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Different forms of sulphur in soils of Udham Singh Nagar district, Uttarakhand and their relationship with soil properties

S.P. SINGH[1], ROOM SINGH, P.C. SRIVASTAVA AND PANKAJ SINGH

Department of Soil Science, G.B. Pant University of Agriculture and Technology, Pantnagar-263 145, India
[1]Department of Soil Science, Rajendra Agricultural University, Pusa, Samastipur-848 125, India

Abstract : Five hundred surface soil samples from Udham Singh Nagar district, Uttarakhand, were analyzed to assess the status of available S. The available S varied from 4.6 to 118.4 mg kg^{-1}. The soil samples testing low, medium and high in available S were 22, 31 and 47 per cent, respectively. Twenty samples each from low, medium and high S categories were analyzed for some selected soil properties and different forms of S. The contents of total, organic, potassium dihydrogen phosphate extractable, calcium chloride extractable and non-sulphate S in soils ranged from 250 to 917, 106 to 585, 10.3 to 120.5, 4.6 to 118.4 and 37.6 to 333.4 mg kg^{-1}, respectively. Among soil properties, clay content, EC, OC, CEC and total N showed highly significant and positive correlation with all the forms of S except the non-sulphate S whereas soil pH was not related with any form of S.

Additional key words : *Forms of sulphur, tarai soils, soil properties*

Introduction

In India, nearly 57 m ha of arable land suffers from various degrees of sulphur deficiency (Tripathi 2003). The availability of S is largely dependent on its fractions. Nearly 20-25% soils are deficient in sulphur in Uttarakhand (Singh 2001). The present work has been undertaken in soils of one of its agriculturally important districts, i.e. Udham Singh Nagar to assess the status of different forms of sulphur and identify the relationship between the sulphur forms and soil properties.

Materials and Methods

Five hundred surface soil samples were collected from 10 villages of Udham Singh Nagar district in May 2004. These soil samples were analysed for available sulphur to categorise them into low, medium and high categories. Twenty soil samples representing each of these categories were selected from four villages. The selected samples were analyzed for particle-size distribution (Black 1965), soil pH (1:2 soil: water suspension) (Jackson 1967), electrical conductivity (Bower and Wilcox 1965), cation exchange capacity (Black 1965), organic carbon (Nelson and Sommers 1996), total nitrogen (Jackson 1967), available sulphur using 0.15% $CaCl_2$ extractant (Williams and Steinbergs 1959), potassium dihydrogen phosphate extractable sulphur (Ensminger 1966), organic sulphur (Evans and Rost 1945) and total sulphur (Black 1965). Sulphur contents in different extracts were analyzed by turbidimetric method (Chesnin and Yien 1950). The non-sulphate sulphur was obtained by substracting the organic sulphur and available sulphur from total sulphur.

Results and Discussion

Status and available sulphur

The available sulphur ranged from 4.6 to 118.4 mg kg^{-1} with a mean value of 24.6 mg kg^{-1} (Table 1). Out of 500 surface soil samples, 8 to 46 % were found deficient, 8 to 86 % medium and 4 to 78 % high in available sulphur. The overall percentage of soil samples testing low, medium and high in available sulphur was 22, 31 and 47, respectively.

Table 1. Available sulphur in soils

Village/ Hamlet	No. of samples	Availale S (mg kg^{-1})			Per cent samples		
		Max.	Min.	Mean	Low	Med.	High
Pipalia	50	33.8	5.3	17.5	12	66	22
Dhada	50	28.5	6.4	15.1	10	86	4
Shankar farm	50	113.8	8.9	17.1	34	48	18
Bhanga	50	98.1	8.9	30.5	28	12	60
Pulbhatta	50	64.0	8.9	31.0	14	8	78
Dopaharia	50	64.7	4.6	28.7	12	18	70
Pantpura	50	45.5	4.6	20.2	42	16	42
Anjania	50	117.0	5.3	33.7	8	34	58
Patery	50	118.4	6.4	23.9	46	8	46
Azadpur	50	77.2	4.6	28.5	14	12	74
Overall	500	118.4	4.6	24.6	22	31	47

Soil properties

The clay, pH, EC, OC, CEC and total N among all the soils ranged from 9.7 to 42.1 per cent, 6.3 to 8.4, 0.12 to 3.9 dSm^{-1}, 0.38 to 2.16 per cent, 9.3 to 21.3 cmol(p$^+$) kg^{-1} and 0.03 to 0.19 per cent, respectively (Table 2). The mean values of clay, EC, OC, CEC and total N were maximum in high S category and, in general, minimum in low S category soils, whereas, the pH values showed a slight decrease with increase in S status.

Forms of sulphur

Total Sulphur

The mean content of total S was maximum in high S category followed by that in medium and low S category soils (Table 3). The total S content of these soils may be rated as high (Stevenson 1986). The values observed in the present study were closer to those reported by Misra *et al.* (1990), Singh *et al.* (1993) and Sharma and Gangwar (1997) for some Indian soils. The content of total S showed highly significant and positive correlation with clay (r = 0.456**), EC (r = 0.370**), OC (r = 0.527**), CEC (r = 0.355**) and total N (r = 0.548**) in all the soils pooled together (Table 4). Similar results were also reported by Sharma and Jaggi (2001) and Gowrisankar and Shukla (1999). Sarkar *et al.* (2007) found significant and positive correlation with organic carbon and total nitrogen. The total S showed highly significant and positive correlation only with clay (r = 0.620**) in soils low in available S (Table 5). The correlation of total S was positive and significant with organic S (r = 0.897**), potassium dihydrogen phosphate extractable S (r = 0.702**), calcium chloride extractable S (r = 0.697**) and non-sulphate S (r = 0.585**) in all the soils pooled together. In soils low in available S, total S showed significant positive correlation with organic S (r = 0.530*) and non-sulphate S (r = 0.713**). In medium S status soils, total S was positively correlated with organic S (r = 0.817**) and non-sulphate S (r = 0.781**), whereas, in high S soils, it was positively correlated with organic S (r = 0.860**), potassium dihydrogen phosphate extractable S (r = 0.493*), calcium chloride extractable S (r = 0.498*) and non-sulphate S (r = 0.711**). The significant positive correlation between total S and organic S obtained in soils irrespective of S status is obvious as a major part of S is present in the organic form. However, the available ($CaCl_2$ extractable as well as KH_2PO_4 extractable) S had such relationship only in high S status soils because they had appreciable amount of available S.

Organic sulphur

The maximum mean content of organic S in high S category soils may be attributed to their relatively high organic matter content (Table 3). The values of organic S in the soils were in accordance with those reported earlier by Kumar and Singh (1974) and Sharma and Gangwar (1997). The relative proportion of organic S in soils of low, medium and high S categories as well as in all soils pooled together was 58, 63, 66 and 63 per cent, respectively. These values were similar to those reported

Table 2. Important properties of selected soils

Particulars	Clay (%)	pH (1:2)	EC (dSm^{-1})	OC (%)	CEC (c mol(p^+) kg^{-1})	Total N (%)
Soils low in available S	9.7-20.9 (14.4)	6.9-8.4 (7.5)	0.12-0.48 (0.27	0.38-1.56 (0.69)	9.8-21.3 (14.2)	0.03-0.12 (0.06)
Soils medium in available S	12.4-23.1 (16.9)	6.3-8.3 (7.4)	0.12-0.54 (0.27)	0.39-1.28 (0.80)	9.3-20.6 (13.0)	0.03-0.11 (0.07)
Soils high in available S	12.1-42.1 (21.9)	6.7-7.9 (7.3)	0.14-3.9 (0.51)	0.59-2.16 (1.09)	9.8-21.1 (16.0)	0.05-0.19 (0.09)

The figures in the parenthesis indicate the mean values of the respective properties

Table 3. Forms of sulphur in selected soil samples (Range and mean)

Particulars	Total S	Organic S	KH_2PO_4 Extr. S	$CaCl_2$ extr. S	Non- sulphate S
	(mg kg^{-1})				
Soils low in available S	252-561 (415)	106-364 (242)	10.3-15.2 (12.2)	4.6-9.2 (7.7)	37.6-319.3 (165.6)
Soils medium in available S	250-667 (439)	166-389 (277)	13.6-23.5 (18.0)	10.2-18.5 (14.8)	48.7-333.4 (147.2)
Soils high in available S	438-917 (687)	229-585 (455)	28.3-120.5 (58.3)	26.2-118.4 (55.0)	57.1-290.9 (177.4)

Mean values shown in parenthesis

Table 4. Relationship between soil properties and forms of sulphur in all soils (pooled together)

Soil properties	Forms of sulphur: Total S	Organic S	KH_2PO_4 Extr. S	$CaCl_2$ extr. S	Non- sulphate S
Sand	-0.612**	-0.607**	-0.590**	-0.599**	-0.195
Silt	0.627**	0.604**	0.544**	0.554**	0.252
Clay	0.456**	0.497**	0.488**	0.493**	0.057
pH	-0.157	-0.222	-0.146	-0.141	0.057
EC	0.370**	0.303**	0.523**	0.527**	0.166
OC	0.527**	0.576*	0.624**	0.560**	0.052
CEC	0.355**	0.337*	0.359**	0.349**	0.139
Total N	0.548**	0.560**	0.621**	0.608**	0.056

*Significant at 5% level; **Significant at 1% level.

Table 5. Relationship between soil properties and forms of sulphur in soils low in available sulphur

Soil properties	Forms of sulphur				
	Total S	Organic S	KH_2PO_4 Extr. S	$CaCl_2$ Extr. S	Non - sulphate S
Sand	-0.466*	-0.327	-0.055	-0.058	-0.266
Silt	-0.168	-0.237	-0.038	0.394	-0.004
Clay	0.620**	0.535*	0.084	-0.221	0.275
pH	0.027	0.109	0.058	-0.275	-0.054
EC	0.163	0.422	0.567**	0.318	-0.166
OC	0.261	0.618**	0.073	-0.293	-0.205
CEC	0.123	0.314	0.151	-0.205	-0.115
Total N	0.265	0.632**	0.112	-0.222	-0.213

*Significant at 5% level; **Significant at 1% level.

Table 6. Relationship between soil properties and forms of sulphur in soils medium in available sulphur

Soil properties	Forms of sulphur				
	Total S	Organic S	KH_2PO_4 Extr. S	$CaCl_2$ Extr. S	Non - sulphate S
Sand	-0.300	-0.286	0.217	0.193	-0.196
Silt	0.328	0.279	-0.323	-0.309	0.255
Clay	0.169	0.210	-0.036	-0.015	0.053
pH	-0.223	-0324	-0.203	0.032	-0.021
EC	0.064	0.099	0.189	0.237	-0.009
OC	0.345	0.459*	0.346	0.234	0.068
CEC	0.366	0.438	0.201	0.150	0.129
Total N	0.352	0473*	0.312	0.223	0.065

*Significant at 5% level; **Significant at 1% level.

Table 7. Relationship between soil properties and forms of sulphur in soils high in available sulphur

Soil properties	Forms of sulphur				
	Total S	Organic S	KH_2PO_4 Extr. S	$CaCl_2$ Extr. S	Non - sulphate S
Sand	-0289	-0.225	-0.192	-0.211	-0.208
Silt	0.344	0.228	0.040	0.061	0.391
Clay	0.119	0.183	0.231	0.243	-0.115
pH	0.076	-0.107	-0.017	0.004	0.325
EC	0.422	0.259	0.563**	0.570**	0.289
OC	0.313	0.194	0.583**	0.564**	0.147
CEC	0.195	-0.034	0.387	0.391	0.301
Total N	0.320	0.204	0.571**	0.553*	0.154

*Significant at 5% level; **Significant at 1% level.

earlier by Takkar (1988) and Bhatnagar *et al.* (2003) but lower than the values reported by Sarkar *et al.* (2007). The organic S showed significant and positive correlation with clay (r = 0.497**), EC (r = 0.303*), OC (r = 0.576**), CEC (r = 0.337**) and total N (r = 0.560**), when all the soils were pooled together (Table 4), whereas, it had a significant positive correlation with clay (r = 0.535*), OC (r = 0.618**) and total N (r = 0.632**) for low S category soils (Table 5) and only with OC (r = 0.459) in medium S category soils (Table 6). The correlation of organic S was significant only with potassium dihydrogen phosphate extractable S (r = 0.656**) and calcium chloride extractable S (r = 0.648**) for all the soils pooled together. The significant relationship between the organic S and available forms of S showed the dependence of available sulphur on the organic S as the organic matter/organic sulphur markedly regulated the sulphate content in the soils (Takkar 1987).

Potassium dihydrogen phosphate extractable S

Potassium dihydrogen phosphate extractable S was maximum in high S category followed by medium and low S category soils (Table 3). The observed values were slightly higher than the 0.15% $CaCl_2$ extractable S that conform to the work of Pal and Motiramani (1971). This could be attributed to the fact that potassium dihydrogen phosphate extracts readily soluble plus part of adsorbed sulphur (Reinsenauer *et al.* 1973). The potassium dihydrogen phosphate extractable S showed significant and positive correlation with clay (r = 0.488**), EC (r = 0.523**), OC (r = 0.604**), CEC (r = 0.359**) and total N (r = 0.621**) for all the soils pooled together, whereas with EC (r = 0.567**) for low S category and with EC (r = 0.563**), OC (r = 0.583**) and total N (r = 0.571**) for high S category soils (Table 7). The inter-relationship of potassium dihydrogen phosphate extractable S was significant only with calcium chloride extractable S (r = 0.998**) for all the soils pooled together as well as for medium (r = 0.826**) and high (r = 0.998**) S category soils.

Calcium chloride extractable S

The ranges were very close to those reported earlier by Mukhopadhyay and Mukhopadhyay (1980) and Sakal *et al.* (2001). Relative proportion of the calcium chloride extractable S was 2, 3, 8 and 5 per cent of total S, respectively, for the soils of low, medium and high S categories and for all the soils pooled together (Table 3). The observed ranges were similar to the values reported earlier by Ram and Dwevedi (1994) for some soils of Kanpur. The calcium chloride extractable S showed significant positive correlation with clay (r = 0.493**), EC (r = 0.527**), OC (r = 0.560**), CEC (r = 0.349**) and total N (r = 0.608**) for all the soils pooled together, but with only EC (r = 0.570**), OC (r = 0.564**) and total N (r = 0.553*) for high S category soils.

Non-sulphate S

The mean content of non-sulphate S was maximum in high S category followed by low and medium S soils (Table 2). These values were very close to the values reported by Mandal (1994). The relative proportion of non-sulphate sulphur for soils of low, medium and high S categories and for all soils pooled together was 40, 34, 26 and 32 per cent of total S, respectively. Relatively high pH together with probable presence of calcium carbonate and relatively low organic carbon content could be the contributing factors leading to higher amount of non-sulphate S in the soils of low S category. Lower non-sulphate S in the soils of high S category might be due to their slightly lower pH and higher organic matter contents. Under these conditions, there is possibility of continuous break down of the non-sulphate S in surface layer with its subsequent leaching to sub-horizons (Takkar 1987).

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