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Short Communication

Distribution of Sulphur in Some Profiles of Shivpuri District of Madhya Pradesh

R.K. BHATNAGAR, K.N. BANSAL AND S.K. TRIVEDI
Department of Soil Science and Agricultural Chemistry, College of Agriculture, Gwalior, Madhya Pradesh, 470002

Sulphur status varies with the depth depending upon soil pH and drainage characteristics of the soils. Negligible use of organic manures and sulphur containing fertilizer have led to low sulphur content in these soils. Several soil factors influence the availability of sulphur and hence the status of different forms of sulphur in soils varies widely with soil type (Balangoudar & Satyanarayana 1990). Soybean and groundnut which require high amounts of S, are extensively grown covering 80 per cent of the area under study. Since no information is available regarding the status of sulphur in soils of Shivpuri district, the present investigation was undertaken to study the forms of sulphur and their distribution in Inceptisols and Vertisols of Shivpuri district of Madhya Pradesh.

Twenty profiles of Vertisols (Kolaras and Pohri tehsils) and 6 of Inceptisols (Shivpuri tehsil) of district Shivpuri of Madhya Pradesh, were exposed and 110 soil samples were collected horizon-wise for physicochemical properties by using standard procedures. Total sulphur was determined in diacid digest (Chaudhary & Cornfield 1966), available sulphur in $CaCl_2$ extract and organic sulphur after extraction with sodium dihydrogenphosphate (4.6 g L^{-1} NaH_2PO_4 in 2*M* acetic acid) (Bardsley & Lancaster 1965). Simple correlations and multiple regressions were calculated between forms of sulphur and soil properties by adopting standard statistical procedures.

The soil characteristics and forms of S in soils are given in tables 1 and 2, respectively. Two main types of soils occur in Shivpuri district *viz*. Inceptisols and Vertisols. Distribution of different forms of S showed decreasing trend with depth in both Inceptisols and Vertisols. Total S in surface soil of Inceptisol and Vertisol ranged from 790 to 813 and 798 to 987 mg kg^{-1} with mean values of 800 and 892 mg kg^{-1}, respectively. Higher amounts of total S in surface than in sub-surface soils has resulted from its recycling, over the years by plants and subsequent organic matter accumulation. It decreased down the depth in both the orders being lowest at 90-120 cm depth. This may be attributed to low carbon content at lower horizons, which is also evident from the fact that total S showed highly significant coefficient of correlation with organic carbon (Vertisols r = 0.746** and Inceptisols r = 0.874**). Total S appears to be a function of soil organic matter as both are significantly and positively interrelated. Similar results were reported by Trivedi *et al*. (2000). It also showed positive relationships with total nitrogen and silt content in both the orders (Table 3), whereas negative relationships were found with pH, $CaCO_3$ and clay content. Negative relationship between pH and total S was also reported by Sharma and Gangwar (1997). Multiple regression studies for Vertisols and Inceptisols indicated significant and positive relationship with total N (b=4320*), significantly negative with pH (b=-72*) and $CaCO_3$ (b=-1.78**).

Organic S in these soils accounted for 59 and 62 per cent in Inceptisols and Vertisols, respectively. The average organic-S values were higher in Vertisols (556 mg kg^{-1}) than Inceptisols (471 mg kg^{-1}) at surface and decreased with depth. Since Vertisols are moderately rich in organic mater, they are likely to be rich in organic sulphur. A significant and negative correlation of organic-S was found with pH, $CaCO_3$, clay and CEC. It showed significant and positive correlations with organic carbon, silt and total N in both the orders (Table 3). In multiple regression studies it showed significant and positive regression coefficient with organic carbon (b = 1.494*) and total (b=3319**).

Table 1. Range and mean values of physico-chemical characteristics of soils

Parameters	Inceptisols		Vertisols	
	Range	Mean	Range	Mean
pH	7.71-8.30	8.04	7.60-8.60	8.05
EC (dS m^{-1})	0.78-0.97	0.86	0.80-0.96	0.81
Organic carbon (g kg^{-1})	3.44-5.74	4.69	4.11-8.25	5.83
Calcium carbonate (g kg^{-1})	12.5-48.7	29.3	8.5-71.6	29.01
Total nitrogen (g kg^{-1})	0.31-0.84	0.51	0.20-1.10	0.59
CEC [cmol(p^+)kg^{-1}]	18.53-22.02	20.48	30.03-33.53	31.85
Clay (%)	33.29-39.21	35.82	37.56-44.93	41.19
Silt (%)	26.50-32.83	29.63	24.33-30.9	27.20
Sand (%)	33.87-35.04	34.55	30.73-33.42	31.64
Silt+clay (%)	64.94-66.12	65.43	66.57-69.26	68.36

Table 2. Status of different forms of sulphur (mg kg^{-1})

Average depth (cm)	Total-S		Organic-S		Sulphate-S	
	Range	Mean	Range	Mean	Range	Mean
Inceptisols (6 profiles)						
0-15	790-813	800	437-488	471	11.25-13.25	12.27
15-30	668-698	676	381-419	401	9.25-11.50	10.51
30-60	510-534	522	283-319	303	8.96-10.25	9.39
60-90	403-480	440	217-262	248	7.59-8.75	8.32
90-120	293-310	300	155-180	172	6.75-7.70	7.41
Vertisols (20 profiles)						
0-15	798-987	892	441-668	556	9.87-16.25	12.40
15-30	672-781	727	346-491	436	8.75-12.33	10.59
30-60	480-603	546	282-392	333	8.04-10.50	9.45
60-90	387-492	422	212-300	254	7.25-9.13	8.48
90-120	310-385	368	167-206	191	7.81-7.65	7.65

The calcium chloride extractable sulphur content ranged from 11.25 to 13.25 and 9.87 to 16.25 with mean values of 12.27 and 12.40 mg kg^{-1} in surface soils of Inceptisols and Vertisols, respectively. Available sulphur content declined with increase in depth. At sub-surface (15-30 cm) the contents in both the soils were more or less similar, whereas available sulphur found in deeper layers were less than the critical limit 10 mg kg^{-1}. By and large, these soils can be considered as marginal in available S status. The calcium chloride extractable sulphate-sulphur showed positive significant coefficient of correlation with OC (r = 0.794**), silt (r = 0.850**) and total N (r = 0.615**) in Inceptisols and r = 0.545**, 0.615** and 0835** with OC, silt and total N respectively in Vertisols (Table 3). According to Takkar *et al*. (1984) soil organic matter regulates markedly the content of sulphate-S in alluvial soils. Positive relationship of calcium chloride extractable sulphur with organic carbon content and nitrogen was also reported by Trivedi

Table 3. Co-efficients of correlation between forms of sulphur and soil properties

Forms of S	pH	EC	OC	$CaCO_3$	Clay	Silt	Silt+ clay	Sand	CEC	Total-N
Inceptisols										
Total-S	-0.844**	0.129	0.874**	-0.913**	-0.887**	0.829**	-0.084	0.084	-0.830**	0.947**
Org-S	-0.833**	0.129	0.863**	-0.926**	-0.891**	0.826**	-0.076	0.076	-0.806**	0.957**
$CaCl_2$-S	-0.765**	0.192	0.794**	-0.876**	-0.804**	0.850**	-0.255	0.217	-0.761**	0.913**
Water Sol.-S	-0.738**	0.262	0.756**	-0.812**	-0.742**	0.823**	-0.217	0.255	-0.740**	0.867**
Vertisols										
Total-S	-0.885**	-0.008	0.746**	-0.912**	-0.822**	0.806**	0.186	-0.224	-0.746**	0.968**
Org.-S	-0.846**	-0.006	0.746**	0.746**	-0.803**	0.806**	0.154	-0.199	-0.723**	0.957**
$CaCl_2$-S	-0.809**	-0.136	0.545**	0.545**	-0.625**	0.612**	0.171	-0.204	-0.566**	0.835**
Water Sol. S	-0.821**	-0.128	0.560**	0.560**	-0.650**	0.615**	0.211	-0.164	-0.582**	0.844**

et al. (1998). Positive but non-significant relationship between sulphate-sulphur and EC was found in Inceptisols. In multiple regression studies it showed significant and negative regression coefficients with organic carbon (b = -0.263*), pH (b = -1.666*) and positive with silt (b = 0.598*) and total N (b = 52.944*). These results corroborate the findings of Sharma and Gangwar (1997).

In general, pH and electrical conductivity had negative or very low positive correlation with all the forms of sulphur. This may be explained on the basis of the presence of H^+ and OH^- ions on the soil complex, where H^+ ions attract SO_4^{2-} ions. Under high salinity conditions SO_4^{2-} ions may be leached down because of the presence of salts in soluble forms. Positive correlation of different forms of sulphur with organic carbon and total N clearly indicates that the organic matter serves as a reservoir of sulphur (Tabatbai & Bremner 1972).

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Growth Pattern of Urdbean *Rhizobium* sp. with PSB and PGPR in Consortia

HARKESHWAR PRASAD AND R. CHANDRA
Department of Soil Science, College of Agriculture, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttaranchal, 263145

Seed inoculation with effective *Rhizobium* inoculant is recommended to ensure adequate nodulation and N_2 fixation for maximum growth and yield of pulse crops. In last decade many workers have reported that rhizobacteria belonging to groups of phosphate solublising bacteria (PSB) and plant growth promoting rhizobacteria (PGPR) influence the symbiosis, particularly the early events (Dashti *et al.* 1998). Many of these rhizobacteria were found to be synergistic with *Rhizobium* and their co-inoculation with *Rhizobium* showed an improvement in N_2 fixation, nutrient uptake and yield of pulse crops (Algawadi & Gaur 1998; Dube 1997). Since dual inoculation practice is taking a serious turn in maximization of yield of pulse crops, it becomes necessary to develop a common delivery system of all these organisms in plant rhizosphere. To understand the compatibility among different microorganisms, the foremost way is to observe their interaction under cultural conditions. Keeping the above in view, survival of urdbean *Rhizobium* sp. with PSB (*Bacillus megatherium*) and/or PGPR (*Pseudomonas fluorescens*) was examined in consortia in broth medium and inoculant carrier.

An effective strain of *Rhizobium* sp. (UP-1) of urdbean was obtained from the culture collection of AICRP on Pulses in the Soil Science Department and PGPR (*Pseudomonas fluorescens*, GRP-3) from Dr. B.N. Johri, Department of Microbiology in the Uni-