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Full Length Research Paper

Effects of elemental sulfur and sulfur-containing waste on nutrient concentrations and growth of bean and corn plants grown on a calcareous soil

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This study was carried out to investigate the effects of elemental sulfur (S) and S-containing waste from an S factory on nutrient concentrations and growth of bean and corn plants. Therefore, elemental S and S containing waste corresponding to 40, 80 and 120 kg S da^{-1} were applied to pots. Each plant was grown twice on the same soils to determine initial and residual effects of applied S. Results showed that applications of elemental S and S-containing waste resulted in a decrease of soil pH, but general increase in nutrient concentrations for both plants and increase in residual available nutrient concentration in the experimental soils. In addition, it was found that S-containing waste could be used as an alternative to elemental S for improvement of plant nutrition in calcareous soils.

Key words: Calcareous soil, plant growth, plant nutrition, sulfur application.

INTRODUCTION

Low availability of some nutrients rather than low nutrient content is one of the major factors for the widespread occurrence of plant nutrient deficiency in soils. There are numerous soil factors affecting plants nutrient uptake from soil. Among them, high pH and $CaCO_3$ levels are predominantly responsible for low availability of other plant nutrients. In addition, other factors such as genotypic differences affect the plant growth. Plant species as well as varieties grown under the same conditions show different responses to nutrient and nutrient concentrations (Marschner, 1995). Under unfavorable soil conditions such as high pH and $CaCO_3$, soil fertilizer applications may not solve the nutrient problem. Therefore, some additional precautions should be exercised to improve the nutrient uptake in these conditions.

Most of the agricultural land of Turkey contains relatively high amounts of $CaCO_3$ and low organic matter resulting in high pH soils. Eyuboglu (1999) reported that approximately 59% of Turkish soils contained more than 5% $CaCO_3$ and over 63% of the soils had a pH higher than 7.5. In another study, it was found that 140 soil samples taken from 0 - 20 cm depth in the province of Isparta had $CaCO_3$ content 25% higher than the average and more than 91% of soils were slightly alkaline (Erdal et al., 2004).

Nutrient availability of soils can be increased by application of elemental sulfur (S). Thus, there is growing interest in S applications to improve solubility of nutrients and overcome nutrient deficiencies in both alkaline and calcareous soils (Gupta and Mehla, 1980; Dawood et al., 1985; Neilsen et al., 1993). The oxidation of S into H_2SO_4 is especially beneficial for alkaline soils for increasing nutrient availability by reducing pH (Burns, 1967). Because of the high cost and adverse effects of commercial fertilizers, use of natural sources and some organic and inorganic wastes as soil amender and fertilizer has recently gained importance in agricultural production (Bender et al., 1998; Erdal and Tarakcıoglu, 2000; Atilgan et al., 2008). In a study, designed to investtigate the possible use of different mixtures of converter sludge, a by-product of steel factory, as an iron fertilizer and amendment in some calcareous soils, it was found that mixtures containing elemental S significantly decreased the pH of soil (Abbaspour et al., 2004). In a pot experiment, soil pH was significantly reduced as a result of applications of S alone and together with N increased

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the availability of micronutrients as well as plant dry matter yield (Soliman et al., 1992). Erdal et al., (2000) indicated that while soil pH decreased by 0.11 - 0.37 unit, plant dry weight and phosphorus concentration and uptake were increased with the application of sulfur. In other studies conducted with different soils and plants, dry matter production, nutrient concentrations and plant nutrient uptake, chlorophyll concentrations, nodule formations on roots were increased by S applications (Kaplan and Orman, 1998; Erdal et al., 2004).

There are many functions of sulfur in plants. It is a constituent of the amino acids cysteine and methionine and hence part of proteins. It also plays an important role in the synthesis of vitamins and chlorophyll in the cell (Marschner, 1995; Kacar and Katkat, 2007). As a result of S deficiency, plants show retarded growth and reduction in yield and quality. The primary objective of this study was to determine the effect of elemental S and S containing waste on growth and mineral uptake of plants grown in a calcareous soil. In addition, the potential use of S containing waste was investigated as an alternative to elemental S applications.

MATERIALS AND METHODS

Pot experiments were carried out under greenhouse conditions at soil science and plant nutrition department, Suleyman Demirel university, Isparta, Turkey. The soil used for experiment was clay loam having 8.1 pH (1:2.5 soil-water suspension), 25.5% $CaCO_3$ (using calcimetric method), 1.9% organic matter (determined by Walkley and Black method), 50 kg/ha 0.5 M NaHCO extractable P (measured by Olsen's method) and 500 kg/ha 1 N NH_4NOAc exchangeable K (determined by atomic absorption spectrophotometer method). The available Fe, Cu, Zn and Mn as determined by DTPA extraction using atomic absorption spectrophotometer were 3.1, 1.0, 0.37 and 3.0 $mgkg^{-1}$, respectively.

In the experiment, 10 seeds of bean (*Phaseolus vulgaris* cv. Şehirali-90) and corn (Zea mays cv. TTM-815) were sown separately into pots containing 2 kg soil. After emergence of seedling, five homogeneous plants were left in each pot. Experiment was conducted according factorial design with three replications. Four different levels of S (40, 80 and 120 kg S da^{-1}) as elemental S (98% S) and sulfur containing waste (19 % S) obtained from Keciborlu sulfur factory (it is not active now) were applied. Estimated amount of waste is over than 1,000000 tons. Some characteristics of S containing waste were as follows; pH: 1.6; $CaSO_4$ 4.64%: CaO: 2.38% and SiO: 54.1%.

Two experiments were conducted consecutively on the same soils to evaluate primary and residual effects of S and S containing waste. In the initial experiment, 300 ppm N (NH_4NO_3), 100 ppm P (H_3PO_4) and 100 ppm K (KNO_3) were given as basal fertilizer and plants were grown for three months. The first experiment was completed when plants were harvested. In the second experiment, seeds were sown on the same soils in the experiment 1 and the same treatments were applied. Then an additional 200 ppm N and 100 ppm K were applied to the soils and plants were grown for 3 months.

After a three month growth period, plants were cut above the soil and samples were washed with tap water to remove surface residues and soaked in 0.2 N HCl, follow by rinsing with distilled water, after then, samples were dried at 65°C for 48 h to a constant weight. Dried samples were ground to powder using a mortar and pestle, and stored in polyethylene bottles.

Nitrogen content of samples was determined according to the Kjeldahl method (Bremler, 1965). For this purpose, 0.5 g of the ground samples were digested using by a block digesting system (KB 8 S Kjeldatherm, Gerhardt) in a digesting tube with 6 ml of concentrated H_2SO_4 in the presence of 5 g a catalyst (K_2SO_4 + $CuSO_4$). After 40% NaOH (w/w) was added, the sample was distilled using an automated unit (VAP2O, Gerhardt). The ammonium N was fixed in 2% H and was titrated with 0.1 N H in the presence of an indicator (bromo-cresol green and methyl red in 95% ethanol). To determine the P, K, Ca, Mg, Fe, Cu, Zn and Mn content in plant tissues, 0.5 g ground samples were digested with a microwave digester. The samples were filtered and volume filled up to 100 ml with distilled water. Phosphorus content in the filtrate was determined with a spectrophotometer (Shimadzu UV-1208) at 430 nm according to the vanadomolybdophosphoric acid method. The other elements were measured by an atomic absorption spectrophotometer (AAS, Varian AA 240FS) (Kacar and Inal, 2008). To evaluate the effects of sulfur sources on available nutrients in the soil, soil samples were taken from each pot of the second experiment and K, Mg, Ca, Fe, Cu, Mn and Zn analyses were done as described by Olsen et al. (1954), Knudsen et al. (1982), Lindsay and Norwell (1978).

Statistical analysis using SAS program was done based on randomized block design.

RESULTS

Nutrient concentrations and dry matter production of bean plant

The effects of different S sources and doses on N, P, K, Ca, Mg and Fe concentrations were given in Table 1. Application of elemental S and S containing waste positively affected nitrogen (N) concentration of bean. As a result, N concentration of plant significantly increased in comparison with the control without S application (-S) in both experiments. N concentration of bean plants in the S waste applied pots was higher than that of elemental S applied pots. In the first experiment, P concentration of bean decreased with application of S from both sources as compared to the control. However, concentrations of P enhanced regularly with applications of elemental and waste S in the second experiment. On the other hand, applications of increasing levels of S from both sources did not show any significant effect on plant K concentrations in neither of the experiments. Nevertheless, mean values indicated that K levels of plants were slightly higher in the second experiment comparing to first experiment. Even though calcium (Ca) levels of bean varied in each experiment, the average Ca concentrations of plants gradually increased with applications of increasing S levels in both experiments. Plant Ca levels in the second experiment were significantly higher in comparison with the first experiment. In terms of magnesium (Mg) concentration of plant, it was found that there was not significant difference between different S sources and doses in the first experiment. The level of Mg in plants decreased at higher levels of elemental S applications, but increased with the application of S containing waste

Table 1. Effects of elemental S and S-containing waste on N, P, K, Ca, Mg and Fe concentrations of bean plant.

S Sources	S Doses kg da^{-1}	N (%)			P (%)		
		Experiment 1	**Experiment 2**	**Mean**	**Experiment 1**	**Experiment 2**	**Mean**
Elemental Sulfur	Control	3.94	3.13	3.54	0.34	0.31	0.33
	40	4.08	3.83	3.96	0.27	0.53	0.40
	80	4.39	4.17	4.28	0.28	0.48	0.38
	120	4.48	4.48	4.48	0.24	0.50	0.37
Mean		4.22	3.90		0.28	0.46	
Waste Sulfur	Control	4.05	3.22	3.63	0.29	0.28	0.29
	40	4.17	4.29	4.23	0.25	0.12	0.18
	80	4.34	4.81	4.57	0.20	0.30	0.25
	120	4.54	5.13	4.84	0.17	0.62	0.39
Mean		4.27	4.36		0.23	0.33	
		$LSD_{(0.05)}$ Exp: 0.057; S: 0.057; D: 0.08; ExSxD: 0.16			$LSD_{(0.05)}$ Exp: 0.015; S: 0.015; D: 0.021; ExSxD: 0.042		
S Sources	**S Doses kg da^{-1}**	**K (%)**			**Ca (%)**		
		Experiment 1	**Experiment 2**	**Mean**	**Experiment 1**	**Experiment 2**	**Mean**
Elemental Sulfur	Control	1.71	1.80	1.76	1.64	1.38	1.51
	40	1.38	1.63	1.51	1.51	1.76	1.64
	80	1.57	1.67	1.62	1.64	1.95	1.79
	120	1.87	1.79	1.83	1.79	1.92	1.86
Mean		1.63	1.72		1.64	1.75	
Waste Sulfur	Control	1.73	1.78	1.76	1.69	1.45	1.57
	40	1.69	1.57	1.63	1.45	1.61	1.53
	80	1.54	1.74	1.64	1.52	1.84	1.68
	120	1.67	1.83	1.75	1.84	1.9	1.87
Mean		1.66	1.73		1.63	1.70	
		$LSD_{(0.05)}$ Exp: 0.076; D: 0.108; ExSxD:			$LSD_{(0.05)}$ Exp: 0.083; D: 0.117; ExD: 0.165		
S Sources	**S Doses kg da^{-1}**	**Mg (%)**			**Fe (ppm)**		
		Experiment 1	**Experiment 2**	**Mean**	**Experiment 1**	**Experiment 2**	**Mean**
Elemental Sulfur	Control	0.24	0.27	0.26	267.0	142.0	204.5
	40	0.24	0.27	0.26	238.7	146.3	192.5
	80	0.24	0.23	0.24	294.7	165.7	230.2
	120	0.24	0.21	0.23	273.7	182.3	228.0
Mean		0.24	0.25		268.5	159.1	
Waste Sulfur	Control	0.24	0.28	0.26	271.6	134.3	203.0
	40	0.24	0.26	0.25	269.0	134.7	201.8
	80	0.24	0.30	0.27	353.6	124.0	238.8
	120	0.25	0.33	0.29	280.0	128.0	204.0
Mean		0.24	0.29		293.6	130.3	
		$LSD_{(0.05)}$ Exp: 0.017; S: 0.017; ExS: 0.024			$LSD_{(0.05)}$ Exp: 5.221; D: 7.384; ExSxD:		

Exp = Experiment; S = sulfur sources; D = doses.

average values of two experiments showed better results in S containing waste applications. The first experiment's results showed that Fe concentration increased with both elemental and S containing waste applications except for 120 kg da^{-1} S doses. While Fe concentrations of plants increased with elemental S applications, it decreased with application of S containing waste in the second experiment.

Plant Cu, Mn and Zn concentrations and dry matter production are given in Table 2. Increasing levels of both elemental and waste sulfur applications significantly increased the mean values of copper (Cu) concentrations

Table 2. Effects of elemental S and S-containing waste on Cu, Mn, Zn concentrations and dry matter production of bean plant.

S sources	S Doses kg da^{-1}	Cu (ppm)			Mn (ppm)		
		Experiment 1	Experiment 2	Mean	Experiment 1	Experiment 2	Mean
Elemental Sulfur	Control	2.81	3.00	2.91	28.9	28.3	28.6
	40	3.71	5.03	4.37	22.7	78.3	50.5
	80	5.33	4.47	4.90	20.3	80.0	50.2
	120	5.70	4.90	5.30	18.7	79.0	48.9
Mean		4.39	4.35		22.7	66.4	
Waste Sulfur	Control	3.1	2.78	2.94	31.0	30.4	30.7
	40	2.72	3.77	3.25	27.6	52.8	40.2
	80	2.92	4.17	3.55	27.8	63.4	45.6
	120	2.93	4.37	3.65	22.7	72.3	47.5
Mean		2.92	3.77		27.3	54.7	
		$LSD_{(0.05)}$ Exp: 0.913; S: 0.913; D: 1.291; ExSxD: 2.582			$LSD_{(0.05)}$ Exp: 0.382; S: 0.382; ExS: 0.541; SxD: 0.764		
S sources	**S Doses kg da^{-1}**	**Zn (ppm)**			**Dry Matter (g pot^{-1})**		
		Experiment 1	**Experiment 2**	**Mean**	**Experiment 1**	**Experiment 2**	**Mean**
Elemental Sulfur	Control	28.8	26.9	27.9	3.13	3.55	3.34
	40	65.4	36.1	50.8	3.49	3.65	3.57
	80	78.8	37.9	58.4	4.46	3.95	4.21
	120	78.1	37.1	57.6	4.46	4.12	4.29
Mean		62.8	34.5		3.89	3.82	
Waste Sulfur	Control	29.1	28.7	28.9	3.44	3.26	3.35
	40	61.3	42	51.7	2.59	3.69	3.14
	80	69.4	47.7	58.6	2.36	3.43	2.90
	120	78.5	46.3	62.4	2.47	4.05	3.26
Mean		72.8	38.7		2.72	3.61	
		$LSD_{(0.05)}$ Exp: 1.414; S: 1.414; D: 2.0; ExSxD: 4.000			$LSD_{(0.05)}$ Exp: 0.049; S: 0.049; D: 0.070; ExSxD: 0.139		

Exp = Experiment; S = sulfur sources; D = doses.

of plants. The rate of increase was higher in elemental S applied plants than that of waste containing S applied plants. The mean values of two experiments showed that Cu concentrations of bean rose with applications of both elemental S and S containing waste. Elemental S application had more positive effect on plant Cu concentration when compared to waste S source. Interesting results were found in terms of Mn between the first and the second experiments. While manganese (Mn) concentrations of bean in the first experiment reduced with both S resources, in the second experiment, Mn concentrations increased significantly comparing to the control. Sulfur applications resulted in Zn increase in bean in individual doses as well as the mean values of both experiments. Application of elemental S had positive effect on dry matter production of bean for both experiments and these results affected the means positively. Even though S-containing waste had a positive effect on dry matter production in the second experiment, it had a negative effect in the first experiment and showed adverse effect on the mean values of dry matter production.

Nutrient concentrations and dry matter production of corn plant

Variation in nutrient concentrations depending on S doses from different sources is given in Table 3. Corn N concentration was significantly increased with S doses in 2 continuing experiments individually and their means. Both sources of S showed similar effects on plant N concentrations. Concentration of P from elemental S applied corn plants did not change in 2 experiments but quite significant differences in P concentrations of S containing

Table 3. Effects of elemental S and S-containing waste on N, P, K, Ca, Mg and Fe concentrations of corn plant.

S sources	S Doses kg da^{-1}	N (%)			P (%)		
		Experiment 1	Experiment 2	Mean	Experiment 1	Experiment 2	Mean
Elemental Sulfur	Control	3.16	2.99	3.08	0.23	0.23	0.23
	40	3.21	3.31	3.26	0.24	0.24	0.24
	80	3.47	4.25	3.86	0.25	0.24	0.25
	120	3.44	4.67	4.06	0.28	0.28	0.28
Mean		3.32	3.81		0.25	0.25	
Waste Sulfur	Control	3.20	2.83	3.02	0.23	0.23	0.23
	40	3.33	3.36	3.35	0.25	0.52	0.39
	80	3.54	4.35	3.95	0.23	0.56	0.40
	120	3.67	4.64	4.16	0.23	0.64	0.44
Mean		3.44	3.80		0.24	0.49	
		$LSD_{(0.05)}$ Exp.: 0.057; D: 0.081; ExS: 0.081; ExD:0.114			$LSD_{(0.05)}$ Exp.: 0.010; S: 0.010; D: 0.014; ExSxD: 0.027		
S sources	S Doses kg da^{-1}	K (%)			Ca (%)		
		Experiment 1	Experiment 2	Mean	Experiment 1	Experiment 2	Mean
Elemental Sulfur	Control	3.81	3.49	3.65	0.49	0.51	0.50
	40	3.86	3.42	3.64	0.74	0.68	0.71
	80	3.80	3.40	3.60	0.81	0.83	0.82
	120	3.68	3.46	3.57	0.89	0.85	0.87
Mean		3.79	3.44		0.73	0.72	
Waste Sulfur	Control	3.74	3.65	3.70	0.54	0.61	0.58
	40	3.69	3.69	3.69	0.77	0.72	0.75
	80	3.70	3.73	3.72	0.81	0.79	0.80
	120	3.84	3.78	3.81	0.86	0.78	0.82
Mean		3.74	3.71		0.75	0.73	
		$LSD_{(0.05)}$ Exp.: 0.097; S: 0.097; D: 0.138; ExSxD: 0.275			$LSD_{(0.05)}$ Exp.: 0.048; S: 0.048; D: 0.068; ExS: 0.068		
S sources	S Doses kg da^{-1}	Mg (%)			Fe (ppm)		
		Experiment 1	Experiment 2	Mean	Experiment 1	Experiment 2	Mean
Elemental Sulfur	Control	0.23	0.22	0.22	134.1	128.6	131.4
	40	0.23	0.22	0.23	186.3	136.3	161.3
	80	0.24	0.23	0.23	207.7	140.7	174.2
	120	0.24	0.27	0.25	235.3	147.9	191.6
Mean		0.24	0.24		190.9	138.4	
Waste Sulfur	Control	0.23	0.21	0.22	127.7	115.7	121.7
	40	0.23	0.24	0.23	174.3	86.3	130.3
	80	0.23	0.23	0.23	183.2	82.3	132.8
	120	0.24	0.25	0.24	204.1	76.0	140.1
Mean		0.23	0.23		172.3	90.1	
		$LSD_{(0.05)}$ Exp.: 0.008; D: 0.011; ExD: 0.015			$LSD_{(0.05)}$ Exp.: 2.958; S: 2.958; D: 4.183; ExSxD: 8.367		

Exp = Experiment; S = sulfur sources; D = doses.

waste applied corn plants were observed between the first and the second experiments. Sulfur doses increased concentrations of P in all corn plants especially, ones taken from the S-containing waste applied pots. While potassium concentrations of plant decreased with elemental S application, it generally increased with application of S-containing waste. In terms of Ca concentrations, quite significant increment was determined in both experiments regardless of the S sources. Looking at average values, plant Mg concentrations slightly increased with S doses and no differences were found between the two experiments in terms of Mg. Elemental and S-containing waste doses significantly increased Fe concentrations of corn plants especially, in the first experiments. Though there was a slight increase in Fe concentrations of corn plants in the second experiment with elemental S application, S-containing waste application resulted in a decrease in Fe concentration of corn plants comparing to the control plants.

In terms of the mean Fe values of two experiments, plant Fe concentrations significantly increased with application of elemental S and S-containing waste. Increasing levels of both sulfur sources led to an increase of Cu, Mn and Zn concentrations in corn in two experiments as well (Table 4). Generally, concentrations of these nutrients in corn plants from the second term experiment were significantly higher than in plants from the first term experiment. The effects of waste S source on Cu, Mn and Zn concentrations were found to be higher than that of elemental S applications. Dry weight of corn plant did not change significantly with the applications of different levels of S elemental and S-containing waste sources. Based on the mean values, elemental S applications did not have positive effect on plant growth whereas S-containing waste application especially at moderate doses significantly increased plant dry matter production (Table 4).

Soil pH and residual nutrient concentrations of bean and corn soils

The effects of applications of elemental and S-containing waste on soil pH are presented in Table 5. Sulfur applications resulted in decreased in soil pH. While the initial soil pH was 8.12, it was reduced to 7.49 and 7.55 with application of elemental S, and 7.77 and 7.61 with S-containing waste applications at the highest S level (120 kg S da^{-1}).

As seen in Table 6, all residual nutrient concentrations of soils taken from the bean grown pots significantly increased with increasing S doses from both S sources after two harvest except for Cu and K in elemental S application and Cu in S-containing waste application. Concentrations of nutrient available for plants such as N, Fe, Cu, Mn and Ca in corn grown soils after the end of two experiments increased, whereas Mg levels did not change and Zn and K concentrations decreased with the application of elemental S. On the other hand, concentrations of nutrients available for whole plant in soils treated with S-containing waste after the experiments were higher than that of the control soil without S application.

DISCUSSION

Applications of elemental S and S-containing waste on calcareous soil resulted in an increase nutrient concentrations in bean and corn and residual nutrient concentrations in soil after the harvest. There might be numerous factors may influencing the nutrient concentrations in plants. Acidifying effect leading to partial neutralization of $CaCO_3$ can be one of the most important factors for increased nutrient content. During the oxidation of S, soil pH can be decreased and thus, unavailable form of most nutrients can be changed to available form for plant uptake. As known, most nutrients in the soil are available pH ranging from 6.5 to 7.5 and decrease in pH especially in alkaline soils with high pH, increase the availability of nutrients (Marschner, 1995). The acidifying effect of S has been reported by several authors and similar results were found by Soliman et al. (1992), Neilsen et al. (1993) and Kaplan and Orman (1998). Erdal et al. (2000) reported that application of elemental S to the soil resulted in 0.11 - 0.37 unit decrease in soil pH and the phosphorus uptake of plant and residual P in the soil after the harvest. Results showed that soil pH were decreased by 0.37 and 1.08 units after the application of S containing waste, whereas, soil pH was declined by 0.37 and 0.51 units after the applications of elemental S (Orman and Kaplan, 2000). In another study, elemental S and S-containing waste from an S factory decreased pH from 8.2 to 7.7 and 7.8 respectively and leaf Fe concentration increased similarly with applications of elemental S and S-containing waste depending on decrease in pH (Erdal et al., 2006). Similarly, Kalbasi et al. (1988) reported that applications of S changed pH of the soil or rhizosphere from alkaline to acidic and resulted in increased Fe concentration in plants.

The results of this study showed that nutrient concentrations of bean and corn plants were different from each other in response to applications of both elemental S and S-containing waste. This can be explained with the genotypic differences of plants in terms of nutrient uptake (Marschner, 1995; Kacar and Katkat, 2007).

In summary, both elemental S and S-containing waste had a positive effect on nutrient uptake of plants. It was shown that S containing waste had a significantly higher positive effect on plant nutrition uptake and S containing waste sources can be used instead of elemental S. But decreasing effect of waste sulfur in soil pH should be taken into consideration and amount of waste should be calculated carefully before using especially on soils with low pH.

Table 4. Effects of elemental S and S-containing waste on Cu, Mn, Zn concentrations and dry matter production of corn plant.

S Sources	S Doses kg da^{-1}	Cu (ppm)			Mn (ppm)		
		Experiment 1	Experiment 2	Mean	Experiment 1	Experiment 2	Mean
Elemental Sulfur	Control	2.17	2.15	2.2	35.7	41.3	38.5
	40	2.19	3.46	2.8	27.3	56.4	41.9
	80	3.3	4.91	4.1	20.7	59.7	40.2
	120	3.24	3.21	3.2	28.3	64.1	46.2
Mean		2.7	3.4		28.0	55.4	
Waste Sulfur	Control	2.31	2.28	2.3	42.3	44.8	43.6
	40	3.17	6.14	4.7	24.8	77.3	51.1
	80	3.68	7.73	5.7	22.7	77.7	50.2
	120	3.61	6.13	4.9	19.9	81.5	50.7
Mean		3.2	5.6		27.4	70.3	
		LSD$_{(0.05)}$ Exp.: 0.142; S: 0.142; D: 0.201; ExSxD: 0.403			LSD$_{(0.05)}$ Exp.: 2.588; S: 2.588; D: 3.660; ExS: 3.660; ExD:5.176; SxD: 5.176		
S sources	**S Doses kg da^{-1}**	**Zn (ppm)**			**Dry Matter (g pot^{-1})**		
		Experiment 1	**Experiment 2**	**Mean**	**Experiment 2**	**Experiment 2**	**Mean**
Elemental Sulfur	Control	34.9	31.3	33.1	15.4	17.8	16.6
	40	34.2	33.3	33.8	17.5	18.5	18.0
	80	35.3	47.2	41.3	15.1	15.2	15.2
	120	37.7	52	44.9	15.1	16.0	15.6
Mean		35.5	41.0		15.8	16.9	
Waste Sulfur	Control	35.7	38.1	36.9	14.8	15.5	15.2
	40	44.8	41.3	43.1	16.1	15.9	16.0
	80	48.7	41.8	45.3	15.7	18.2	17.0
	120	46.3	46.8	46.6	13.9	14.3	14.1
Mean		43.9	42.0		15.1	16.0	
		LSD$_{(0.05)}$ Exp.: 1.681; D: 2.377; ExSxD: 4.755			LSD$_{(0.05)}$ Exp.: 1.115; S: 1.115		

Exp = Experiment; S = sulfur sources; D = doses.

Table 5. Effects of elemental S and S-containing waste on soil pH.

S Sources	S Doses kg da^{-1}	Plants	
		Bean	Corn
Elemental Sulfur	Control	8.12	8.12
	40	7.95	7.89
	80	7.66	7.74
	120	7.49	7.55
Waste Sulfur	Control	8.12	8.12
	40	8.00	8.02
	80	7.84	7.89
	120	7.77	7.61

Table 6. Effects of elemental S and S-containing waste on residual nutrient concentrations of bean and corn soils.

S sources	S Doses kg da^{-1}	Nutrient concentrations							
		N (%)	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Bean soils									
Elemental Sulfur	0	0.63	579.0	115.0	3319.0	2.56	2.21	2.56	1.09
	40	0.68	590.0	118.5	3517.0	3.09	1.99	2.75	1.05
	80	0.70	563.0	123.0	4083.0	2.99	2.30	3.40	1.31
	120	0.75	576.0	127.7	4190.0	4.26	1.81	3.51	1.38
Mean		0.69	577.0	121.1	3777.3	3.23	2.08	3.06	1.21
Waste Sulfur	0	0.61	582.0	121.7	3327.0	1.99	2.09	2.52	1.24
	40	0.66	626.0	129.7	3837.0	2.30	2.11	3.54	1.39
	80	0.65	598.0	123.2	3680.0	2.43	2.00	4.19	1.54
	120	0.71	613.0	133.7	4031.0	3.00	1.91	4.17	1.96
Mean		0.66	604.8	127.1	3718.8	2.43	2.03	3.61	1.53
	LSD$_{(0.05)}$	D: 0.044	S: 23.0	S: 5.068 D: 7.168	D: 285.8	S: 0.302 D: 0.426	ns	S: 0.473 D: 0.669	S: 0.259 D: 0.366
Corn soils									
Elemental Sulfur	0	0.49	312.5	120.7	3327.0	2.39	1.67	1.58	1.33
	40	0.57	292.2	120.2	3843.0	2.66	1.79	2.55	1.15
	80	0.61	284.8	120.1	4136.0	3.25	1.74	3.40	1.42
	120	0.70	324.7	120.7	4001.0	2.42	1.75	2.55	1.34
Mean		0.77	303.6	120.4	3826.8	2.68	1.74	2.52	1.31
Waste Sulfur	0	0.55	331.2	112.1	3323.0	1.67	1.66	1.95	1.27
	40	0.60	386.0	126.0	3294.0	2.37	1.90	3.46	1.59
	80	0.69	318.2	122.4	4193.0	2.18	1.99	3.25	1.53
	120	0.70	359.5	129.2	4027.0	2.23	1.83	3.60	1.74
Mean		0.75	348.7	122.4	3709.3	2.11	1.85	3.07	1.53
	LSD$_{(0.05)}$	D: 0.025	S: 18.60 D: 26.31 SxD: 37.2	ns	D: 332.2	S: 0.165 D: 0.233 SxD: .330	S: 0.084 D: 0.118	S: 0.260 D: 0.368 SxD: .521	S: 0.099 D: 0.140 SxD:0.199

S = Sulfur sources; D = doses; ns = not significant.

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