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Effects of sulfur and nitrogen on nutrients uptake of corn using acidified water

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A greenhouse experiment was carried out with elemental sulfur (S) and nitrogen (N) fertilizer using acidified water (pH 6.5) to determine nutrients uptake and growth of maize plants grown in calcareous sandy soil. Four levels of elemental sulfur (0, 1, 5 and 10 t ha^{-1}), two levels of N (0 and 0.34 t N ha^{-1}) were tested at Al Foah Agricultural Experiment Farm, United Arab Emirates (UAE) University. In Al Semaih soil, the pH (1.21-1.33) and electrical conductivity (EC) (7.61 dSm^{-1}) decreased by application of elemental S plus N, while EC rose (3.84 dSm^{-1}) and pH reduced (1.20 to 1.11) in Al Zaid soil. Acidity improved by decreasing soil pH, Na and Cl concentration in both soils. A significant change was observed by application of acidified water at Al Semaih soil causing high levels in the initial status of EC, Na and Cl concentrations in the soil. A negative relationship was observed with soil pH among N, P, S, Fe, Zn and Mn, while uptake availability of sulfur and nitrogen had positive relationship with all nutrients. Elemental sulfur at the rate of 5 t ha^{-1} and nitrogen had a significant contribution towards uptake availability of N, P, S, Fe, Zn and Mn in both Al Zaid and Al Semaih soils. Based on experimental findings, elemental S at the rate of 5 tha^{-1} and N fertilizer (0.34 t ha^{-1}) is suitable for the growth of maize at both soils. Al Zaid soil possesses advantages over Al Semaih soil due to its high nutrient uptake ability.

Key words: Calcareous soil, corn, elemental sulfur, nitrogen, nutrients uptake.

INTRODUCTION

Plant growth and crop productivity is greatly influenced by the availability of plant nutrients in soil which can be regulated by both native and applied nutrients in calcareous sandy soils (Janzen and Bettany, 1987). Poor availability of nutrients is a challenging issue for plant growth in calcareous sandy soil. There are numerous factors controlling plant nutrient uptake availability. Among them, high pH, electrical conductivity and $CaCO_3$ levels, are predominantly responsible for poor uptake and availability of plant nutrients (Kaya et al., 2009). In United Arab Emirates, major agricultural land are sandy calcareous and contains relatively high amounts of $CaCO_3$, possess extremely poor organic matter, resulting in high pH of the soils, which directly influence the availability of nutrients for plant growth. Elemental sulfur (S) can be used as a nutrient and an acidifier (Lindemann et al., 1991; Neilsen et al., 1993). The acidity produced during elemental S oxidation increases the availability of nutrients such as P, Mn, Ca and SO_4 in soils (Lindemann et al., 1991), which may enhance the chemical and physical characteristics of alkaline and sodic soils (Wainwright, 1984). Plant nutrients availability and uptake ability in calcareous soil can be enhanced by acidification which has large cumulative effects on the overall N balance and on the amount of soil nitrogen reserves (Cassman et al., 2002). The soil enriched with organic matter is characterized by the high degree of base

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saturation which promotes the conditions of acidification; and the resulting sulfur could be more available for plants (Wainwright, 1984). Increased application of nitrogen fertilizer increases sulfur response but may adversely affect crop quality by increasing its N/S ratio, leading to a reduction of protein-nitrogen and an increase in nitrate-nitrogen, and other non-protein nitrogen fractions. Nitrogen and sulfur are utilized mostly for protein synthesis in plants and it is necessary for the synthesis of amino acids, proteins and other cellular components which play an important role in the protection of plants against stress and pests (Luit et al., 1999).

Sulfur is a constituent of the amino acids cysteine and methionine and hence, part of proteins which play an important role in the synthesis of vitamins and chlorophyll in the cell (Marschner, 1995; Kacar and Katkat, 2007). Sulfur uptake efficiency increases, and the deficiency symptom disappears, upon application of N fertilizer in the form of urea in S deficient soil (Murphy, 1999). Sulfur is considered one of the major essential plant nutrients and an amendment used for reclaiming alkaline and calcareous soils (Marschner, 1996).

Maize as an oilseed crop is highly responsive to S; making maize an ideal crop for sulfur application in the forms of elemental S and ammonium sulfate or urea, especially in alkaline and calcareous soils (Ghosh et al., 2000). Sulfur as an essential nutrient, comes in the sixth level of essentiality after N, P, K, Ca and Mg. Sulfur deficiency in some major crops grown in UAE soils were identified (Soaud et al., 2002a, b). The importance of elemental S application was indicated by the improvement in the availability of some nutrients in different types of soil and their uptake by plants (Saleh, 2001; Saleh and Abushal, 1998; Bayoumi et al., 1997; El-Fayoumy and El-Gamal, 1998). Improved nutrient management is required to grow crops successfully on calcareous soils. Nutrient management in calcareous soils differs from that in non-calcareous soils because of the effect of soil pH on soil nutrient availability and chemical reactions that affect the loss of N and or fixation of most nutrients. Iron, Zn, Mn and Cu deficiencies are common in soils that have a high $CaCO_3$ due to reduced solubility at alkaline pH values (Marschner, 1995; Brady and Weil, 1999). The presence of $CaCO_3$ directly or indirectly affects the chemistry and availability of N, P, Mg, K, Mn, Zn, Cu and Fe (Marschner, 1995; Obreza et al., 1993). Sulfur fertilization is relatively inexpensive and its use leads to substantial benefits of yield and quality of crops. Little is known about uptake pattern and metabolism of the sulfur 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, declining of sulfur supply from the atmosphere has already caused substantial losses of nitrogen from agro-ecosystems to the environment (Luit et al., 1999). Therefore, a strong focus on reducing nitrogen leads to arid environments and the interaction between nitrogen and sulfur metabolism needs more clarification with view to improve environmental 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. Limited information on plant regulation of sulfur and nitrogen fluxes in relation to metabolic need of the cultivars for growth at specific circumstances and on the mechanisms involved.

For a better understanding of uptake and assimilation of elemental sulfur and nitrogen, the present study was undertaken as an integrated research approach to determine the effect of elemental sulfur singly or combined with or without nitrogen fertilizer using acidified water in response to growth and nutrients uptake by maize plants in sandy calcareous soils.

MATERIALS AND METHODS

Pot experiments were carried out under greenhouse conditions at Al Foah Agricultural Experiment Farm (27°N and 22°S latitude and 51°W and 57°E longitude), United Arab Emirates (UAE) University. The soil used for experiment is sandy calcareous soil which was collected from Al Zaid and Al Semaih, Abu Dhabi UAE. The soil was air-dried and part of the soil was sieved through 1 mm stainless steel sieve and stored in plastic bags for physicochemical analysis. Physicochemical properties of the soil are presented in Table 1. Soil pH was determined from soil suspension and prepared at 1:2.5 soil water ratios. Soil pH was measured using combined pH meter model 900A (Thomas, 1996). Electrical conductivity was measured by the saturation extracts of soil samples using Orion model 120 microprocessor conductivity meters. Water soluble cations (Ca, Mg, Na and K) and anions (Cl, HCO_3, CO_3 and SO_4) were determined as the recommended method of soil analysis (Page et al., 1982). After harvesting of maize plants, soil parameters such as electrical conductivity (EC), concentration of SO_4 in saturation extracts and pH in soil suspensions were again determined. Free-draining polyethylene pots (height 25 cm x diameter 23 cm) were filled with 5.0 kg of soil. Initially, each pot received 3.8 kg of soil. Prior to sowing, phosphorus (P_2O_5) and potassium (K_2O) were mixed thoroughly with 1.2 kg soil at the rates of 3.3 and 1.1 g pot^{-1} in the forms of single super-phosphate and potassium sulfate, respectively; thereafter placed in each pot to make it up to 5 kg of soil. In the treatments which comprised the addition of nitrogen was applied at rates of 1.49 g per pot at 10 and 17 days after germination on the soil surface and irrigated with normal and acidified water, respectively. Four levels of elemental sulfur at the rates of 0, 1, 5 and 10 t ha^{-1} and two levels of N at rates of 0 and 0.34 t ha^{-1} were tested in pots under greenhouse conditions, respectively. Two experiments with same set of treatments were carried out simultaneously using each with acidified irrigation water (pH 6.5) under Al Zaid and Al Semaih soils. Treatment combinations are presented in Table 2. Experiment was laid out in a factorial completely randomized design with three replications. Elemental S powder particle size < 150 µm was collected from TAKREER Company, Ruwais, Abu Dhabi, United Arab Emirates. Ten maize seeds (cv. Merit (Asgrow vegetable seeds, CA, USA)) were sown per pots at a depth of 5 mm into the soil. After emergence, all seedlings were kept until final harvest. The pots were placed in an evaporative cool greenhouse. The pots were saturated with acidified water up to field capacity for proper germination and growth of maize plants. Plant growth was

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

Soil property	Al Zaid	AL Semaih
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

monitored by recording above ground dry matter at the time of harvest (35 days after germination). Eight maize plants were selected at random and harvested for nutrient analysis and dry matter yield. After harvest, roots and shoots were washed in deionized water and oven dried for 48 h at 72°C. The weight was taken and the dry matter ground to powder in a ball mill. Samples were digested by the dry ashing method as described by Jones and Case (1990). Total content of micronutrients (Fe, Mn and Zn) were determined by the atomic absorption spectrophotometer Varian, model SpectrAA 220 FS. Sulfur content was measured using inductively coupled plasma-atomic emission spectrometry (ICP-AES), Varain model vista MPX. Phosphorus was determined calorimetrically according to the method described by Kuo (1996). For the determination of the total concentration of nitrogen, the automatic distillation unit of nitrogen (FOSS, 2200 Kjeltic auto distillation) was used. Nitrogen was then determined by acid titration (Munsinger and McKinney, 1982). All analyses were performed by Microsoft excel statistical software packages. The data were analyzed using a statistical analysis system (SAS, 1999). Following the analysis of variance procedures, differences among treatment means were determined using the least significant differences (LSD) comparison method.

RESULTS

Initial electrical conductivity (EC) in Al Zaid and Al Semaih soil was 3.36 and 18.27 d Sm^{-1}, respectively (Table 1). Electrical conductivity rose (7.20 d Sm^{-1}) significantly ($p<0.05$) in Al Zaid soil, while it was reduced (10.66 d Sm^{-1}) in Al Semaih soil by the application of elemental sulfur with nitrogen fertilizer (Table 3). In Al Zaid soil, elemental sulfur at the rate of 5 t ha^{-1} with nitrogen fertilizer (10 t ha^{-1}) plus N or without N fertilizer, recorded maximum EC. The lowest electrical conductivity was obtained from that without application of elemental sulfur and nitrogen fertilizer (Table 3). In Al Semaih soil, the highest reduction of EC was recorded from elemental sulfur (ES) at the rate of 10 t ha^{-1} with N fertilizer. A significant change in electrical conductivity had also been observed with other treatments when only acidified water was used. Electrical conductivity did not decline much with application of elemental sulfur at the rate of 1 t ha^{-1} with nitrogen but drastically reduced by the application of elemental S at rates of 5 and 10 t ha^{-1} plus N or without N (Table 3). Initial soil pH in Al Zaid and Al Semaih soil was 9.08 and 9.01, respectively (Table 1). Soil pH was affected significantly ($p<0.05$) by application of elemental sulfur, nitrogen and their interaction. Soil pH decreased significantly ($p<0.05$) by addition of elemental S at rates of 5 and 10 t ha^{-1} in the presence of N or absence of N fertilizer in both soils. Soil pH reduced appreciably even in the control treatment because of the use of acidified water in both soils (Table 3).

The initial Na concentration in Al Zaid and Al Semaih soil were 28.70 and 171.1 cmol L^{-1}, respectively (Table 1). By application of elemental S with N fertilizer, Na concentration reduced significantly ($p<0.05$) in both soils (Table 4). In Al Zaid soil, maximum reduction rate (25.07 to 26.37 cmol l^{-1}) was observed by the application of elemental S at the rates of 5 and 10 t ha^{-1} in the absence of N fertilizer, while in Al Semaih soil, Na concentration was drastically reduced from elemental S at the rates of 5 and 10 t ha^{-1} when no nitrogen was used. The rate of reduction was noticeably higher in Al Semaih soil than Al Zaid soil. Potassium content in the soil was enriched significantly ($p<0.05$) by the application of elemental S and N fertilizer in both soils. Higher enrichment of K in the soil was observed with higher application of elemental S with N fertilizer in both soils. The enrichment of K in soil was directly related with higher levels of elemental S and N application for both soils. The rate of enrichment was almost similar in both soils (Table 4). Chloride content in soil was reduced significantly ($p>0.05$) by the application of elemental S at the rates of 5 and 10 t ha^{-1} with or without N fertilizer in both soils. The rate of reduction was remarkably higher in Al Semaih soil than Al Zaid soil (Table 4).

Nutrients uptake by maize plant was significantly influenced ($p<0.05$) by the application of elemental S, N and their interaction. The highest nitrogen uptake (31.12 and 30.66 mg g^{-1}) was recorded by the application of elemental S at the rate of 5 t ha^{-1} plus N fertilizer in Al Zaid and Al Semaih soils, respectively. Intermediate nitrogen uptake was recorded from elemental sulfur at the rates of 10 and 1 t ha^{-1} in the presence of N, respectively. The lowest nitrogen uptake was obtained by the control treatment where no elemental sulfur and nitrogen were applied. Nitrogen uptake was appreciably

Table 2. Treatment variation at greenhouse at Al Foah agricultural experiment farm.

Treatment	Soil type		Treatment detail
	Al Zaid	AL Semaih	
S0N0	Al Zaid	AL Semaih	Elemental S 0 + N 0 (control)
S0N1	Al Zaid	AL Semaih	Elemental S 0 + N 0.34 t ha^{-1}
S1N0	Al Zaid	AL Semaih	Elemental S 1 t ha^{-1} + N 0
S1N1	Al Zaid	AL Semaih	Elemental S 1 t ha^{-1} + N 0.34 t ha^{-1}
S2N0	Al Zaid	AL Semaih	Elemental S 5 t ha^{-1} + N 0
S2N1	Al Zaid	AL Semaih	Elemental S 5 t ha^{-1} + N 0.34 t ha^{-1}
S3N0	Al Zaid	AL Semaih	Elemental S 10 t ha^{-1} + N 0
S3N1	Al Zaid	AL Semaih	Elemental S 10 t ha^{-1} + N 0.34 t ha^{-1}

Table 3. EC and pH of soil as affected by elemental S and N fertilizer using acidified water after harvesting of corn.

Treatment	EC (dSm^{-1})		pH	
	Al Zaid soil	Al Semaih soil	Al Zaid soil	Al Semaih soil
S0N0	5.53	15.75	8.24	8.08
S0N1	5.65	15.17	8.11	8.05
S1N0	5.66	14.61	8.10	7.91
S1N1	5.92	13.62	8.01	7.84
S2N0	5.80	13.07	7.97	7.80
S2N1	6.95	13.06	7.92	7.72
S3N0	6.11	12.95	7.90	7.70
S3N1	7.20	10.66	7.88	7.68
LSD (0.05)	0.25	0.99	0.12	0.12

EC, Electrical conductivity.

Table 4. Chemical properties of soil as affected by elemental S and N fertilizer using acidified water after harvesting of corn.

Treatment	Na (cmol L^{-1})		K (cmol L^{-1})		Cl (cmol L^{-1})	
	Al Zaid soil	Al Semaih soil	Al Zaid soil	Al Semaih soil	Al Zaid soil	Al Semaih soil
S0N0	35.99	95.87	1.99	5.29	43.33	122.00
S0N1	26.35	102.53	2.02	5.80	37.00	119.00
S1N0	27.14	90.10	1.95	4.44	35.00	116.33
S1N1	31.72	112.20	2.62	5.24	31.00	107.00
S2N0	26.37	101.53	2.26	5.20	29.33	116.33
S2N1	31.13	78.27	2.48	5.19	29.00	101.67
S3N0	25.07	104.30	2.34	4.88	27.00	100.67
S3N1	29.72	86.40	3.03	5.56	22.00	80.33
LSD (0.05)	3.65	8.85	0.40	1.61	8.25	21.50

higher in Al Zaid soil than Al Semaih soil (Table 5). The highest and lowest uptake of P and S was obtained by elemental S at the rate of 10 t ha^{-1} plus N fertilizer and control treatment, respectively in both Al Zaid and Al Semaih soils, respectively. Intermediate uptake of phosphorus and sulfur was obtained from elemental S at the rate of 5 t ha^{-1} plus N in both kinds of soil (Table 5). The highest and lowest uptake of Fe was recorded by the application of elemental S at the rate of 5 t ha^{-1} with N fertilizer and control treatment in both Al Zaid and Al Semaih soil, respectively. Iron uptake was appreciably higher at Al Zaid soil than Al Semaih soil. The highest

Table 5. Nitrogen, phosphorus and sulfur uptake by maize as affected by elemental S and N fertilizer using acidified water.

Treatment	N (mg g^{-1})		P (mg g^{-1})		S (mg g^{-1})	
	Al Zaid soil	Al Semaih soil	Al Zaid soil	Al Semaih soil	Al Zaid soil	Al Semaih soil
S0N0	6.68	7.05	8.42	6.71	6.71	6.5
S0N1	29.94	29.41	8.68	8.29	7.79	7.43
S1N0	6.98	7.11	8.37	8.39	8.98	7.71
S1N1	29.95	28.19	9.99	9.64	9.84	9.64
S2N0	7.45	7.32	9.51	9.01	9.65	10.00
S2N1	31.12	30.66	11.68	11.2	12.20	11.05
S3N0	7.01	7.20	9.20	8.97	10.20	10.56
S3N1	30.10	28.88	11.71	11.55	13.71	13.38
LSD (0.05)	0.68	0.50	0.55	0.40	0.40	0.60

Table 6. Iron, zinc and manganese uptake by maize as affected by elemental S and N fertilizer using acidified water.

Treatment	Fe (mg g^{-1})		Zn (mg g^{-1})		Mn (mg g^{-1})	
	Al Zaid soil	Al Semaih soil	Al Zaid soil	Al Semaih soil	Al Zaid soil	Al Semaih soil
S0N0	0.02	0.03	0.05	0.03	0.06	0.07
S0N1	1.12	0.43	0.09	0.06	0.90	0.82
S1N0	0.02	0.03	0.07	0.04	0.13	0.20
S1N1	1.12	0.77	0.07	0.06	1.08	1.22
S2N0	0.02	0.03	0.05	0.05	0.10	0.14
S2N1	1.86	1.20	0.10	0.08	1.41	1.60
S3N0	0.01	0.03	0.05	0.06	0.08	0.15
S3N1	1.43	1.16	0.08	0.07	1.09	1.00
LSD (0.05)	0.04	0.04	0.01	0.01	0.05	0.04

uptake of Zn was recorded by the application of elemental S at the rate of 5 t ha^{-1} with N followed by the application of elemental S at the rate of 10 t ha^{-1} with nitrogen. Elemental sulfur at the rates of 10 and 1 t ha^{-1} with N recorded identical and intermediate Zn uptake in both soils (Table 6). The highest uptake of Mn was recorded by elemental S at the rate of 5 t ha^{-1} with N in both soils. Intermediate Mn uptake was recorded by elemental S at the rate of 10 and 1 t ha^{-1} in Al Zaid and Al Semaih soil, respectively. Minimum manganese uptake was obtained by control treatment for both soils. Manganese uptake was comparatively higher in Al Semaih soil than Al Zaid soil (Table 6).

Dry matter yield was influenced significantly ($p<0.05$) by the application of elemental S, N and their interaction (Figure 1). The highest dry matter accumulation (42.4 g m^{-2} for Al Semaih and 156 g m^{-2} for Al Zaid), was produced by the application of elemental sulfur at the rate of 5 t ha^{-1} with nitrogen in both soils. Intermediate dry matter accumulation was recorded by the application of elemental S at the rate of 1 t ha^{-1} with N fertilizer in both soils. The lowest dry matter was recorded from control treatment where elemental S and N were not applied. Dry matter accumulation was significantly high ($p<0.05$) at Al Zaid soil than Al Semaih soil. In Al Semaih soil, dry matter accumulation was lesser due to poor nutrient status of the soil. The correlation analysis showed that, dry matter yield was positively correlated with uptake availability of all nutrients and the electrical conductivity. Soil pH was negatively correlated with dry matter, EC and all nutrients uptake in both soils (Table 7). Total dry matter had strong positive correlation with N, Fe and Mn in Al Zaid soil, while in Al Semaih soil, dry matter had strong positive correlation with N, P, S and Fe. The interrelationship among nutrients had positive correlation in respect of nutrients uptake in both soils but the correlation was a bit stronger in Al Semaih soil than Al Zaid soil. There was a highly significant positive linear relationship among elemental sulfur, nitrogen and phosphorus uptake and nitrogen with phosphorus, sulfur, iron and manganese in Al Semaih soil while in Al Zaid soil, a strong correlation was observed between S and P and N with Fe, Zn and Mn only (Table 7). The slopes indicated that, for every 1.0 g of N uptake, 41 to 51 g dry matter yield was gained while for every 1.0 g of S uptake; only 9 to 10 g dry matter was accumulated for the two types of soil (Table 8). The dry matter yield clearly indicates that higher rate of elemental sulfur along with nitrogen

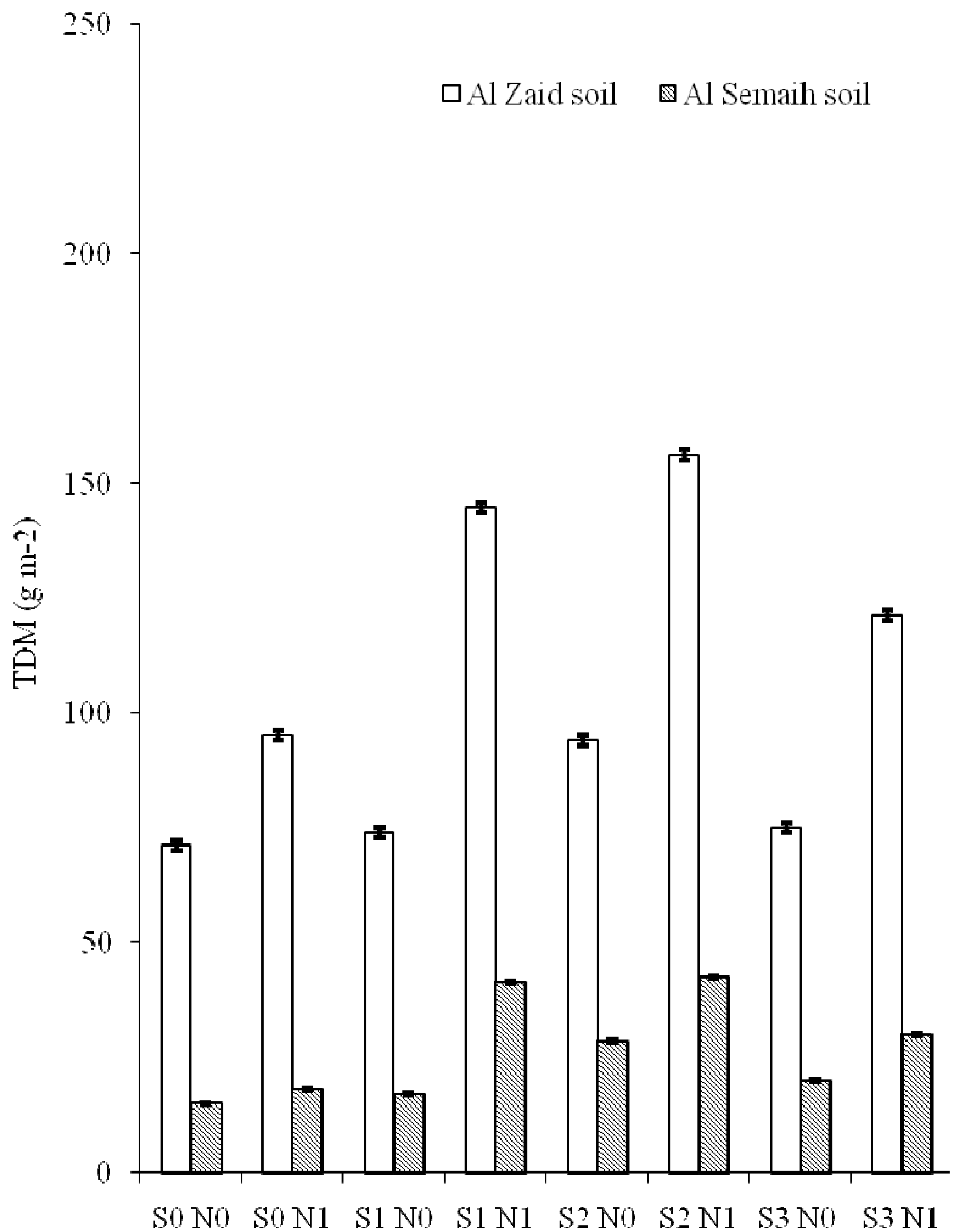

Figure 1. Total dry matter accumulation of corn as affected by ES and N using acidified water (error bars denoted LSD value at 0.05 level).

application played significant role in sandy calcareous soil.

DISCUSSION

In our study, both pH and electrical conductivity (EC) decreased significantly ($p<0.05$) in Al Semaih soil while EC rose and pH was reduced in Al Zaid soil. The soil pH dropped from an initial value of 9.08 to 7.88 and 9.01 to 7.68 by application of elemental S and N in Al Zaid soil and Al Semaih soil, respectively. Oxidation of elemental sulfur and subsequent production of acid resulted in a reduction in the pH in all the soils relative to the original soil. Soil pH reduced significantly ($p<0.05$) as a result of the addition of sulfur singly or combined with N fertilizer which increased the availability of micronutrients as well as plant dry matter yield. Acidifying effect leading to

Table 7. Interrelationships among dry matter yield, EC, soil pH and nutrient uptake of N, P, S, Fe, Zn and Mn.

Al Zaid soil	**EC**	**pH**	**N**	**P**	**S**	**Fe**	**Zn**	**Mn**
TDM	0.65*	-0.50*	0.82**	0.65**	0.57**	0.88**	0.67*	0.91**
EC		-0.47	0.57*	0.61*	0.63*	0.46	-0.18	0.59*
pH			-0.72*	-0.79*	-0.69*	-0.57*	-0.13	-0.62*
N				0.60*	0.50*	0.94**	0.80**	0.96**
P					0.92**	0.76**	0.48	0.60**
S						0.62**	0.48	0.60**
Fe							0.89**	0.96**
Zn								0.87**
Al Semaih soil								
TDM	0.54*	-0.77*	0.90**	0.96**	0.93**	0.80**	0.68*	0.78*
EC		-0.58*	0.67*	0.56*	0.65*	0.54*	-0.30	0.63*
pH			-0.84**	-0.85**	-0.89**	-0.70**	-0.23	-0.81**
N				0.87**	0.86**	0.92**	0.67*	0.95**
P					0.97**	0.70*	0.59*	0.76*
S						0.69*	0.59*	0.77*
Fe							0.81**	0.96**
Zn								0.77*

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

Table 8. Regression equation and coefficients of determination (R2) for relationship between dry matter yield and elemental S and N uptake using acidified irrigation water in Al Zaid and Al Semaih soil.

Parameter	**Regression equation**	R^2
Al Zaid soil		
Acidified water	$y = -31.399 + 0.0513x_1$	0.8887
Acidified water	$y = -0.8403 + 0.0093x_2$	0.8623
Al Semaih soil		
Acidified water	$y = -5.101 + 0.0411x_1$	0.8018
Acidified water	$y = -0.2247 + 0.0109x_2$	0.8671

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

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 availability of all nutrients had negative effects with soil pH which affects both the chemical forms and solubility of nutrient elements. In alkaline soils, decrease in pH increased the availability of nutrients and in the other soil, most nutrients are available with pH ranging from 6.5 to 7.5 (Marschner, 1995). Erdal et al. (2000) reported that, soil pH decreased by 0.11 to 0.37 units; plant dry weight, phosphorus concentration and uptake were increased with the application of sulfur. Similarly, Soliman et al. (1992) found that, soil pH decreased by 0.2, 0.5 and 0.9 units as a result of increasing S applications. Our findings agree with that mentioned by other investigators and partially agree with the result of Lopez et al. (1999). They reported that, pH in soil decreased when elemental S was added along with higher concentrations of electrical conductivity. In addition to supplying sulfur as a nutrient, S compounds are also used as soil amendments. These compounds act as soil acidifiers which neutralized $CaCO_3$ with acid; thus, in turn, may lead to a lowering of soil pH and improved nutrient availability in the soil. The rates of soil acidifiers required to cause a plant response depend on the amount of $CaCO_3$ in the soil (Finck, 1982). Calcareous soils are alkaline because of the presence of $CaCO_3$ which 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 in an exchangeable form for plants. Both Zn and Mn deficiencies are pH-dependent and their concentrations in solution decreases 100-fold for each unit increase in pH (Lindsay, 1972).

Nitrogen uptake was appreciably higher at Al Zaid soil especially when elemental sulfur was applied at the rate of 5 t ha^{-1} plus N compared with Al Semaih soil which resulted in higher dry matter yield. Nitrogen uptake is closely correlated with dry matter yield and may reflect on nutrient uptake ability of nitrogen for maize growth. In this study, significantly higher ($p<0.05$) nitrogen uptake was obtained by interaction effect of elemental sulfur and nitrogen compared with the control and other treatments which did not receive N fertilizer. The combined effect of elemental S and N played a significant role in N uptake by young maize plants. Regardless of the levels of elemental S, N fertilizer had positive influence on N uptake by maize. The results coincide with the findings of Chaubey et al. (1993) who observed that, the increased N contents of linseed grain and straw was obtained by the application of sulfur in sandy and loam soils. High nitrogen concentration of groundnut was observed in calcareous soil using S application compared with zero sulfur. Sufficient S is essential to prevent undesired N losses to the environment due to reduced nitrogen utilization (Haneklaus et al., 1999). In our study, with high levels of elemental S and N application, N uptake was comparatively higher (31.12 mg g^{-1}) than the lowest level of elemental sulfur (28.19 mg g^{-1}). Therefore, sulfur input is not only important in the growth of maize but also, with regard to nitrogen utilization. Schung (1991) reported that, under sulfur-deficient soil, nitrogen utilization may be as low as 25%. For an environmental sustainable production of maize crops, a sufficient S supply is essential in order to minimize N losses. Therefore, our results revealed that, application of elemental S at the rate of 5 t ha^{-1} with N fertilizer (0.34 t/ha) is seemingly better for maize plants.

In both soil, P uptake was almost similar, although, maize in Al Semaih soil did not accumulate identical dry matter of maize because, not only P, all other nutrients uptake were closely linked to biomass accumulation and nutrient uptakes were also closely correlated with dry matter yield which might reflect on nutrient uptake availability. Phosphorus uptake was higher due to amendment of soil by adding higher levels of elemental S and N. High rate of elemental S, concentrated in a small volume of calcareous soil creates an acidic zone quickly and increases the availability of P and micronutrients to roots growing in and near the acidic zone (Obreza et al., 1993). Sulfur uptake was enhanced by the application of elemental sulfur and the uptake of S was tremendously higher at high levels of elemental S with N and had strong and positive effect on dry matter yield. During sulfur uptake by maize plants, S oxidation rate were increased by applying S fertilizer (Lefroy et al., 1997). Higher application of elemental S markedly increased Zn uptake in plants, particularly *Helianthus annuus* in calcareous soil and our findings coincided with the results of Kayser et al. (2001). Application of elemental S increased Zn solubility in the soil and by the soil, amending Zn concentration in sunflower and peanut plants also significantly increased ($p<0.05$) in calcareous soil (Kayser et al., 2001; Singh et al., 1990). Kaplan and Orman (1998) reported similar findings and they found that, the application of elemental S at the rate of 2 t ha^{-1}, increased Mn and Zn content in the shoots of sorghum plants under calcareous soils in Turkey. The application of higher levels of elemental S with N played significant role in respect of Mn uptake of maize plants. The results clearly showed that, Mn uptake increased significantly ($p<0.05$) in maize plants when grown with moderate levels of elemental sulfur with nitrogen, whereas without elemental S and N recorded poor uptake of Mn. Manganese uptake was high along with higher application of nitrogen which was most evident at the higher sulfur application rates (Kaya et al., 2009; Soliman et al., 1992).

High total dry matter yield is an additive effect of shoot and root dry weight over time. In our study, dry matter accumulation was varied due to the application of variable quantities of elemental S and N fertilizer using acidified water. Similar results were obtained by Besharati and Rastin (1999), who reported that, S application had significant effects on dry matter of roots and shoots of maize grown in calcareous soils under greenhouse conditions. Elemental sulfur had a significant effect on dry matter yield and the combined effect of elemental S along with N significantly increased ($p<0.05$) in the dry matter yield of maize plants. A combined application of P and S resulted to a significant increase ($p<0.05$) in dry matter yield but due to lower rates of S application, P uptake was poor in wheat plant in sandy calcareous soil (Randhawa and Arora, 2000). High dry matter production is one of the prerequisites for greater productivity in crop plants (Muchow et al., 1993; Motior and Ahad, 1995). Dry matter yield of any crop depends on the advancement of plant age and its direct influence on yield (Fageria and Baligar, 2001). The use of optimum quantity of nutrients is one of the important strategies for increasing crop growth and yield (Fageria and Baligar, 1996). Dry matter yield increased by the application of N and/or S (Soliman et al., 1992). Thus, dry matter yield of the present study indicated that, the application of elemental S at the rate of 5 t ha^{-1} with N fertilizer (0.34 t ha^{-1}) were found suitable for maize which may reflect on nutrient uptake ability for maize growth in calcareous soil. Both dry matter and nutrient uptake increased with the application of elemental S at the rate of 5 t ha^{-1} plus N at the rate of 0.34 t ha^{-1}. The oxidation of elemental S resulted in both direct chemical changes through lowering soil pH, electrical conductivity and increasing soil sulfate concentration.

Our results suggest that, the application of elemental sulfur in calcareous soil is a good alternative for the improvement of soil properties, especially considering its beneficial effect on nutrients uptake pattern. Based on these findings, it is recommended that application of elemental sulfur at the rate of 5 t ha^{-1} with nitrogen is economically and technically suitable to grow maize in calcareous soil. Considering physicochemical properties of soil, dry matter yield and nutrients uptake, acidified irrigation water was helpful in the Al Semaih soil than in Al Zaid soil.

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