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FORMS OF SULPHUR AND THEIR RELATIONSHIP WITH SOIL PROPERTIES IN SOILS OF JORHAT DISTRICT OF ASSAM

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ABSTRACT

*Forms of sulphur and their relationship with soil physico-chemical properties were investigated in some surface soils of Jorhat District of Assam. The abundance of various fractions of S was in the decreasing order of total S > organic S > heat soluble S > sulphate S > water soluble S > adsorbed S. Among the sulphur fractions, organic S constituted the dominant fractions (89.2-93.6%) of total S followed by heat soluble S (9.0-17.2 %), sulphate S (5.0-8.4%), water soluble S (3.6-9.0%) and adsorbed S (1.3-3.5%), respectively. All fractions of sulphur exhibited a significant positive correlation with clay, organic carbon and CEC. The significant correlation between different fractions of sulphur suggested an interrelated dynamic equilibrium among all fractions of S. Organic carbon was the most dominant factor governing the Sulphur Availability Index(r=0.433**) followed by CEC(r=0.395**). About 17.5 % of the investigated soils were found deficient in available S.*

Key words: Forms of sulphur, soil properties, sulphur availability index, Jorhat

INTRODUCTION

Sulphur (S) has been widely recognized as the fourth major plant nutrient after nitrogen, phosphorus and potassium for some years. Now sulphur is emerging as the third most important nutrient after nitrogen and phosphorus if extensiveness of deficiencies and not the amounts absorbed by crops is used as the criteria. Widespread deficiency of sulphur in different soils in several states of India have been attributed to continuous use of high analysis S free fertilizers, inclusion of high yielding varieties in the intensive cropping systems and restricted use of organic manures. High annual rainfall (>2000) in Assam, enhances the leaching loss of sulphate, thus catalyzing the incidences of S deficiencies (Borkotoki and Das 2008). To know the exact S supplying capacity of a soil, it is desirable to study the different forms of S rather than the available A as about 90% of total S is present in organic form. Forms of sulphur and their interrelationship with soil properties decide on the sulphur supplying power of a soil by influencing its release and dynamics in soil (Basumatari *et al.* 2010, Das *et al.* 2012). Thus, the knowledge of different forms of S is essential in improving its nutrition of crop. So far, inadequate information is available regarding the status of forms of S in soil of Jorhat district. In view of this, the present study was undertaken to assess the status of different forms of S and identify the relationship between the S forms and soil properties.

MATERIALS AND METHODS

The present investigation was confined to eight different blocks of Jorhat district of Assam. Altogether, 200 surface samples were collected from different blocks of Jorhat district. The soil map released by NBSS & LUP, Regional centre, Jorhat in 1999 was used during collections of samples for this study. The processed soil samples (<2mm) were analyzed for various physico-chemical properties by adopting standard procedures (Jackson 1973). Soil samples were analyzed for different fractions of S *viz*; total S (Chapman and Pratt 1961), organic S (Evans and Rost 1945), water soluble S (Williams and Steinbergs 1959), monocalcium phosphate extractable S (Ensminger 1954), heat soluble S and sulphate S (Williams and Steinbergs 1959). Adsorbed S was calculated by deducting the values obtained with 0.15 % $CaCl_2$ extractable S from those obtained with 500 ppm $Ca(H_2PO_4)_2$ extractant (Fox *et al.* 1964). Sulphur in all extracts was determined turbidimetrically (Chesnin and Yien 1951). Sulphur availability index (SAI) was calculated as per equation given by Donahue *et al.* (1977) as:

SAI = (0.4 × $CaCl_2$ extractable SO_4 in mg kg^{-1} soil) + % organic matter

Simple correlations of different S fractions with some of the relevant physical and chemical properties were worked out by standard statistical methods.

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RESULTS AND DISCUSSION

Soil Properties

Some of the important physico-chemical properties are presented in Table 1. Sand is the dominant fraction of mechanical composition and influences the soil texture which varies from sandy loam to silt loam. Soil reaction, in general, was found to be strongly acidic to neutral in reaction with pH values ranging from 4.0-7.0. The organic C content of the soil was low to high with values ranging from 3.5-9.8 g kg^{-1} with a mean value of 6.5 g kg^{-1}. The CEC of the soil was found to be low [5.0-9.0 cmol (p^+) kg^{-1}]. The available nitrogen, phosphorus and potassium content of the soils were in low to medium in range.

Table 1: Physico-chemical properties of soils of different blocks of Jorhat district of Assam

Block	Sand (%)	Silt (%)	Clay (%)	pH	O.C (g kg^{-1})	CEC cmol (p+) kg^{-1}	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
Bagchung	15.5-77.8 (58.6)	11.0-57.5 (25.5)	10.0-27.0 (16.3)	4.3-6.6 (5.5)	3.5-9.7 (5.8)	5.2-8.8 (6.5)	120.0-525.0 (286.3)	8.1-31.8 (20.3)	157.8-331.3 (226.9)
Dhekargorah	15.5-78.8 (46.3)	10.95-57.5 (30.8)	10.0-39.8 (22.7)	5.0-6.7 (5.7)	6.2-8.4 (7.5)	5.2-9.0 (7.0)	170.0-501.1 (340.4)	10.0-43.3 (24.7)	108.7-328.9 (244.9)
Kaliapani	18.6-77.5 (54.0)	11.3-55.5 (27.1)	10.0-36.5 (18.8)	4.0-6.1 (5.1)	5.5-9.8 (7.4)	5.1-8.1 (6.8)	123.0-465.5 (313.6)	13.0-54.0 (28.1)	103.0-331.2 (212.9)
Titabar	20.5-77.5 (58.3)	11.0-54.5 (25.4)	10.0-32.0 (16.7)	4.7-6.8 (5.8)	6.0-9.4 (7.4)	5.3-7.8 (6.5)	201.0-478.5 (321.9)	18.5-48.0 (32.2)	108.7-328.9 (250.0)
Majuli	20.5-79.5 (57.8)	10.5-54.5 (26.4)	10.5-26.0 (16.4)	4.6-7.0 (5.9)	4.3-8.9 (7.0)	5.2-8.3 (6.6)	171.1-320.0 (253.5)	11.8-37.0 (25.0)	121.5-335.5 (252.9)
Sipahikhula	20.5-77.3 (50.8)	10.0-54.5 (30.3)	12.0-27.0 (19.8)	4.8-6.5 (5.8)	3.5-8.0 (5.2)	5.1-8.5 (6.7)	107.6-425.0 (272.6)	13.8-37.5 (25.0)	107.5-325.0 (232.8)
Selenghat	20.5-79.5 (56.5)	10.0-54.5 (26.8)	10.5-29.0 (16.9)	4.5-6.7 (5.5)	4.0-8.2 (5.3)	5.0-7.7 (6.1)	123.0-425.0 (274.1)	9.9-33.0 (20.9)	107.5-316.7 (220.2)
Ujani Majuli	22.8-77.3 (53.3)	10.0-52.0 (26.0)	10.0-39.0 (20.6)	4.3-6.7 (5.5)	4.8-8.7 (6.5)	5.0-8.3 (6.5)	119.5-367.5 (240.9)	14.7-35.0 (23.4)	121.4-335.5 (242.1)

Forms of sulphur

Total S

Total S content, which indicates the reserve pool of this element in soil, ranged from 125.4 to 662.1 mg kg^{-1}. Among the blocks, soils from Dhekargorah block recorded the highest content of total S (470.8 mg kg^{-1}) while the lowest was found in Ujani Majuli block (341.9 mg kg^{-1}). About 89.2-93.6 % of total S was in organic fraction. Comparatively lower values of total S in Ujani Majuli block might be attributed due to lower amount of organic C and clay in this block. Total S exhibited a significant positive correlation with organic C (r=0.563**), clay (r=0.379**), CEC (r=0.572**), available N (r=0.661**), available K_2O (r=0.366**) but negatively with sand content (r= -0.250**). This indicated that total S content of the soil increased with an increase in organic C and finer fractions of the soils whereas, decreased with an increase in sand. Thus, it is established fact that fine textured soils controls total S along with organic C. These findings corroborate with the findings of Kour and Jalai (2008) and Borkotoki and Das (2008). Total S was found to be significantly and positively correlated with all fractions of S, except the adsorbed fraction in some block. Thus, it indicated that all fractions of S maintained a dynamic equilibrium in these soils. Existence of various relationships among various fractions of S was also reported by Basumatari *et al.* (2010).

Organic S

The organic S was found to be the dominant fractions of S in soils and accounted for 89.2-93.6 % of total S in these soil samples. The soils of Dhekargorah block exhibited the highest content of organic S (427.3 mg kg^{-1}) followed by Bagchung block (426.7 mg kg^{-1}) (Table 2). Such variation was found to be mainly due to variation of soil organic matter and soil texture. Further, it was observed that among the blocks, the organic C and clay per cent was observed highest in Dhekargorah block. These observations were sustained by the significant positive correlation of organic S with organic C (r= 0.532**) and clay(r=0.346**) (Table 3). These findings corroborate with the findings of Das *et al.* (2011). Like that of total S, organic S content also showed highly significant positive correlation with available N (r=0.633**) and CEC (r=0.528**) but negative with soil pH (r= -0.499**) and sand (r=-0.221**). This might be due to the fact that organic C is the main source of organic S, therefore positive significant correlation are expected. Borkotoki and Das (2008) and Basumatary and Das (2012) had also made similar observation in soils of Assam. Organic S maintained a significant and positive relationship with all fractions of S confirming their influence in maintaining organic matter bound S in a dynamic equilibrium, except the adsorbed fraction. Similar results were also reported by Das *et al.* (2012) and Singh (2015).

Table 2: Different forms of S (mg kg^{-1}) in soils of different blocks of Jorhat district of Assam

Block	Total S	Organic S	Adsorbed S	Sulphate S	Heat soluble S	Water soluble S	SAI*
Bagchung	250.0-649.0 (455.7)	237.5-600.0 (426.7)	2.3-11.2 (6.8)	5.0-45.0 (28.0)	10.9-85.5 (43.0)	5.5-29.0 (16.2)	2.7-19.7 (9.7)
Dhekargorah	300.0-662.1 (470.8)	262.8-591.2 (427.3)	3.0-25.5 (10.6)	12.7-50.0 (32.8)	30.5-85.2 (64.0)	17.3-39.0 (27.4)	6.2-21.4 (14.1)
Kaliapani	262.6-625.5 (440.5)	246.2-586.6 (405.2)	2.8-15.0 (8.0)	10.6-64.0 (27.3)	28.8-78.7 (61.1)	5.5-36.3 (22.0)	5.3-27.3 (12.5)
Titabar	279.9-623.1 (443.3)	237.5-574.1 (405.5)	2.0-13.8 (7.0)	4.7-55.0 (22.1)	35.0-87.7 (63.3)	5.3-45.9 (22.7)	2.9-23.6 (10.4)
Majuli	215.5-512.5 (366.1)	195.5-475.0 (326.4)	2.4-21.0 (8.9)	6.3-52.0 (26.5)	10.5-82.5 (63.1)	6.5-45.5 (25.8)	3.7-22.3 (11.9)
Sipahikhula	215.5-512.5 (387.5)	195.5-447.0 (347.5)	2.4-18.0 (7.5)	6.3-56.0 (32.5)	18.0-78.0 (55.8)	13.0-49.0 (25.0)	3.3-23.8 (12.9)
Selenghat	212.5-625.0 (391.7)	203.8-575.3 (362.3)	1.6-11.2 (4.9)	5.0-53.0 (24.0)	32.5-87.5 (61.7)	5.3-42.0 (17.1)	2.7-33.2 (12.0)
Ujani Majuli	125.4-600.0 (341.9)	105.8-563.8 (307.5)	3.1-25.0 (11.7)	10.0-46.3 (28.0)	31.0-80.0 (51.5)	5.8-45.0 (26.8)	4.8-19.7 (12.3)

**SAI: Sulphur Availability Index*

Water soluble S

Water soluble S accounts for a small fraction of total S. This form, on an average, contributed 3.6-9.0 % of total S. Relatively low concentration of this fraction might be due to leaching loss of sulphate from soil layers. The highest and the lowest content of water soluble S was found in soils of Dhekargorah block and Bagchung block with a mean value 27.4 and 16.2 mg kg^{-1}, respectively .Water soluble S had a positive and significant interrelationship with all other fractions of S except the adsorbed fraction in some blocks. Similar observations have also been reported by Basumatari *et al.* (2010) in some Inceptisols of Assam.

Water soluble S exhibited a positive and significant correlation with clay (r=0.490**), organic C (r=0.467**), CEC (r=0.467**) and available N (r=0.289**) indicating the influence of organic matter and clay fractions on S availability. Similar observations have also been made by Borkotoki and Das (2008) in some Entisols of Assam. The observed significant positive correlation between water soluble S and available N in the present investigation can be explained with the fact that S being an integral part of organic matter, the amount of organic C determines available S status. Moreover, since S and N are the essential constituents of proteins in organic matter, they maintain a definite N: S ratio in the later. Hence, a significant and positive correlation of available S with available N is imminent. Water soluble sulphur was also found to be positively correlated with CEC implying that sulphate is loosely bound in exchangeable bases which could be dissolved easily by distilled water containing NaCl (Basumatary *et al.* 2008).On the other hand, it exhibited a negative correlation with pH and P_2O_5 because when pH increases, sorption of sulphur and phosphorus decreases which in turn augment the water soluble S in solution. This was in close agreement with the findings of several earlier workers (Basumatary *et al.* 2008, Das *et al.* 2011, Basumatary and Das 2012) in soils of Assam.

Heat soluble S

This fraction of S also referred to as mineralizable S, constituted about 9.0-17.2 % of total S. Mineralizable S content was comparatively larger than that of water soluble-S, sulphate–S and adsorbed-S. Higher amount

Table 3: Correlation coefficient values (r) among different forms of sulphur and soil properties

Soil properties	Total S	Organic S	Adsorbed S	Sulphate S	Heat soluble S	Water Soluble S	SAI
pH	-0.525**	-0.499**	-0.249**	-0.425**	-0.376**	-0.355**	-0.187**
OC	0.563**	0.532**	0.359**	0.459**	0.476**	0.467**	0.433**
CEC	0.572**	0.528**	0.351**	0.439**	0.456**	0.467**	0. 395**
N (kg ha^{-1})	0.661**	0.633**	0.178*	0.422**	0.434**	0.289**	0.342**
P_2O_5 (kg ha^{-1})	-0.088	-0.096	-0.107	-0.045	0.007	-0.029	-0.023
K_2O (kg ha^{-1})	0.366**	0.317**	0.267**	0.378**	0.355**	0.403**	0.227**
Sand (%)	-0.250**	-0.221**	-0.173	-0.147	-0.114	-0.383**	-0.139
Silt (%)	0.139	0.119	0.046	0.228**	0.107	0.160	0.120
Clay (%)	0.379**	0.346**	0.345**	0.464**	0.392**	0.490**	0.206**

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

of heat soluble S is attributed to release of additional amount of S from organic as well clay minerals on wet and dry heating of the soil during extraction. Among the blocks, the soils of Dhekargorah block contained the highest amount of heat soluble S (64.0 mg kg^{-1}) while the lowest in soils of Bagchung block (43.0 mg kg^{-1}). A significant positive correlation between heat soluble S and almost all the soil properties revealed that heat soluble S had direct bearing with these properties. Similar observations have also been reported by Borkotoki and Das (2008) in some Inceptisols of Assam. Significant and positive correlation of heat soluble S with all fractions of S indicated that almost all fractions of S had contributed towards heat soluble S (Sharma and Jaggi 2001, Basumatary *et al.* 2008).

Adsorbed S

This form of S contains adsorbed SO_4^{-2} along SO_4^{-2} ion present in soil solution. Thus, the adsorbed S, generally, is obtained by subtracting the values of SO_4^{-2} (0.15% Ca Cl_2) from that of Ca (H_2 PO_4) extractable S. This fraction accounted for the smallest fraction of the total S. It constituted 1.3-3.5 % of total S of the soils. Low adsorbed S indicated that due to high rainfall of Assam, OH^- ions in the rain water displaced the adsorbed sulphate resulting in its leaching losses. Adsorbed S was the highest in soils of Ujani Majuli block (11.7 mg kg^{-1}) and the lowest in soils of Selenghat block (4.9 mg kg^{-1}). Correlation study indicated that adsorbed S was positively correlated with clay (r=0.345**), organic C (r=0.359**), CEC (r=0.351**) and available N (r=0.178*) of the soil (Table 3). Since, adsorbed S is considered as the potential source of available S in soil, it is remarkable to observe a positive correlation of adsorbed SO_4^{2-} with organic C, clay and silt and thereby, indicated their dominant role in sulphate sorption in these soils. Adsorbed S was found to be positively correlated with all fractions of S.

Table 4: Correlation coefficient values (r) among different fractions of sulphur

Soil properties	Organic S	Adsorbed S	Sulphate S	Heat Soluble S	Water soluble S	Sulphur availability index
Total S	0.988**	0.311**	0.453**	0.522**	0.420**	0.315**
Organic S		0.274**	0.370**	0.482**	0.359**	0.215**
Adsorbed S			0.205**	0.264**	0.351**	0.160*
MCP S			0.944**	0.502**	0.664**	0.730**
Sulphate S				0.471**	0.621**	0.774**
Heat soluble S					0.499**	0.299**
Water soluble S						0.463**
SAI						1.00

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

Sulphate S

Sulphate fraction of S is most important for plant nutrient point of view and may prove a suitable index in evaluating the amount of S available to the plants. This fraction constituted 5.0-8.4 % of total S. Soils of Dhekargorah block exhibited the highest amount of sulphate S (32.8 mg kg^{-1}) whereas the lowest was observed in soils of Titabar block (22.1 mg kg^{-1}). High value of S may be due to high content of organic matter and finer fractions of soils in Dhekargorah block. Sulphate S exhibited a significant positive correlation with clay (r=0.464**), organic-C (r=0.459**), CEC (r=0.439**), available N (r=0.422**), available K_2O (r=0.378**) and negative with soil pH (r=-0.425**), and sand (r=-0.147). Such correlation might be due to strongly weathered acid soils rich in Fe and Al oxides that caused more adsorption of S from the soil solution (Biswas *et al.* 2003) while the solution pH which controls the polarity and surface density of adsorption plane like Fe and Al oxides in such a way that their magnitude increases with drop in soil pH, resulting in enhancement of sulphate adsorption with decrease in pH and *vice versa*. The observed significant positive correlation of sulphate S with clay and organic C suggests that sulphur supplying power of these soils is largely dependent upon both these parameters. These results are in accordance with those of Ghosh *et al.* (2005) and Kour and Jalai (2008). Sulphate S existed in a state of dynamic equilibrium which was evident from the positive significant correlations with almost all fractions of S. This is in close agreement with findings of Sharma and Jaggi (2001) and Pandy *et al.* (2015).

Table 5: Percent samples in deficient, medium and sufficient category

Blocks	Available sulphur %		
	Deficient	Medium	Sufficient
Bagchung	28.0	24.0	48.0
Dhekargorah	0.0	16.0	84.0
Kaliapani	8.0	36.0	56.0
Titabar	28.0	24.0	48.0
Majuli	20.0	8.0	72.0
Sipahikhula	16.0	12.0	72.0
Selenghat	32.0	24.0	44.0
Ujani Majuli	8.0	16.0	76.0
Mean	17.5	20.0	62.5

Delineation of Sulphur Deficient Areas

The delineation of sulphur deficient areas in the present investigation was done by computing the Sulphur Availability Index (SAI) using the following relationship:

SAI = (0.4 × $CaCl_2$ extractable SO_4 in mg kg^{-1} soil) + % organic matter

Based on SAI values (<6.0 low, 6-9 medium and > 9 high in sulphur status), 17.5, 20.0 and 62.5 % soils of Jorhat district were categorized as S-deficient, medium and sufficient, respectively. Maximum deficiency (32 %) was observed in soils of Selenghat block while the Dhekargorah block was not deficient in available sulphur. Correlation studies showed that organic-C was the most dominant factor governing sulphur availability index (r=0.433**) followed by CEC (r= 395**). Sulphur availability index was also significantly influenced by clay, pH, available N and available K_2O (Table 3). All the forms of S were significantly correlated with sulphur availability index in these soils (Table 4).

From the study, it can be concluded that all the forms of sulphur were positively and significantly correlated among themselves indicating existence of dynamic equilibrium among different forms of sulphur. Using SAI values for delineation of sulphur deficient areas in the present investigation, it was observed that 17.5% areas were S-deficient, 20.0% medium and 62.5% S-sufficient. Maximum deficiency (32%) was observed in soils from Selenghat block while maximum sufficiency (84%) in soils from Dekargorah block.

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