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Transformation of different forms of sulphur in an Alfisols under laboratory and field conditions with maize (*Zea mays* L.)

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Abstract : Field experiment involving four levels of sulphur application (0, 15.0, 30.0, and 45.0 kg S ha^{-1}) indicated the depletion of S-fractions after maize harvest. The available sulphate - S was reduced beyond the critical limit of 10 mg kg^{-1}. Significant increase in residual S fractions was observed except non-sulphate S due to different levels of applied S. There was significantly higher sulphate-S in soil due to added S. Sulphur transformation was also studied under laboratory incubation over a period of two months with seven levels of added sulphur (0, 7.5, 15.0, 30.0, 37.5 and 45.0 kg S ha^{-1}) in soil of the experimental site. Soil samples were drawn twice (on 30^{th} and 60^{th} day) to determine the status of different S fractions. The values of all the S fractions increased with levels of applied S and time of incubation. The correlation between the S fractions at both the stages of incubation indicated significantly positive relations.

Additional key words: *Sulphur fractions, transformation, maize and inter-relationships*

Introduction

The importance of sulphur in plant nutrition is well documented. Sulphur in soils remains both in inorganic and organic forms. These forms of S undergo many transformations as a result of the activities of plants, animals and microorganisms. The S fractions in soils are correlated well with the crop yield and quality parameters (Williams and Steinbergs 1959; Stanford and Lancaster 1961). The information on the changes in different S fractions, *viz.* sulphate S, water soluble S, organic S, non-sulphate S and total S under different crops is scanty particularly in the Alfisols of Karnataka. Thus an understanding of sulphur nutrition of plants and transformation of sulphur in soil is essential. Thus, the present study was undertaken to study the transformation behaviour of added S levels under both field and laboratory conditions.

Material and Methods

To study the effect of graded levels of S application on S fractions during crop growth in field and laboratory conditions, experiments were conducted in an Alfisol at the Main Research Station, University of Agricultural Sciences, Dharwad during the year 1997-98. Initial soil analysis of the experimental site was carried out as per the procedure outlined by Jackson (1973) and Piper (1966).

Field experiment was conducted with maize *cv.* Deccan-103, during summer season of 1998. In both the field and laboratory experiments, basal application of 150 kg N, 75 kg P_2O_5 and 37.5 kg K_2O ha^{-1} were applied through urea, diammonium phosphate (DAP) and muriate of phosphate (MOP), respectively (taking in to account the contribution of P_2O_5 from SSP and N from DAP). In the field experiment, S was applied @ 0, 15, 30 and 40 kg S ha^{-1} through single super phosphate (SSP) in a randomized complete block design (RCBD). Soil samples were collected at 60 days after sowing (60 DAS) and of harvest. An incubation study was carried out at room temperature for two months. One kg of processed surface soil was taken in a series of breadboxes of two kg capacity from the place of field experiment. In the laboratory incubation experiment, S was applied at seven levels of (0, 7.5, 15.0, 30.0, 37.5 and 45.0 kg S ha^{-1}) and replicated thrice in completely randomized design (CRD).

The soils were maintained at field capacity by applying water as and when required. Soil samples were drawn at 30 and 60 days interval and analyzed for different S fractions.

Available S was extracted with 0.15 per cent $CaCl_2$ extractant (Williams and Steinbergs 1959) and analyzed turbidimetrically (Chesnin and Yien 1951). Water-soluble sulphur extracted by one per cent NaCl was estimated (Williams and Steinbergs 1959). Total sulphur was estimated by acid digestion method as described by Bardsley and Lancaster (1965). Organic sulphur was estimated by HCl digestion, $Ca(OAc)_2$ leaching and ignition with $NaHCO_3$ and final extraction with NaH_2PO_4 + 2*N* acetic acid extracting solution (Bardsley and Lancaster 1965). Non-sulphate sulphur was obtained by deducing sulphate sulphur, water-soluble sulphur and organic sulphur from total sulphur.

Results and Discussion

The initial soil (sandy clay loam) had pH 6.8, EC 0.27 dSm^{-1}, organic carbon 1.22 g kg^{-1}, available nitrogen 469 kg N ha^{-1}, available phosphorus 14.5 kg P_2O_5 ha^{-1} and available potassium 221.3 kg K_2O ha^{-1} and CEC 24.3 cmol (p^+) kg^{-1}. A slightly higher content of S fractions was noticed due to the higher organic carbon content of soil.

Laboratory study

The data on the availability of S fractions as influenced by added S levels and days of incubation (Table 1) indicate an increase in S levels and days of incubation. Maximum values were obtained with highest level of applied S (45 kg S ha^{-1}) at both the days of incubation. Total sulphur increased from 970.45 to 985.09 and 1021.75 mg kg^{-1} at 30^{th} and 60^{th} days over no S treatment might be due to the activity of microbes which utilize S as their energy source. The increase in total sulphur with added S and time of incubation is also due to increase in other S fractions. Organic S in the control decreased with time of incubation and was less than the initial value of 116.67 mg kg^{-1}. This may probably be due to no addition of S and mineralisation of S by the soil microorganisms. The application of S significantly increased the organic S from 112.10 to 242.47 mg kg^{-1} at 30^{th} day and from 114.50 to 254.63 mg kg^{-1} at 60^{th} day of incubation from T_1 to T_7 treatments, respectively. The assimilation of sulphate S by the microorganisms might be the reason for immobilization, which resulted in enhanced organic S content. Saggar *et al.* (1981) reported that sulphate S and water-soluble S fractions might be readily converted to organic S during incubation. The water soluble S slightly increased with days of incubation. This may be due the transformation of some S to water soluble S during the initial stages. Significant increase in water soluble S from 18.10 to 47.27 mg kg^{-1} after 30 days and from 20.23 to 48.47 mg kg^{-1} after 60 days of incubation respectively from T_1 to T_7 treatments were observed with added S levels. Jaggi (1973) also reported similar results. Available S (12.50 mg kg^{-1}) decreased to 11.01 mg kg^{-1} after 30 DAI due to microbial assimilation and increased to 14.17 mg kg^{-1} after 60 days after incubation (DAI) due to decreased microbial activity and rapid mineralization. Reddy and Raju (1986) reported that available S was greater at 110 days than at 30 days, in a red sandy loam soil, presumably because of mineralization of organic S by microorganisms. Available S increased from 11.01 to 46.55 mg kg^{-1} after 30 days and from 14.72 to 52.89 mg kg^{-1} after 60 days from T_1 to T_7 treatments, respectively. Classon and Ramaswami (1990) also reported the increase in available S with increasing levels of applied S and time of incubation. Increase in the available sulphate S in the S treated acid soil is due to the multiplication of S oxidizing organisms in the soils after the application of sulphur as reported by Swift (1985). The non-sulphate S also increased with levels of sulphur and time of incubation. This S fraction increased from 823.56 to 843.87 mg kg^{-1} after 30 DAI and to 872.69 mg kg^{-1} after 60 DAI in control treatment. It increased from 843.87 mg kg^{-1} in T_1 to 944.03 mg kg^{-1} in T_7 treatment after 30 DAI and from 872.29 mg kg^{-1} in T_1 to 949.15 mg kg^{-1} in T_7 treatment after 60 DAI, respectively. The variation in this S fraction is due to the variation in other S fractions, *viz.*, available, water soluble and organic S fractions. The total S increased from 970.45 mg kg^{-1} to 985.09 and 1021.75 mg kg^{-1} at 30 and 60 DAI over no S treatment. This increase in the total S content of incubated soil might be due to the activity of microbes, which utilize S as their energy source. The increase in total S with added S and time of incubation is also due to increases in other S fractions.

Table 1. Effect of different levels of sulphur on the availability of sulphur fractions (mg kg^{-1}) in soil under incubation

S fractions /	Total S		Organic S		Water soluble S		Available S		Non-sulphate S	
Treatments	30 DAI	60 DAI	30 DAI	60 DAI	30 DAI	60 DAI	30 DAI	60 DAI	30 DAI	60 DAI
Control (no S)	985.09	1021.75	112.10	114.50	18.10	20.23	11.01	14.72	843.87	872.2
NPK + 7.5 kg S ha^{-1}	1025.42	1088.15	119.37	129.27	24.47	27.80	13.85	19.86	867.74	911.2
NPK + 15 kg S ha^{-1}	1069.63	1123.32	134.77	143.60	26.77	34.17	15.28	25.12	901.82	920.4
NPK + 22.5 kg S ha^{-1}	1142.06	1173.48	155.87	163.40	34.80	38.60	22.91	33.08	929.48	938.3
NPK + 30 kg S ha^{-1}	1192.29	1229.58	192.70	205.30	37.23	42.50	30.48	40.64	931.87	941.1
NPK + 37.5 kg S ha^{-1}	1242.16	1275.43	221.63	235.60	45.67	46.23	35.48	47.12	939.68	946.4
NPK + 45 kg S ha^{-1}	1280.31	1305.04	242.47	254.63	47.27	48.47	46.55	52.89	944.03	949.1
S Em ±	27.013	16.533	4.141	3.006	1.380	1.352	1.593	1.792	30.214	16.22
CD (P=0.05)	81.039	49.599	12.423	9.018	4.140	4.056	4.779	5.376	NS	NS

NS - Non-significant

Table 2. Effect of S addition on dry matter, grain and straw yields and S content and uptake in maize

Treatments	Dry matter accumulation	Crop yield		S Content (%)		S uptake (kg ha^{-1})	
	60 DAS (q ha^{-1})	Grain (q ha^{-1})	Straw (t ha^{-1})	60 DAS	At harvest	60 DAS	At harvest
Control (no S)	34.78	47.66	8.72	0.040	0.075	0.77	2.99
NPK + 15 kg S ha^{-1}	39.06	51.33	9.95	0.106	0.169	2.34	7.28
NPK + 30 kg S ha^{-1}	48.29	54.35	10.50	0.188	0.256	5.03	12.07
NPK + 45 kg S ha^{-1}	52.12	56.16	11.44	0.226	0.367	6.52	18.02
S Em ±	1.147	1.732	0.382	0.007	0.008	0.199	0.521
CD (P=0.05)	3.534	5.338	1.177	0.022	0.026	0.612	1.604

Crop response to added S

Dry matter accumulation, grain and straw yields, nutrient concentration and uptake in maize was significantly affected by S application (Table 2). Higher levels of S application yielded highest drymatter yield at both the stages of crop growth. Singh and Chhibba (1991) also reported similar results in maize and wheat. The grain and straw yields also increased significantly with increasing levels of S application up to 45 kg S ha^{-1} over control. The mean grain yield was 56.16 q ha^{-1} with an increase of 17.83 per cent over control. Application of 15 and 30 kg S ha^{-1} gave an increase of 8.12 and 14.04 per cent grain yield over no S application. Similar trend in increase of straw yield with added S levels was also observed. Sinha *et al.* (1995) also reported significant increase in grain and straw yield of maize with S application. Total S content and uptake were also increased significantly with increase in the levels of S application and decreased gradually towards harvest. Kochar *et al.* (1990) also observed an increase in S content and uptake due to S application in maize. The increase was related to increase in the dry matter yield due to S application.

Forms of S

Soil S fractions originally present in soil to decreased with the growth of maize crop (Table 3). Higher organic S was recorded in soils treated with S. Decrease in organic S with crop growth is due to the S mineralization and availability to plants. Mineralization was enhanced in the presence of plants probably due to greater microbial population in the rhizosphere (Chaudhary and Cornfield 1967) subsequently leading to its uptake by crop plants. Application of S significantly increased the water soluble S and available S but decreased with progressive crop growth. These two S fractions of the soil appeared to be the preferred forms by the plants and might contribute to the pool of available S. The increase in available S due to S application in the present study is in accordance with the reports of Bharat-Singh and Mahendra-Singh (1975). The decrease in available S content with advancement in crop growth may be due to crop uptake in the form of sulphate S. The non-sulphate S content increased with the application of S.This fraction also decreased towards the end of the crop growth period.

Relationship of different forms of S to crop response

Inter-relationship among the different S fractions at different stages showed positive correlations (Table 4) and these S-fractions had significant positive correlation with total S at both the stages. The organic S had significant positive correlation with water soluble S and available S at both the stages but positively correlated to content at 60 DAS and at harvest with non-sulphate S. In general, the total S and water soluble S fractions were correlated with the available S fraction. Williams and Steinbergs (1959) and Bardsley and Lancaster (1965) also reported similar findings. At 60 DAS, dry weight of the plant had positive significant correlation with all the S fractions (Table 5). At harvest, it followed the same trend but it was not-significant with non-sulphate S indicating the inability of the plants to absorb S from non-sulphate S pool. The total plant S content and uptake were correlated significantly and positively to all the S fractions at 60 DAS. At harvest, total plant S content and uptake followed the same trend but showed a positive non-significant relation with non-sulphate S. The positive relation between organic S and total S content and uptake might be due to the uptake of sulphate S released to the soil as a result of microbial assimilation of organic S. A close relation was noticed between total S content and uptake by plant at both the stages. The grain yield of maize correlated significantly and positively to all the S fractions indicating significant contribution from these S fractions. The straw yields also positively and significantly correlated to all the S fractions except non-sulphate S. At harvest, the significant and positive correlations between yields and S fractions indicate the contribution of S fractions towards the available S pool. These results are in conformity with the works of Stanford and Lancaster (1961) and Williams and Steinbergs (1959).

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Table 3. Effect of different levels of sulphur on the sulphur fractions (mg kg^{-1}) in soil under maize

Treatments	Total S		Organic S		Total water soluble		Available S		Non-sulphate S	
	60 DAS	Harvest	60 DAS	Harvest	60 DAS	Harvest	60 DAS	Harvest	60 DAS	Harvest
Control (no S)	898.64	853.45	101.47	84.76	19.95	14.94	15.36	8.64	760.86	744.49
NPK + 15 kg S ha^{-1}	1045.32	938.31	176.81	168.79	29.12	20.77	25.94	14.21	813.37	779.53
NPK + 30 kg S ha^{-1}	1114.03	1027.68	199.89	189.92	48.61	24.02	34.00	16.87	831.53	796.87
NPK + 45 kg S ha^{-1}	1198.90	1087.67	213.97	204.10	62.10	29.78	49.05	24.00	873.79	830.30
S Em ±	27.273	25.075	4.484	3.319	1.159	0.442	0.748	0.839	29.78	26.50
CD (P=0.05)	84.062	77.285	13.820	10.231	3.573	1.362	2.306	2.587	NS	NS

Table 4. Correlation co-efficient (r) between various sulphur fractions.

Different S fractions related	Correlation matrix	
	60 DAS	At Harvest
Total S *vs* Organic S	0.826**	0.819**
Total S *vs* Water soluble S	0.847**	0.827**
Total S *vs* Available S	0.866**	0.671**
Total S *vs* Non-sulphate S	0.871**	0.865**
Organic S *vs* Water soluble S	0.856**	0.895**
Organic S *vs* Available S	0.881**	0.821**
Organic S *vs* Non-sulphate S	0.460*	0.425^{NS}
Water soluble S *vs* Available S	0.961**	0.930**
Water soluble S *vs* Non-sulphate S	0.535*	0.495*
Available S *vs* Non-sulphate S	0.555*	0.300^{NS}

*Significant at 5 % ** Significant at 1 %

Table 5. Correlation coefficient (r) of periodic changes in soil S fractions as influenced by levels of applied S to maize crop

Forms of S	60 days after sowing			At harvest				
	Dry matter accumulation	Plant-S	Plant-S uptake	Dry matter accumulation	Plant-S	Plant-S uptake	Grain yield	Straw yield
Total S	0.826**	0.843**	0.825**	0.644**	0.724**	0.698**	0.675**	0.527*
Organic S	0.811**	0.873**	0.888*	0.768**	0.854**	0.833**	0.708**	0.668**
Water soluble S	0.905**	0.967**	0.946**	0.822*	0.951**	0.946**	0.682**	0.727**
Available S	0.882**	0.943**	0.921**	0.808**	0.905**	0.907**	0.660**	0.738*
Non-sulphate S	0.562*	0.529*	0.499*	0.328^{NS}	0.368^{NS}	0.342^{NS}	0.451*	0.218^{NS}

*Significant at 5 % ** Significant at 1 % NS: Non-significant

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