaluate significant differences between means at 95% level of confidence (SAS, 2003). Further statistical validity of the differences among treatment means was estimated using the least significant differences (LSD) comparison method. MS Excel was used for regression analysis and graphical presentations.

RESULTS

Initial Na concentration was 28.7 and 171.1 (cmol L^{-1}) in Al Zaid and Al Semaih soils, respectively (Table 1). Na concentration decreased significantly with application of S^0 combined with N fertilizer in both soils. Significant reduction rate (18.99 and 22.54 cmol L^{-1}) was observed with the application of S^0 at rates of 5 and 10 t ha^{-1} in absence of N fertilizer in both soils, but slightly higher concentration of Na was observed in Al Zaid soil when neither S^0 nor N fertilizer was applied (Table 2). The reduction rate was noticeably higher in Al Semaih soil than Al Zaid soil. Potassium and chloride content in soil enriched significantly with application of S^0 and N fertilizer in both soils. The enrichment of K and Cl in soil was directly related with higher levels of S^0 and N application in both soils. The rate of enrichment was significantly higher in Al Semaih soil than Al Zaid soil (Table 2).

In Al Zaid soil, initial EC was 3.36 d Sm^{-1} (Table 1) and increased significantly with application of S^0 combined with N fertilizer (Table 2). Maximum EC was obtained from S^0 at the rate of 5 t ha^{-1} combined with N fertilizer and S^0 at the rate of 10 t ha^{-1} combined with N or without N fertilizer. The lowest EC was observed from control treatment. A significant change of EC was observed in Al Semaih soil. EC did not decline much with application of S^0 at the rate 1 t ha^{-1} combined with N fertilizer but drastically reduced with application of S^0 at rates of 5 and 10 t ha^{-1} combined with or without N fertilizer (Table 2). Soil pH changed significantly with application of S^0 and N fertilizer. In Al Zaid soil, pH decreased significantly by addition of S^0 at the rate 10 t ha^{-1} combined with N or without N fertilizer followed by S^0 at the rate of 5 t ha^{-1} combined with N fertilizer. Soil pH reduced significantly with application of S^0 at rates of 5 and 10 t ha^{-1} combined with or without N fertilizer (Table 2).

More also, N, P and S uptake by maize plant were influenced significantly with application of S^0 and N fertilizer. The highest N uptake was recorded with application of S^0 at the rate of 5 t ha^{-1} combined with N fertilizer in both soils, while the lowest N uptake was obtained from control treatment (Table 3). In Al Zaid soil, the highest and lowest uptake of P was obtained with application of S^0 at the rate of 5 t ha^{-1} combined with N fertilizer and control treatment, respectively. In Al Semaih soil, the highest and lowest uptake of P was obtained with application of S^0 at the rate of 10 t ha^{-1} combined with N fertilizer and control treatment, respectively (Table 3). Nitrogen and P uptake was appreciably higher in Al Zaid soil compared to Al Semaih soil. The highest and lowest uptake of S was recorded with application of S^0 at the rate of 10 t ha^{-1} combined with N fertilizer and control treatment in both soils, respectively. Intermediate uptake of S was obtained from S^0 at the rate of 5 t ha^{-1} combined with N in both soils (Table 3).

In addition, Fe, Zn and Mn uptake was affected significantly with application of S^0 and N fertilizer (Table 3). Significantly higher Fe uptake was recorded with application of S^0 at the rate of 5 t ha^{-1} combined with N fertilizer in both soils. The lowest uptake of Fe was obtained from control treatment in both soils. In Al Zaid soil, the highest uptake of Zn was recorded with application of S^0 at the rate of 5 t ha^{-1} combined with N fertilizer. Application of S^0 at rates of 1 and 10 t ha^{-1} combined with N obtained intermediate and identical Zn uptake (Table 3). In Al Semaih soil, the highest uptake of Zn uptake was obtained with application of S^0 at the rate of 10 t ha^{-1} combined with N fertilizer. The lowest uptake of Zn was recorded from control treatment. The highest uptake of Mn was recorded with application of S^0 at the rate of 5 t ha^{-1} combined with N fertilizer in both soils (Table 3). Minimum Mn uptake was obtained from control treatment. Fe and Zn uptake was higher in Al Zaid soil, while Mn uptake was higher in Al Semaih Soil. Dry matter accumulation was affected significantly with application of S^0 and N fertilizer (Figure 1). The highest dry matter accumulation was obtained with application of S^0 at the rate of 5 t ha^{-1} combined with N fertilizer in both soils, while the lowest dry matter was recorded from control treatment. Dry matter accumulation was therefore higher at Al Zaid soil than Al Semaih soil.

In Al Zaid soil, TDM accumulation showed strong positive correlations with N (r^2 = 0.84, P<0.01), Fe (r^2 = 0.87, P<0.01), P (r^2 = 0.84, P<0.01), S (r^2 = 0.82, P<0.01), Zn (r^2 = 0.96, P<0.01) and Mn (r^2 = 0.84, P<0.01). In Al Semaih soil, TDM accumulation showed strong positive correlations with N (r^2 = 0.87, P<0.01), P (r^2 = 0.92, P<0.01), S (r^2 = 0.91, P<0.01) and Fe (r^2 = 0. 95, P<0.01). A positive but weak correlation was observed between TDM accumulation with Zn (r^2 = 0.51, P<0.05) and Mn (r^2 = 0.62, P<0.05). EC showed a strong negative correlation with pH (r^2 = -0.91 to 0.96, P<0.01) in both soils. Soil pH showed negative correlations among nutrient and EC in both soils (Table 4). The inter-relationship among the nutrient was positive in both soils. Polynomial equation of 3rd order showed best fitted curve (R^2 = 0.69 to 0.82). The slopes of the equation indicated a TDM yield of 40 to 45 g for every 1.0 g of N uptake and 9 to15 g biomass yield for every 1.0 g of S uptake for both types of soils (Table 5). Regression analysis of TDM accumulation clearly indicated higher rate of S^0 application is required for maize growth in sandy calcareous soils of UAE.

DISCUSSION

Soil pH affected the availability of all nutrients; trace

Table 3. N, P, S, Fe, Zn and Mn uptake by maize plant as affected by S^0 and N fertilizer under normal irrigation water.

Treatment	Nutrient uptake ((mg g^{-1})					
	N	P	S	Fe	Zn	Mn
Al Zaid soil						
S0N0	5.65	5.70	4.75	0.01	0.06	0.06
S0N*1	28.22	7.99	6.39	0.86	0.08	0.66
S1†N0	7.03	9.38	8.21	0.01	0.08	0.10
S1N1	32.6	10.83	10.83	1.14	0.10	1.31
S5††N0	7.22	9.56	9.09	0.02	0.08	0.11
S5N1	34.19	14.67	12.71	1.63	0.12	1.43
S10†††N0	6.39	10.58	9.91	0.03	0.07	0.14
S10N1	26.44	14.12	13.85	1.56	0.10	1.01
LSD (0.05)	0.75	0.51	0.52	0.05	0.005	0.03
Al Semaih soil						
S0N0	5.40	6.29	5.38	0.04	0.04	0.07
S0N1	28.15	6.61	7.14	0.97	0.05	0.75
S1†N0	6.71	11.73	10.53	0.04	0.03	0.06
S1N1	28.15	12.21	11.56	0.84	0.05	1.56
S5††N0	7.14	12.72	12.42	0.04	0.03	0.20
S5N1	32.47	13.3	13.20	1.31	0.06	1.79
S10†††N0	6.42	12.93	13.07	0.03	0.03	0.12
S10N1	26.47	13.50	13.61	1.06	0.12	0.96
LSD (0.05)	0.50	0.30	0.35	0.02	0.004	0.04

*N1 = N fertilizer 0.34 t ha^{-1}, †S1 = S fertilizer 1 t ha^{-1}, ††S5 = S fertilizer 5 t ha^{-1}, †††S10 = S fertilizer 10 t ha^{-1}.

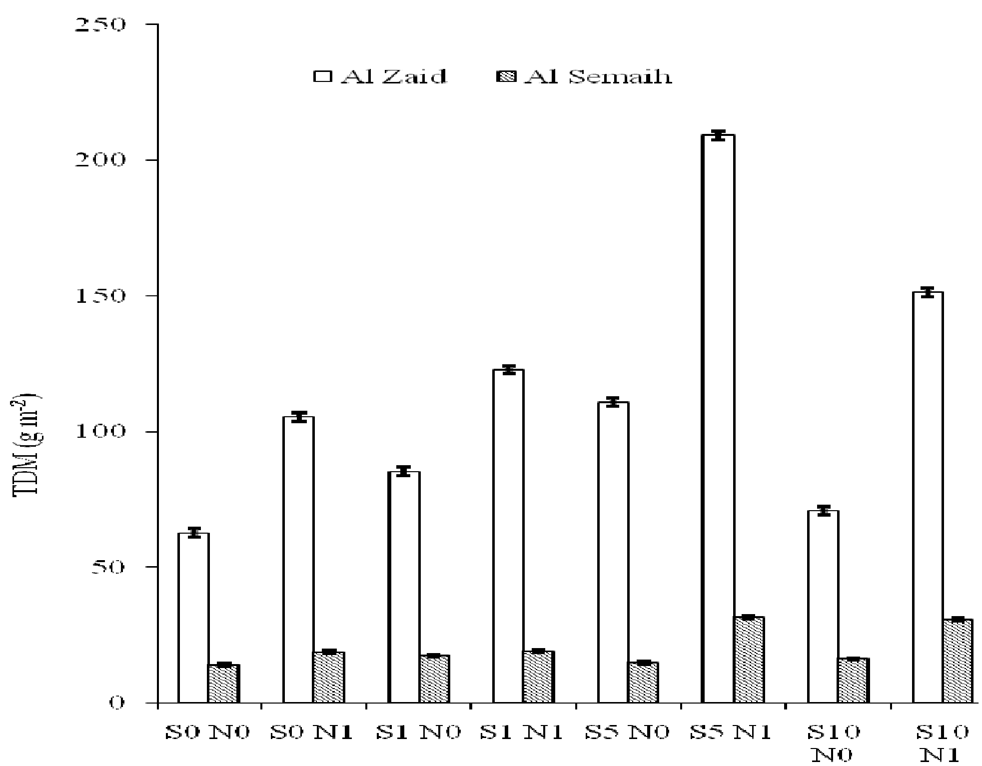

Figure 1. Total dry matter accumulation of corn as affected by elemental S, N and irrigation water. Error bars denotes LSD value at 0.05 level.

Table 4. Interrelationships among dry matter yield, EC, soil pH and nutrient uptake of N, P, S, Fe, Zn and Mn at Al Zaid and Al Semaih soil.

Parameter	EC	pH	N	P	S	Fe	Zn	Mn
Al Zaid soil								
TDM	0.62*	-0.63*	0.84**	0.84**	0.82**	0.87**	0.96**	0.84**
EC		-0.91**	0.91**	0.87**	0.59*	0.38	0.26	0.15
pH			-0.56*	-0.77*	-0.76*	-0.42	-0.02	-0.31
N				0.59*	0.57*	0.94**	0.83**	0.96**
P					0.99*	0.75*	0.87**	0.72*
S						0.72*	0.87**	0.72*
Fe							0.88**	0.95**
Zn								0.91**
Al Semaih soil								
TDM	0.49	-0.56*	0.87**	0.92**	0.91**	0.95**	0.51*	0.62*
EC		-0.96*	0.60*	0.35	0.39	0.39	0.66*	0.54*
pH			-0.72*	-0.87**	-0.79*	-0.58*	-0.04	-0.73*
N				0.69*	0.63*	0.96**	0.15	0.92**
P					0.99**	0.80**	0.14	0.36
S						0.77*	0.63*	0.36
Fe							0.43	0.78*
Zn								0.17

* Significant at 0.05 level of probability; ** significant at 0.01 level of probability.

Table 5. Regression equation and coefficients of determination (R^2) for relationship between dry matter yield and S^0 and N uptake at Al Zaid and Al Semaih soil.

Regression equation	R^2
Al Zaid soil	
$y = - 21.605 + 0.0403x_1$	0.7935
$y = - 0.3279 + 0.0099x_2$	0.6992
Al Semaih soil	
$y = - 4.9048 + 0.045x_1$	0.7485
$y = - 0.9475 + 0.0159x_2$	0.8224

y = Dry matter yield, x_1 = N, x_2 = S.

metals such as Fe, Zn and Mn are more available at lower pH than most nutrients. In this study, both pH and EC decreased significantly by addition of S^0 and N fertilizer. Soil pH reduced significantly as a result of application of S^0 alone and together with N increased the availability of micronutrients as well as plant dry matter yield. Acidifying effect leading to partial neutralization of $CaCO_3$ can be one of the most important factors for increased nutrient content (Kaya et al., 2009). Soil pH can be decreased during oxidation of S and thus, unavailable form of most nutrients can be changed to available form for plant uptake. The soil pH dropped from an initial value of 9.08 to 7.56 by addition of S^0 and N fertilizer. In the present study, soil pH decreased more than 1.0 unit and our findings were the same with that of Soliman et al. (1992) where a decrease of soil pH by 0.2, 0.5 and 0.9 units was reported as a result of increasing S applications.

In addition to supplying S^0 as a nutrient, S compounds are also used as soil amendments. These compounds act as soil acidifiers neutralizing $CaCO_3$ with acid, which in turn may lead to a lowering of soil pH and improved nutrient availability. The rates of soil acidifiers required to cause a plant response depend on the amount of $CaCO_3$ in the soil (El-Tarabily et al., 2006). Calcareous soils are alkaline because of the presence of $CaCO_3$ that dominates the physicochemical properties of the soil. Soil pH is the most important factor which can regulate Zn and Mn supply in calcareous soils. Low levels of soluble Zn are found in alkaline soils and a negligible amount can be exchangeable form (Zn^{2+}) for plants. Both Zn and Mn deficiencies are pH-dependent and their concentration in solution decreases 100-fold for each unit increase in pH (Brady and Weil, 2002).

Elemental S had a significant effect on dry matter content and the combined application of S^0 along with N significantly increased the dry matter content of maize plants. In sandy soil, combined application of P and S resulted in a significant increase in dry matter yield but due to lower rates of S application, P uptake was poor in wheat plant (Randhawa and Arora, 2000). In our study with higher levels of S^0 and N application, N uptake was comparatively higher (34.19 mg g^{-1}) than without S^0 (28.22 mg g^{-1}) application. Therefore S input is not only important with maize growth but also with regard to N utilization. Schung (1991) reported that under S-deficient soil, N utilized may be as low as 25%. Nitrogen uptake was therefore appreciably higher at Al Zaid soil compared to Al Semaih soil which resulted to higher accumulations of TDM. In Al Semaih soil, TDM accumulation was lower and consequently N uptake was quite poor by maize plant. Nitrogen uptake is closely correlated with dry matter yield which may reflect on nutrient uptake ability of N for maize growth. Significantly higher N uptake was obtained by interaction effect of S^0 and N compared to control and other treatment which did not receive N fertilizer. Thus, the combined effect of S^0 and N fertilizer showed significant effect of N uptake by maize plants. These results coincide with the findings of Haneklaus et al. (1999) who reported that higher N concentration of groundnut was observed in calcareous soil using S application compared with zero S. For an environmentally sustainable production of maize, a sufficient supply of S is essential in order to minimize nitrogen losses to the environment. Therefore, our results revealed that application of S^0 at the rate of 5 t ha^{-1} with N fertilizer is seemingly better for maize plants in calcareous soils.

In Al Semaih soil, P uptake and TDM accumulation in corn was poor. These results indicate that TDM yield and P uptake are closely correlated. Phosphorus uptake improved due to amendment of soil by addition of higher levels of S^0 and N fertilizer. Phosphorus uptake showed a strong positive correlation with S uptake under both types of soils. The higher rate of S^0 concentrated in a small volume of calcareous soil creates an acidic zone and increases the availability of P and micronutrients to roots growing zone (Obreza et al., 1993). Sulfur uptake was enhanced with application of S^0 and its interaction with N and had a strong positive effect on TDM accumulation. Application of higher levels of S^0 with N played significant role in respect of Mn uptake of maize plants. Manganese uptake was higher along with higher application of N which was most evident at higher S application rates (Kaya et al., 2009; Soliman et al., 1992). The results clearly showed that Zn and Mn uptake increased significantly by corn plants when grown with moderate levels of S^0 with N, whereas zero S^0 and N recorded poor uptake of Mn. These results coincide with the findings of Kayser et al. (2001) who reported that higher application of S^0 markedly increased Zn uptake by *Helianthus annuus* grown in calcareous soil. Application of S^0 increased Zn solubility due to soil amendment and Zn concentration in sunflower and peanut plants significantly improved in calcareous soil (Kayser et al., 2001). Kaplan and Orman (1998) also reported that application of S^0 at the rate of 2 t ha^{-1} increased Mn and Zn content in the shoots of sorghum plants under calcareous soils in Turkey.

Total dry matter showed profound influence on nutrients uptake with application of S^0 and N fertilizer. Similar results were obtained by Varin et al. (2010) who reported that application of sulfate increased whole plant dry mass, root length and nodule biomass in white clover. Besharati and Rastin (1999) also reported that S application had significant effects on root and shoot dry matter of maize grown in calcareous soils under green-house conditions. Total dry matter was not affected by low concentration of sulfate but affected when by the complete absence of S (Koralewska et al., 2007). The oxidation of S^0 resulted in both direct chemical changes through lowering soil pH, EC and increasing sulfate concentration. The results suggest that the application of S^0 in calcareous soil is a good alternative for the improvement of soil properties, especially considering its beneficial effects on nutrients uptake pattern.

Based on the aforementioned findings, it is therefore recommended that application of S^0 at the rate of 5 t ha^{-1} with N is economically and technically suitable to grow maize in calcareous soil of UAE. Considering chemical properties of soil, TDM accumulation, nutrients uptake and normal irrigation water is suitable for both Al Zaid and Al Semaih soils, respectively.

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