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Distribution of Forms of Sulphur and Their Relationships with Soil Attributes in Tea Growing Soils under Different Agro-climatic Zones of Northeastern India

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ABSTRACT

Distribution of different forms of sulphur (S) and carbon-nitrogen-sulphur relationships were studied in surface and subsurface soils of some tea growing areas of Northeastern India. The soils were strongly acidic in reaction (pH - 4.0 to 5.5), low to very high in organic carbon (4 to 54 g kg^{-1}), with cation exchange capacity (8.8 to 19.2 cmol(p^+)kg^{-1}) and base saturation (50 to 77 %). Organic S mostly contributed to the total - sulphur (62 to 77 %) followed by Non sulphate S (28.8 to 37.2%) and sulphate S (0.7 to 1.4 %). Except sulphate S, other forms of sulphur showed significant positive correlation among themselves as well as with organic carbon and total nitrogen. The C:N, C:S, N:S and C:N:S ratio varied from 8.2 to 10.0, 6.18 to 71.57, 0.62 to 7.26 and 100:10.1:1.4 to 100:12.2:16.2 respectively. Wider C:N:S ratios in all the surface and sub-surface soils indicated that the major portion of nitrogen and sulphur in tea growing soils of Northeastern India is locked up in organic combination which might pose as a potential threat towards tea plantation if application of sulphur is continuously ignored .

1. Introduction

Tea (Camellia sinensis L.) is one of the most accepted beverages globally. Tea plants are perennial shrubs cultivated mainly in acidic soils of the subtropics. The Northeastern region of India produces the world's best quality tea and constitutes over 80 percent of total tea producing zones of India. The yields (1600 $kgha^{-1}$) are however, lower than that obtained in southern part of India (2100 $kgha^{-1}$) (Sharma and Sharma, 1992)[13]. One of the major reasons for the low yield is the low level of available - S in the soils of this region (Sharma and Sharma, 1992)[13]. It is estimated that a hectare of tea removes around 6 kg - S for yielding 30 ton of made tea (Gohain and Dutta, 1994)[7]. Due to heavy rainfall and low pH, leaching and volatization losses from these soils are very high. In addition, use of S free fertilizer further increases the negative balance of S (Reddy et al., 2001)[11] in these soils.

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Soil S is present in both organic and inorganic forms. Most S is accumulated as organic S. The proportion of inorganic S to total S is usually less than 10% in surface soils (Freney, 1986; Nguyen and Goh, 1994)[6][10]. Although inorganic S constitutes a very small proportion of total soil S, it contains SO_4^{2-} ions which can be readily available for plant uptake (Yang et al., 2007)[19]. In contrast, virtually all organic S is unavailable to plants until it is mineralized to SO_4^{2-} (Freney, 1986)[6].

In this context, the knowledge of different forms of sulphur in soils together with their distribution and interrelationship with various soil attributes is essential for improving the sulphur nutrition of tea (Bandyopadhyay and Chattopadhyay, 2002)[1]. Therefore the present study was undertaken to evaluate the status and different fractions of sulphur and their interrelationship with various soil attributes in the tea growing soils of the Northeastern region of India.

2. Materials and Methods

2.1. Study Site

The agro-ecological zone is a homogenous land unit in terms of climate, with a length of growing period and soil-physiographic conditions. Based on the superimposition of these basic maps, viz. soil-physiography, bio-climate and length of growing period, agro-ecological sub regions (AESR) (Mandal et al., 1995)[9] have been generated. The study sites are situated at the Banaspaty (Cachar, 24°50′N and 92°51′E, AESR-15.5), Putharjhora (Jalpaiguri, 26°32′N and 88°46′E, AESR-15.3), and Samabeong Tea Estate (Darjeeling, 27°03′N and 88°18′E, AESR-16.2), India. Soils were collected from different garden cultivated with tea, which is the major land use in this region. The region is typically monsoonal, with three distinct seasons in a year: a warm and wet rainy season (June to September), a heavy winter (October to February), and a hot and relatively dry summer (March to May). The long-term (1983 to 2003) yearly average rainfall is 2845-3500 mm; the average monthly temperature ranges from 5-10°C (January) to 25-30°C (May). The average relative humidity reaches up to 97% during September, and shows the minimum (38%) in March.

2.2. Soil Collection and Analysis

During the summer season (May) of 2006, a total thirty soil samples each from surface (0 – 25 cm) and subsurface (25 – 50 cm) were collected from three major agro-ecological sub regions (AESR) in the tea growing zones of Northeastern India. Soil samples collected from three representative Tea Estates viz Banaspaty, Putharjhora and Samabeong Tea Estate were air dried, sieved and analyzed for different physicochemical properties following standards procedures (Black, 1965)[2]. Total and organic-S were determined as per methods outlined by Choudhary and Cornfield (1966)[5] and Bradsley and Lancaster (1960)[3] respectively. Sulphate-S was extracted with 0.15 percent $CaCl_2$ (Black, 1965)[2]. Sulphur in all the extracts was determined by the turbidimetric procedure of Chesnin and Yien (1951)[4]. The difference between organic-S plus sulphate-S contents and total-S was denoted as nonsulphate-S (Sharma et al., 2003)[15].

2.3. Statistical Analysis

Statistical analyses such as standard deviation, correlation and LSD analyses were carried out using SPSS 13.0.

3. Results and Discussion

3.1 Physico-chemical Properties

Fig. 1 shows the physico-chemical properties of the studied soils. The soils are light in texture and highly acidic (pH - 4.0 to 5.5) in reaction. The concentration of H^+ ions (2.6 to 4.5 cmol(p^+)kg^{-1}) in all the tea growing soils remained higher in comparison to the Al^{3+} ions (1.1 to 2.6 cmol(p^+) kg^{-1}). Cation exchange capacity was between 8.8 to 19.2 cmol (p+)/kg, where as base saturation of the soils was lower (50 to 77 %) than the other soils (Bandyopadhyay and Chattopadhyay, 2002)[1] because of heavy leaching due to high rainfall conditions.

Organic carbon and total N contents were higher in the soils of AESR 16.2 followed by that of AESR 15.3 and AESR 15.1. Higher organic carbon status in the soils of AESR16.2 might be attributed to lower temperature regime, which prevented faster microbial decomposition of organic matter (Saggar et al., 1998)[12]. Availability of N, P_2O_5 and K_2O revealed that the soils were moderately to well supply with nutrients (Sharma et al., 2003)[15].

3.2. Total Sulphur

Total S content was highest in Samabeong followed by Putharjhora, and Banaspati (Fig. 2). The S contents ranged from 512 to 1200 mgkg^{-1}. Total-S was higher in the surface horizons and decreased at the sub-surface levels in all the soils. This might be due to the fact that most of the sulphur present in these soils was organic in nature. Total-S status was reported to follow similar trend in the soils from different parts of India (Sharma et al., 2003, Bandyopadhyay and Chattopadhyay, 2002)[15][1]. Total-S showed significant and positive relation with organic carbon (r = 0.625**) and total–N (r = 0.626**) while negative correlation with clay (r = - 0.356**) (Table 1).

3.3. Organic Sulphur

Organic–S contents ranged from 222.9 to 940 mg kg^{-1}

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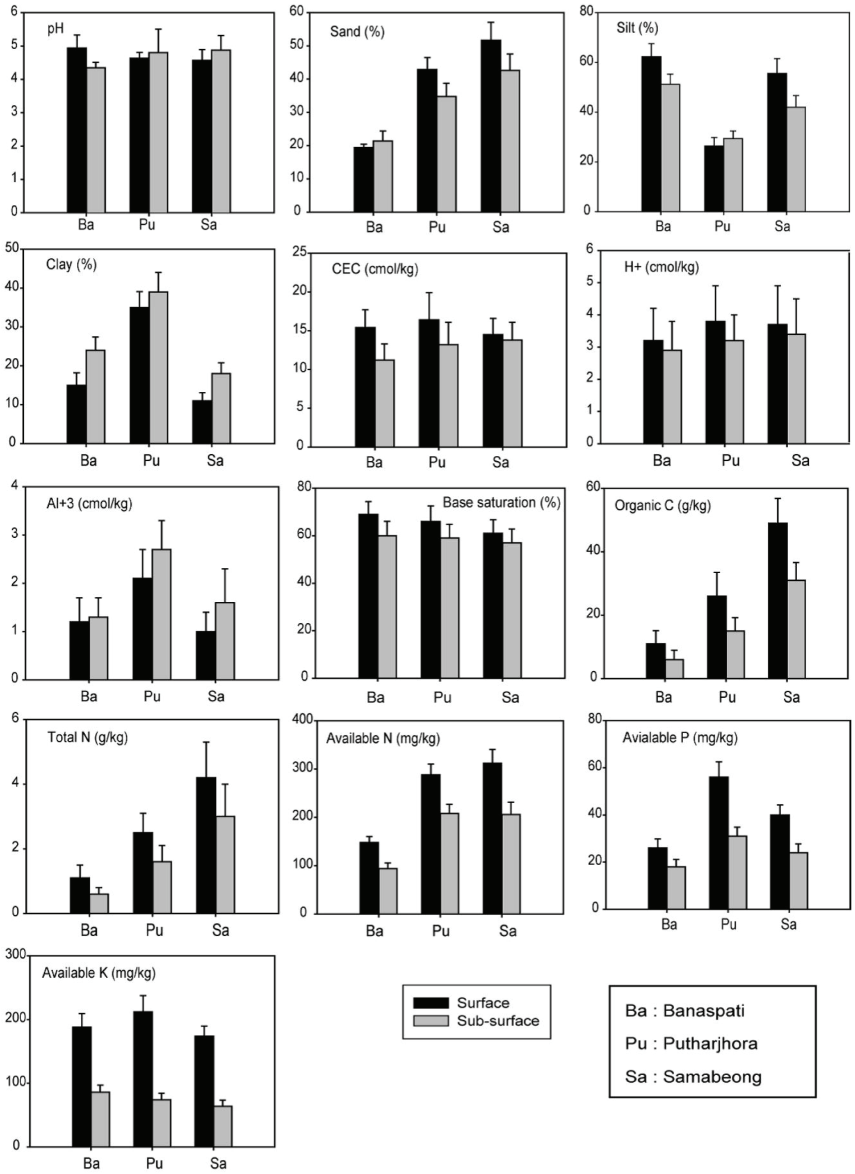

Figure 1. Physico-chemical properties of studied soils

and the value decreased in the sub-surface soils. The higher values of the organic – S in surface soils might be due to high content of organic matter (Srinivasarao et al., 2004)[16]. Organic–S constituted about 62 to 77 percent of total sulphur and this clearly indicated that major part of S in soils was locked up in organic matter and soil minerals, which might serve as a storehouse for tea nutrition following the mineralization process (Saggar et al., 1998)[12]. Kanwar and Takkar (1964)[8] found organic-S in the range of 46 to 91 percent of total–S in the tea growing soils of Kangra valley, India. In the soils of Samabeong and Putharjhora tea estate organic–S accounted for larger percent of total – S in comparison to the soils of Banaspaty tea estate, which may be attributed to the high organic carbon in these soils (Takkar, 1988)[17]. All the profiles showed the decreasing trend of organic S with the depth. The extent of decrease in organic S was in accordance with the decrease of organic carbon content of the soil. Intensive root activity, besides addition of considerable leaf litter during cropping, contributed to the higher organic carbon content in surface layers of the profiles, thus resulting in larger organic S in surface soils (Srinivasarao et al., 2004)[16]. Organic-S showed significant and positive correlation with Organic carbon (r = 0.629**) and total-N (r = 0.629**) and significant negative correlation with clay content (r = -0.389*) (Table 1). The positive relationships of organic-S with organic carbon and total-N suggested a simultaneous increase in the status of nitrogen and organic – S in these soils with increase in organic carbon content.

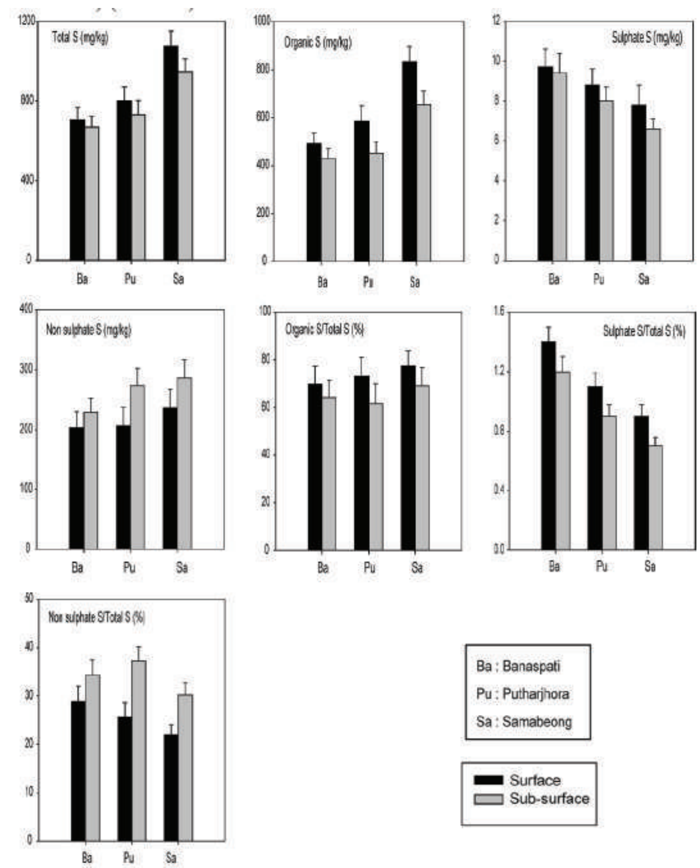

Figure 2. Distribution of different forms of sulphur in studied soils

Table 1. Correlation coefficient among soil attributes and forms of sulphur in studied soils

Parameter	pH	Org.C	Clay	CEC	Ex.Al^{3+}	Total-N	N:S	C:S	NS-S	SO_4-S	Org.-S
Total - S	0.191	0.625**	-0.356**	-0.158	-0.159	0.626**	0.251	0.264	0.492**	0.208	0.978**
Org - S	0.21	0.629**	-0.389**	-0.087	-0.155	0.629**	0.256	0.271	0.459**	0.352*	-
SO_4 - S	0.38**	-0.313*	0.132	-0.033	-0.369**	-0.319*	-0.531**	-0.525**	-0.022	-	-
NS - S	-0.018	0.468**	-0.017	-0.362**	-0.066	0.360*	0.106	0.107	-	-	-
C:S	0.09	0.900**	-0.056	0.503**	0.556**	0.903**	0.999**	-	-	-	-
N:S	0.073	0.889**	-0.05	0.499**	0.555**	0.894**	-	-	-	-	-

NS-S : Non sulphate sulphur ; *Significant at 5% level; **Significant at 1% level.

3.4. Sulphate Sulphur

Sulphate–S content in the soils varied from 4.0 to 10.9 and constituted merely 0.7 to 1.4 per cent of total sulphur. Available S content was found to be higher in surface layers and decreased with the depth in most of the profiles. Larger available S status in surface layers could be attributed to higher organic carbon content in those layers. Thus a sizeable chunk of total - S remained as unavailable form. This was in close agreement with the findings of Yang et al (2007)[19]. Considering the critical value of 10 ppm for sulphate-S (Kanwar and Takkar, 1964 and Banyopadhyay and Chattopadhyay, 2002)[8][1] in soils, most of the soils are deficient in available sulphur content and thus may contribute significantly to the lower productivity of tea with respect to southern part of India (Takkar, 1988)[17]. A positive and significant correlation (r = 0.380*) was found between pH and sulphate–S which indicates that availability of sulphate-S increases with increase in soil

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pH (Takkar, 1988)[17].

3.5. Non Sulphate Sulphur

Non sulphate-S content in the soils ranged from 189.7 to 300 $mgkg^{-1}$ with a mean accounted 28.8 to 37.2 percent of total S. Non sulphate-S content in the soils increased in sub-surface soils indicating comparatively higher presence and highly reactive insoluble compounds of Fe and Al as well as low content of organic matter in these soils (Saggar et al., 1998)[12]. Non sulphate-S showed significant and positive correlation with organic carbon(r = 0.468**) and total-N (r = 0.360*) but a significant negative correlation was found with CEC (r = -0.362**) (Table 1).

3.6. Inter-relationship amongst Different forms of Sulphur

Since sulphur transformation and its availability in soils is dependent on its various forms, inter-relationship among them may be indicated from highly significant correlation of total-S with organic-S, sulphate-S and non sulphate-S. The existence of similar relationship was earlier reported by Srinivasarao et al. (2004)[16]. Organic–S showed a significant positive correlation with sulphate-S (r = 0.352*) and non sulphate-S (r = 0.459**) suggesting high linkage of these forms with organic fraction of the soils (Table 1).

3.7 Carbon – Nitrogen – Sulphur Interrelationships

The knowledge on the C:N, C:S, N:S and C:N:S ratios is helpful in understanding the mineralization, immobilization, stability and instability of the most important organically bound nutrients in soils such as nitrogen and sulphur (Saggar et al., 1998)[12]. The wider ratio (greater than the threshold values) indicates that a particular nutrient would exist in an immobilized form culminating into less mineralization which further indicates that it would be more stable in a given soil in its organic form (Sharma et al., 2003)[15]. However, reverse would be true if the ratios are narrower i.e. a narrow ratio would indicate that the organically bound nutrient is fairly amenable to mineralization and would likely exist to a greater extent, in an inorganic form (Sharma et al., 2003)[15].

The study of the relationship between S and other soil constitutes such as C and N showed that the C:N, C:S, N:S and C:N:S ratios of tea growing soils in surface and sub-surface layers were quite variable (Table 2). The C:N ratio ranged from 8.2: 1 to 10: 1 in surface layer and sub-surface layer with a grand mean of 9.5: 1 which resembles the values obtained by Sharma et al. (2003)[15] working with some tea growing soils of India. In general, higher values of C:N ratios were observed in lower depth, which might be due to anaerobic condition and low mineralization in lower depths as compared to upper depths (Sharma et al., 2000)[14]. In addition, nitrogen abundance may increase in topsoil during degradation because mineralized nitrogen is retained within microbial biomass (Saggar et al., 1998)[12], which is generally lowered with soil depth.

Likewise, the C:S ratio ranged from 12.00: 1 - 51.67: 1 in surface layers and 6.18: 1 – 71.57: 1 in the sub-surface layers. Similarly the N:S ratio in surface and sub-surface soil ranged from 1.30: 1 – 5.33: 1 and 0.62: 1 – 7.26: 1 respectively. The C:N:S ratio of these soils, varied widely from 100: 10.1: 1.4 to 100: 12.2: 16.2 with a mean value of 100: 10.55: 5.07. The variations in these soils may be attributed to the variation in agro-ecological zone which could be explained on the variety of factors such as type of soil, status and kind of organic matter vis-à-vis climatic

Table 2. Relationships among organic carbon, total nitrogen and sulphur in the studied soils

Soil depth (cm)	C : N	C : S	N : S	C : N : S
Banaspaty T.E. (Cacher)				
Surface (0 –25)	8.2 – 10.0	12.73 – 16.90	1.43 – 1.69	100:10.0:5.9 – 100:12.2:7.9
Subsurface (25 –50)	8.2 – 10.0	6.18 – 14.66	0.62 – 1.61	100:10.0:6.8 – 100:12.2:16.2
Putharjhora T.E. (Jalpaiguri)				
Surface (0 –25)	9.0 – 9.7	12.00 – 51.67	1.30 – 5.33	100:10.3:1.9 – 100:11.1:8.3
Subsurface (25 –50)	9.3 – 10.0	13.96 – 53.23	1.50 – 5.70	100:10.0:1.9 – 100:10.8:7.2
Samabeong T.E. (Darjeeling)				
Surface (0 –25)	9.5 – 9.8	38.14 – 51.82	3.90 – 5.27	100:10.2:1.9 – 100:10.6:2.7
Subsurface (25 –50)	9.4 – 9.9	36.76 – 71.57	3.92 – 7.26	100:10.1:1.4 – 100:10.7:2.7
Mean	9.50	29.83	3.12	100:10.55:5.07
LSD (p=0.05)	0.39	1.46	0.13	-

situation-most importantly rainfall, temperature and elevation (Mondal et al., 1995)[9].

Further more a highly significant and positive correlation between C:N and C:S indicates that N and S are the important constituents of soil organic matter and that accumulation of one is accompanied by the simultaneous accumulation of all other components. This suggests that an increase in N content in soil also results in an increase in the S content (Takkar, 1988)[17]. In many of the previous studies documented by different workers (Sharma et al., 2003)[15], the accepted norms to categorise the soils into narrow and wider ratio suggests a C:N:S ratio < 100: 10: 1 as a narrow ratio and vice-versa. Based on these criteria, it was observed that all of the studied tea soils had wider C:N:S ratios in surface and sub-surface layers. Hence considering the magnitude of the ratio obtained it may be concluded that the major portion of nitrogen and sulphur in tea growing soils of Northeastern India is locked up in organic combination. This may serve as a store-house for tea nutrition following mineralization, for which there is a great possibility in a given tea soil ecosystem as this system operates probably through nutrient recycling similar to forest system (Vannier and Guillet, 1994; Sharma et al., 2003)[18][15].

4. Conclusion

The findings of the study revealed that the majority of soil sulphur exists as organic form with a wider C:N:S ratio. This indicates that the availability of sulphate - S in soil might be a major cause of concern with respect to balance nutrition in tea plantations. So long habits of sulphur free fertilization should be abandoned with emphasis on split doses of sulphur fertilization on the basis of soil fertility as well as soil adsorption characteristics.

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