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Effect of Sulfur Blended N-Fertilizers on Nitrogen Use Efficiency and Quality of Lettuce Yield

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Abstract: Volatilization of NH_3 is a major factor affects ammonical fertilizer use efficiency particularly when N-fertilizers are surface applied to sandy soil characterized by high pH values and low CEC. Effect of blending various N-fertilizers; urea, U, ammonium sulfate, AS, ammonium nitrate, AN and di-ammonium phosphate, DAP; with elemental sulfur, on fertilizer-N utilization and quality of lettuce yield were studied. The results of lettuce yield grown in greenhouse showed significant increase in lettuce fresh yield (ranging from 9.8-18.9%) of treatments received S comparing with those received no S. The effect of S on dry matter of leaves and stems was insignificant. Total N content of leaves and stems showed a significant increase varied between 10.4-20.6 and 8.4-18.5%, respectively. Total-N uptake by lettuce plants treated with sulfur-blended fertilizers was increased by 20%(U)-52(AN)%. Also, an increase in N recovery reached 70% of the applied was observed for sulfur- blended N- fertilizer treatments, instead of 39-52% of those received no S. Nitrate and sulfate contents of lettuce dry matter were significantly increased using S-blended fertilizers particularly in the case of ammonium nitrate (AN) and ammonium sulphate (AS). The results of soil analysis showed significant decrease in soil pH in the treatments received S blended fertilizer compared to those received no S. On the other hand, electrical conductivity increased significantly from 1.8-2.1 to 2.1-3.2 dS m^{-1} as a result of S addition. Insignificant increase in both SO_4 and NH_4 contents were recorded for S treated samples.

Key words: Sulfur, N-Fertilizers, N recovery, Lettuce yield, Soil Properties

Introduction

Urea hydrolyzes rapidly following its application to soils. Ammonium accumulates in the application zone and pH increases due to the consumption of H^+. The resultant pH from urea hydrolysis in most soils ranges from 7.0 to 9.0 (Kissel *et al*., 1988). As soil pH rises, the proportion of NH_3 over NH_4 increases and NH_3 volatilization can occur when urea is surface applied (Ferguson *et al*., 1984). Investigators have found that > 50% of surface applied urea-N could be lost through NH_3 volatilization (Al-Kanani *et al*., 1991; Abdel-Maged, 1997). Gasser (1964) reported that volatilization take place directly after addition of ammonium sulphate. Similar conclusion was reported by Shammas *et al*. (1997).

To solve NH_3 volatilization problems and enhance urea efficiency, it is essential to slow down urea hydrolysis to avoid both NH_3 build up and pH increase in soil. Maintaining a low pH in the vicinity of the urea granule reduces urea hydrolysis and NH_3 volatilization. Addition of H_3PO_4 reduced NH_3 volatilization by retarding hydrolysis and by reducing the pH increase from urea hydrolysis (Bremner and Douglas, 1971). Ammonia volatilization could also be decreased by mixing urea with triple super phosphate (TSP) applied to an acid soil (Fan and Mackenzie, 1993), or mixing with KCl (Ouyang *et al*., 1998).

Laboratory experiments done by authors during years 1997/1998 showed that 50% reduction in ammonia volatilization upon mixing urea fertilizer with elemental sulfur (Shahin and Suliman, 1998). The objectives of the present work were; 1) studying the effect of mixing ammonium fertilizers as well as urea with elemental sulfur, on lettuce yield; 2) efficiency of N uptake by plants in sandy soil; and 3) studying the effect of S blended N-fertilizers on soil properties.

Materials and Methods

A greenhouse experiment was set up in 1998/1999 at the experimental and research station of the faculty of Agriculture and Vet. Medicine, King Saud University, Al-Qassim branch.

Preparation of lettuce seedlings: Lettuce seeds (variety Paris Island) were germinated in a medium of wet peat moss and sand (1:1) covered with black plastic sheets at 24±3°C during day h and 18±2°C at night. After germination, the plastic sheets were removed and fertilizer was added daily with irrigation water at rate of 50 mg N/l using liquid fertilizer (NPK) of order (20-20-20). After three weeks, i.e. appearance of at least three leaves, healthy and similar seedlings were chosen for planting in the experimental plots in lines at distances of 75 and 20 cm between lines and plants, respectively. The seedlings were planted on both sides of each line.

Experimental design: The factorial experiment design (2×4) in a complete randomized blocks was used. The trial contains 24 experimental plots of 3 × 1.5 m for each. Four sources of N were used namely: urea (U), ammonium nitrate (AN), ammonium sulfate (AS) and di-ammonium phosphate (DAP). All fertilizers were added at rates of 250 kg N ha^{-1} with two levels of elemental S (0 and 500 kg ha^{-1}). All treatments were replicated three times. A constant rate of both P-fertilizer (45 kg P_2O_5 kg ha^{-1} of triple super phosphate) and K-fertilizer (150 kg ha^{-1} of potassium sulphate) were added to all treatments. After seedlings, the plants got the first dose, which represents of the total amount of all fertilizers, which added in spots nearby plants, hence irrigation took place directly using drip system. The addition of fertilizers was repeated weakly at constant rate followed by irrigation, which stopped ten days before harvesting.

Sampling

Plant samples: After six weeks of planting, four complete initial leaves were collected from each replicate for analysis. At the end of the experiment, fresh yield was determined, then three plants were chosen to represent each replicate in which leaves and stems were separated.

Soil samples: Surface soil samples (0-15 Cm) representing each experimental treatments were collected after harvesting, then transported to the laboratory, air dried, then sieved using 2 mm sieve and stored for analysis.

Laboratory analyses: After determination of fresh weight, the stems and leaves were cut down to thin sections, then dried at 70°C for 48 h, then weighed and milled. Dry matter were used for chemical analysis:

- Total N content was determined using Kijldahl method (distillation of NH_4) after digestion in the presence of salicylic acid and sodium thiosulphate to reduce nitrate and nitrite to ammonium (Nelson and Sommers, 1980).
- Nitrate was determined in plant and soil samples spectrophotometrically at wavelength of 410 nm using the method of Cataldo *et al.* (1975).
- Sulfate concentration in both acid digestion extract of plant and soil water extract was measured turbid metrically according to Rainwater and Thatcher (1960).
- Ammonium concentration in soil extract was measured spectrophotometrically using Neseler's solution. Significant correlation ($r=0.994^{**}$) was obtained between the results of Neseler's method and those of the distillation one done in the presence of MgO (Keeny and Nelson, 1982).
- Plant available P was extracted using 0.5 M $NaHCO_3$ (Olsen *et al.*, 1954). Concentration of P in soil extract was measured spectrophotometrically according to Jackson (1985).
- Soil pH was measured potentiometrically using pH meter.
- Electrical conductivity of soil extract was measured using EC meter.

Statistical analysis: The obtained data were performed according to the general linear models procedure using SAS program.

Results and Discussion

Fresh and dry weight of leaves: The results of Table 1 shows marked increase in both fresh and dry weight of leaves of the treatments received sulfur blended fertilizer compared with those untreated. The increments in fresh weight varied between 9.76% in the treatments of (AS) and 18.9% for (DAP), whereas those of dry weight varied between 11.59% (AS) and 28.98% (DAP). The statistical analysis of complete randomized blocks design (CRBD) using general linear model (GLM) showed significant differences for both fresh and dry weight of lettuce leaves treated with S-blended fertilizer compared with those received no S (Table 2).

Fresh yield of lettuce: The results (Table 1) show that the yield of fresh lettuce heads (ranging from 4.86-6.64 t d^{-1}) varied as the source of N varied. The highest yield was recorded for urea, while the lowest one was for ammonium nitrate (AN).

Higher yields (ranging from 7.43-8.38 t d^{-1}) were obtained for the treatments received S-blended fertilizer. Statistical analysis show that, while the effect of fertilizer was insignificant (Table 2), addition of S had led to highly significant variation for the common (interference effect) for fertilizer (T) and sulfur (S) at ($P \leq 0.0047$), comparing the general average (7.93 t d^{-1}) of lettuce yield of plants treated with S with that of non treated (5.75 t d^{-1}) verified an increase of 38% in the yield due to S additives. The fresh weight of lettuce stem was found to represent 9.36-18.9% of that of lettuce head. This ratio didn't prove any trend as an effect of fertilizer treatment or S additives.

Dry matter content: The results of Table 1 show that the percent of dry matter in leaves (ranging between 4.94 - 5.94%) were higher than those of stems (ranging between 3.96-5.29% of the fresh weight). However, the dry matter yield of stems varied significantly ($P \leq 0.05$) as

Table 1: Fresh and dry weight of leaves, fresh yield of lettuce, dry matter of stem and total N and uptake as affected by S application

Fertilizer	Sulfur	Fresh. Wt. (4 Leaves)	Dry Wt. (4 leaves)	Lettuce fresh yield	DM% leaves	DM% stem	Total N leaves	Total N Stem	N Uptake
U	- S	40.6	2.10	6.64	5.5	5.18	3.55	2.65	133.2
	+ S	46.2	2.43	7.43	5.65	5.27	3.92	3.14	145.0
AN	- S	38.7	2.23	4.86	5.78	4.30	3.56	2.93	98.0
	+ S	45.1	2.67	8.38	5.94	4.47	4.0	3.31	165.0
AS	- S	43.0	2.33	6.41	5.41	3.96	3.37	2.84	120.0
	+ S	47.2	2.60	7.82	5.47	5.04	3.84	3.17	150.0
DAP	- S	41.8	2.07	5.12	4.94	4.94	3.89	2.98	102.0
	+ S	48.8	2.67	8.10	5.55	5.29	4.30	3.23	176.0

Table 2: Analysis of variance (F–values) of the tested parameters

	R		T		S		T × S	
Tested parameter	F	P	F	P	F	P	F	P
Fresh wt (4 leaves)	0.41	0.6692	2.06	0.1511	24.39***	0.0002	0.40	0.7538
Dry wt (4 leaves)	1.87	0.1913	0.57	0.6465	11.23**	0.0048	0.35	0.7871
Fresh yield (t/d)	0.58	0.5722	1.17	0.3572	78.25***	0.0001	6.78**	0.0047
Dry matter (leaves)	2.05	0.1654	1.84	0.1864	0.69	0.4214	0.15	0.9257
Dry matter (stem)	1.11	0.3571	5.14*	0.0132	3.15	0.0977	1.14	0.3687
Total-N (leaves)	0.10	0.9071	1.55	0.2454	2.85	0.1133	0.85	0.4886
Total-N (stem)	2.25	0.1420	0.69	0.5756	10.07**	0.0068	0.21	0.8890
NO_3 – leaves	0.19	0.8290	5.99**	0.0076	17.71***	0.0009	1.12	0.3761
NO_3 –stem	3.72	0.0508	25.36***	0.0001	36.45***	0.0001	3.13	0.0596
Soil – pH	0.15	0.8629	1.43	0.2754	30.68***	0.0001	1.63	0.2274
Soil – EC	8.61**	0.0036	34.76***	0.0001	224.17***	0.0001	3.16	0.0579
Soil – SO_4	2.29	0.1378	44.24***	0.0001	128.84***	0.0001	0.37	0.7738
Soil – NH_4	3.69	0.0517	3.17	0.0575	40.74***	0.0001	0.98	0.4321

R= Replicates, T= Fertilizers (4), S= Sulfur levels (2), F= F-values, P= Probability levels, *= Significant, **,***= High Significant at 0.01, 0.001

Table 3: Duncan grouping test considering sulfur effect on lettuce parameter

	Mean*		
Tested parameter	- S	+ S	Critical range
Fresh wt (4 leaves)	41.025b*	46.825a	2.624
Dry wt (4 leaves)	2.183b	2.592a	0.2614
Fresh yield (t d^{-1})	5.753b	7.933a	0.528
Dry matter (leaves)	5.409a	5.653a	0.494
Dry matter (stem)	4.595a	5.018a	0.558
Total-N (leaves)	3.5925a	4.0152a	0.4539
Total-N (stem)	2.8467b	3.2125a	0.258
NO_3-leaves (mg kg^{-1})	7060b	8649a	1663
NO_3–stem (mg kg^{-1})	4375b	6514a	728
Soil – pH	7.548a	6.873b	0.280
Soil – EC (dS m^{-1})	3.225b	6.14a	0.444
Soil–SO_4 (mg kg^{-1})	28.695b	47.093a	4.033

* Means having the same letter are not significantly different

Table 4: Changes in soil – pH, EC, sulphate and ammonium as affected by S-blended fertilizers

Fertilizer	Sulfur	pH	EC (dS m^{-1})	SO_4 (mg kg^{-1})	NH_4 (mg kg^{-1})
U	- S	7.85	2.43	21.92	65.42
	+ S	6.81	4.61	42.56	77.36
AN	- S	7.44	3.94	23.14	67.15
	+ S	6.81	7.35	30.11	80.27
AS	- S	7.32	3.95	46.98	77.15
	+ S	6.91	7.29	69.11	94.25
DAP	- S	7.58	2.58	22.74	61.83
	+ S	6.95	5.32	46.59	78.35

fertilizer used varied. Duncan test showed that means of dry matter of stems of U and DAP treatments were higher than those of AN and AS (Table 3).

Total nitrogen content: The percent of total –N in lettuce leaves (Table 1) varied between 3.37 and 3.89% in the

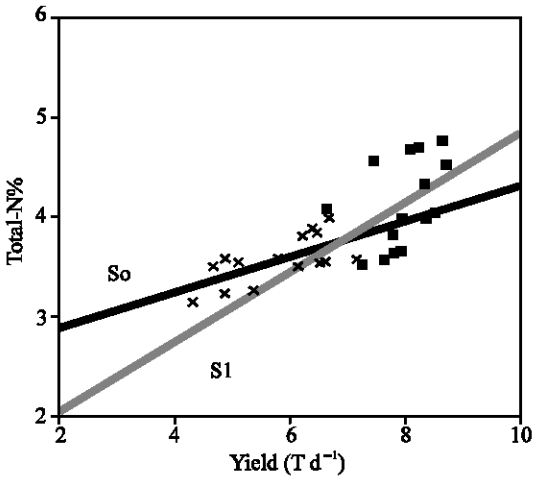

Fig. 1: Relationship of lettuce yield with total-N in the presence of sulfur

treatments received no S, against 3.84 to 4.3% of those treated with S, i.e. addition of S blended-fertilizers lid to an increase varied between 10.4-20.6% in N content in lettuce leaves. Also, an increase (varied between 3.4 to 18.5%) in total N content of stem was obtained for the plants treated with S blended –N fertilizers compared with those of plants of no S additives. The statistical analysis gave significant difference (P, 0.01%) due to S additives.

Significant correlation (r=0.667) was obtained between total–N of t he dry matter of stems and fresh yield. The relationship (Fig. 1) shows higher response particularly in

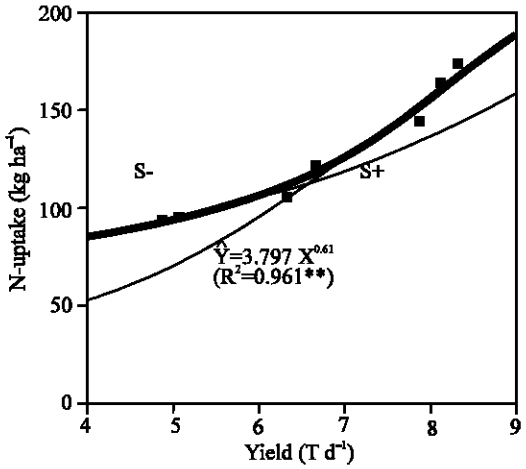

Fig. 2: Relationship between lettuce yield and total N-uptake as affected by sulfur

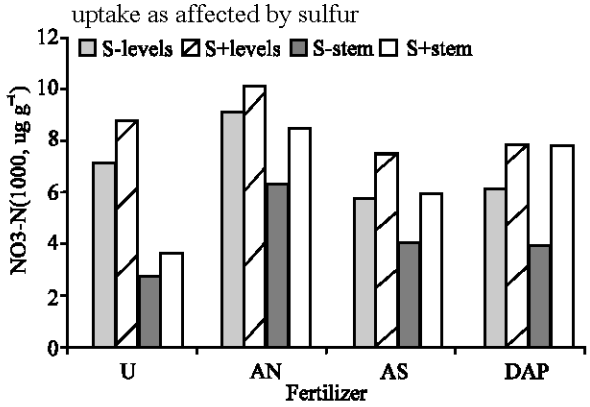

Fig. 3: Effect of sulfur on nitrate concentration In lettuce leaves and stems

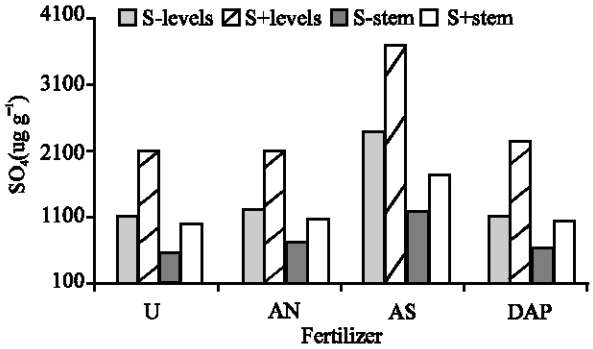

Fig. 4: Changes in sulphate concentration in lettuce leaves and stems as affected by S-blended fertilizers

the presence of S-blended fertilizer. Similar conclusion was reported by Lal *et al.* (1997). They found high N recovery of wheat in sandy soil treated with S.

Total N uptake: Total –N uptake by lettuce plants of the treatments received no S varied between 98.3-133.2 kg ha^{-1}, against 144-176 kg ha^{-1} of those treated with S blended N fertilizers. These results verifying the role of S in increasing N fertilizer utilization which varied between 20% (U) and 53% (AN). Also, N recovery which calculated as the following:

$$\text{Recovery\%} = \frac{\text{N-uptake (kg ha}^{-1})}{\text{N-applied (kg ha}^{-1})} \times 100$$

increased and ranged from 39-53% in the treatments received no S, against higher percentages (ranging from 58-70%) of those treated with S. These results could be attributed to the reduction of NH_3 volatilization from urea and other ammonium fertilizers blended with S.

Statistical analysis proved highly significant correlation (r^2 = 0.961) between fresh yield of lettuce and N uptake. An exponential relationship (Fig. 2) shows that the response of yield to N was higher in the presence of S. The form of the regression equation was:

$$Y = 3797 \ Y^{0.161}$$

Nitrate accumulation in lettuce: Nitrate concentration in the leaves of the treatments received no S varied from 5589-9270 mg kg^{-1} dry matter (Fig. 3). These values were found to represent 16-25% of total N in the leaves. On the presence of S, nitrate level in the lettuce leaves increased from 7576-10308 mg kg^{-1} dry matter which represent 20-26% of total N. Analysis of variance proved significant difference in NO_3 concentration for both N-fertilizer and S treatments (Table 2). These results were confirmed by Duncan test (Table 3).

In general, concentration of nitrate in stem was relatively low comparing with that of leaves. It amounted 35-40% and 72% of those of leaves of the treatments of U and AN, respectively. Nitrate concentrations in the stems of U treatments (ranging from 2930-6515) were 28 and 31% higher than those (ranging from 3632-8547 mg kg^{-1} DM) of stems of AN treatment. The results of the analysis of variance (Table 2) show significant differences for both fertilizer and S treatments. Duncan test (Table 3) showed that nitrate value of AN treatment was significantly higher than those of other treatments.

Sulfate concentration in lettuce: Sulphate concentration (Fig. 4) in lettuce leaves varied between 1090 and 2382 ug g^{-1} DM for the treatments of no S application, against a range of 2077-3697 ug g^{-1} DM in the presence of S. Increasing of SO_4 content of lettuce tissues could be attributed to the oxidation of added S to plant available form, SO_4. Sulphate concentration in stem was generally lower than that in leaves and ranged from 584-1182 mg

kg^{-1} DM. Concentrations of SO_4 in lettuce plants treated with S were generally higher (about 70%) than those of untreated.

Effect of S blended-fertilizer on soil properties:

- A marked decrease was noticed for pH values (Table 4) of soil treated with S blended –N fertilizer, comparing with those received no S. The highest reduction was recorded for urea treatments in which pH values reduced from 7.85 to 6.81. This reduction could be attributed to the proton released from dissociation of H_2SO_4 that resulted from oxidation of elemental S. Statistical analysis (Table 2) proved significant differences only between S treatments. Average of reduction in pH values was 0.72 unit as obtained by Duncan test.
- Electrical conductivity (Table 2) of soils treated with S (ranging from 4.61-7.35) were higher than those (ranging from 2.43-3.45 dS m^{-1} for U and AN, respectively) reported for untreated ones. Increasing salinity could be attributed to oxidation of elemental S, hence alteration to soluble SO_4 which contribute to an increase in electrical conductivity (EC) of soil extract. Both, analysis of variance and Duncan test proved significant difference in soil salinity between S treated and untreated replicates.
- Sulfate content in soil varied as added fertilizer varied. In general the level of SO_4 of the treatments received elemental S was higher than their corresponding of no S application. The highest SO_4 contents were recorded for AS treatments. The statistical analysis (Table 4) proved significant difference between both fertilizer and S treatments.
- Ammonium contents in the treatments of S blended –fertilizer (ranging from 77.36-94.95) were higher than those (ranging from 61.80-77.15 mg kg^{-1} soil) received no S (Table 4). Application of S lead to an increase of 29% in NH_4 content comparing with non treated ones. However, these differences were insignificant according to the results of the statistical analysis (Table 4).

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