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Status of Plant Available Sulphur and Its Relationship to Other Soil Characteristics in Pothwar Soils

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Abstract. Assessment of the amount of plant available sulphur (SO_4-S) in soils of Pothwar, Pakistan revealed the average S contents in the soil to range from 5.7 to 21.7 µg/g. Five out of fifteen soil series were deficient (< 10 µg S/g) in SO_4-S with a range of 5.0 to 9.0 µg/g, six were deficient only at upper (0-15 cm) soil depth while, the remaining four had satisfactory level (10-30 µg S/g) at both the soil depths. Sulphur exhibited significant positive correlation with clay ($r = 0.77^{**}$), EC_e ($r = 0.77^{**}$), organic C ($r = 0.82^{**}$), total N ($r = 0.88^{**}$) and extractable P ($r = 0.72^{**}$) contents in soil. Correlation coefficients of SO_4-S with sand (r = -0.41), soil pH (r = -0.49) and $CaCO_3$ ($r = -0.60^{*}$) contents were negative. Organic C and N had the most pronounced effects ($R^2 > 65$) on S availability in soil.

Keywords: soil sulphur, soil characteristics, Pothwar

Introduction

The Pothwar Plateau (latitude 32º 10 to 34º 9 N and longitude 71º 10 to 73º 55 E) constitutes an important part of the rainfed agricultural area of Pakistan. It consists mainly of Rawalpindi, Chakwal, Attock and Jhelum districts of northern Punjab, Pakistan. The annual rainfall varies from 500 to 1000 mm, out of which almost 70 percent is received in the form of heavy summer rains.

The main crops of Pothwar are wheat, millet, pulses, rapeseed and groundnut. The area contributes significantly, to agricultural and livestock production of Pakistan. Farmers of Pothwar region practice low inputs in agriculture because of high costs, uncertainty of rainfall and unawareness of modern technology. The use of fertilizers in this area is 3 to 4 times less in comparison to that of irrigated regions (Ahmed and Rashid, 2003; Ali *et al.,* 2002). Almost all soils of Pothwar are deficient in nitrogen and phosphorus while potassium is adequate for plant growth except in sandy soils.

Sulphur is the fourth major plant nutrient and in conjunction with NPK, plays a vital role in cell wall formation, protein synthesis and enzyme reactions as well as in seed formation and oil synthesis in oilseed crops. The deficiency of S has been reported by Rashid *et al.* (1995) and Ahmad *et al.* (1994) in the Pothwar area. However, the information regarding the sulfur status of Pothwar soils and its response in crops is not adequate (Ahmad *et al.*, 1994).

Rapeseed and mustard are important oilseed crops of the Pothwar. They require comparatively greater amount of S for proper growth and higher yields than cereals. It has been estimated that 60 kg of sulphur is removed in producing one ton of rapeseed (Ahmed and Rashid, 2003). Therefore, to get better yields of oilseeds in this area, the knowledge of sulphur status and S supplying capacity of soil is imperative.

Sulphur in Pothwar soils is mostly inherited from parent material (inorganic) or added through rainwater because it is speculated that the amount of S generated from organic sources in Pothwar soils cannot be appreciable due to relatively low organic matter in soil and lack of recycling of crop residues. Rich source of S from canal and tubewell water is not available in this rainfed area. The present study was carried out to assess plant available S (SO_4-S) in prominent soil series of Pothwar region of Pakistan and to study its relationship with other important soil characteristics.

Materials and Methods

Soils belonging to 15 dominant series in the Pothwar tract of the Punjab province of Pakistan were collected from their relevant locations, earmarked by the Soil Survey of Pakistan (Soil Survey of Pakistan, 1971; 1967). Four soil series (Qutbal, Missa, Rajar and Basal) from Attock district, five soil series (Talagang, Balkassar, Chakwal, Satwal and Therpal) from Chakwal district and six soil series (Guliana, Kahuta, Rawalpindi, Rawal, Tirnaul and Qazian) from Rawalpindi district were collected. These soils were classified as (1) *Typic Ustochrepts*: Missa, Basal, Talagang, Rawalpindi, Rawal, Tirnaul, (2) *Typic Haplustalfs:* Balkassar, Chakwal, Therpal, Kahuta and Gulianan, (3) *Typic Ustorthents*: Qutbal, Missa and Rajar, (4) *Typic Torripsamments*: Qazian and (5) *Typic*

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Chromusterts: Satwal (Table 1). These soils fall into two climatic zones, high and medium rainfall, of the Pothwar region. Soil sampling was carried out during the months of September and October, 2004. At the time of sampling, most of the sampling fields were kept fallow in order to conserve moisture for the winter crops. The moisture content in most of the soils was below the field capacity as sampling was carried out during the dry period following the summer rains. Information about the sampling area, soil series, soil type and parent material is given in Table 1. Quadruplicate soil samples were taken from two depths, i.e., 0-15 and 15-30 cm using a soil auger, transferred into polyethylene bags and brought to the laboratory. The field moist samples were spread over the polyethylene sheets separately, hand-picked to remove stones, homogenized and stored in plastic containers until analysis. The mean annual temperature in the experimental area was 24.5 °C and the mean annual precipitation was 750 mm. However, precipitation is unevenly distributed over the year, i.e., approximately 60% in the monsoonal months of July and August.

A small portion of each sample was taken, air-dried, ground, mixed thoroughly and analysed for different soil properties. The samples were analysed for texture, EC_e, pH, soil organic C, total N and extractable P by methods described by Page *et al*. (1982); 0.15 % $CaCl_2$ extractable SO_4-S by turbidimetric method (Verma *et al*., 1977). The data for SO_4-S were classified into four categories, deficient (< 10 μg/g), satisfactory (11-30 μg/g), adequate (31-100 μg/g), and excessive (> 100 μg/g) as described by Ahmad *et al.* (1994).

The relationships between plant available S content and different soil properties were analysed by simple linear correlation and regression analysis using MS Office (Excel) package-2003 and Stat View 5.0 (SAS Inst. Inc.).

Results and Discussion

Plant available sulphur (SO_4-S) status of Pothwar soils. The data presented in Table 2 and Fig. 1 revealed that Satwal and Chakwal soils had significantly higher plant available S (SO_4-S) contents, though both were statistically at par with each other, followed by Talagang soils. Five out of fifteen soils i.e., Missa, Rajar, Rawal, Therpal and Qazian were deficient (<10 μg S/g), having 5.0 to 9.0 μg S/g at both soil depths; six soils, i.e., Basal, Qutbal, Guliana, Rawalpindi and Tirnaul, were deficient only at upper depth (0-15 cm), while the remaining four i.e., Balkassar, Chakwal, Satwal and Talagang had satisfactory level of sulphur (10-30 μg S/g) at both the soil depths.

Overall, the average SO_4-S content in soils under study was 11.7 μg/g (Table 3). The minimum mean SO_4-S (5.7 μg/g) was recorded at Qazian (*Typic Torripsamments*) and maximum (21.7 μg/g) at Satwal (*Typic Chromusterts*). Though the average values of SO_4-S were in the satisfactory range but all the soils of Attock district and most of the Rawalpindi district were deficient in sulphur, while most of the soils belonging to Chakwal area, except Therpal, had sufficient S content.

The present results of study are supported by Ahmad *et al.* (1994) and Saleem and Davide (1987) who attributed low S in soils of rainfed areas of Pakistan to leaching losses and no

Table 1. Parent material, climate and cropping pattern and texture of soils of Pothwar region

Soil series	Area	Climate	Parent material	Textural class	Soil classification
Basal	Attock	Sub-humid to semi arid	Loess	Silt loam	*Ustochrepts*
Missa	Attock	Sub- humid	Loess	Silt loam	*Ustochrepts*
Qutbal	Attock	Sub-humid	Loess	Loam	*Ustorthents*
Rajar	Attock	Sub- humid	Loess	Loam	*Ustorthents*
Balkassar	Chakwal	Sub-humid	Residuum (sandstone)	Loam	*Haplustalfs*
Chakwal	Chakwal	Sub- humid	Loess	Loam	*Haplustalfs*
Talagang	Chakwal	Sub-hum to semi arid	Alluvium	Loam	*Ustochrepts*
Therpal	Chakwal	Sub-humid	Alluvium	Sandy loam	*Haplustalfs*
Satwal	Chakwal	Sub-humid	Loess	Sandy clay loam	*Chromusterts*
Guliana	Rawalpindi	Humid to sub-humid	Loess plain	Loam	*Haplustalfs*
Kahutta	Rawalpindi	Humid	Residuum (sandstone)	Sandy loam	*Haplustalfs*
Qazian	Rawalpindi	Humid to sub-humid	Tertiary (sandstone)	Loamy sand	*Torripsamments*
Rawal	Rawalpindi	Humid	Mountain Outwash	Sandy loam	*Ustochrepts*
Rawalpindi	Rawalpindi	Sub-humid	Loess	Loam	*Ustochrepts*
Tirnaul	Rawalpindi	Humid	Residuum, colluvial(shale)	Silt loam	*Ustochrepts*

Table 2. Plant available S (SO_4-S) in Pothwar soils

Soil series	Depth		
	0-15 cm	15-30 cm	Mean
Basal	8.3	13.0	10.7[e]
Missa	6.2	9.6	7.9[gh]
Qutbal	9.2	15.6	12.4[d]
Rajar	7.0	9.0	8.0[g]
Balkassar	10.5	16.3	13.4[c]
Chakwal	20.2	22.8	21.5[a]
Talagang	18.0	22.3	20.2[b]
Therpal	5.5	6.5	6.0[i]
Satwal	21.3	22.0	21.7[a]
Guliana	8.7	13.2	11.0[e]
Kahutta	7.8	11.2	9.5[f]
Qazian	5.0	6.3	5.7[j]
Rawal	6.7	8.5	7.6[h]
Rawalpindi	8.8	12.5	10.7[e]
Tirnaul	7.5	11.3	9.4[f]
Mean	10.0[b]	13.30[a]	11.7
ANOVA		LSD	SE
Series		0.307	0.108
Depth		-	-
SD		0.435	0.153
CV (± %)	2.28		

Means followed by the same letter (s) are not significantly different (P<0.05; DMR test)

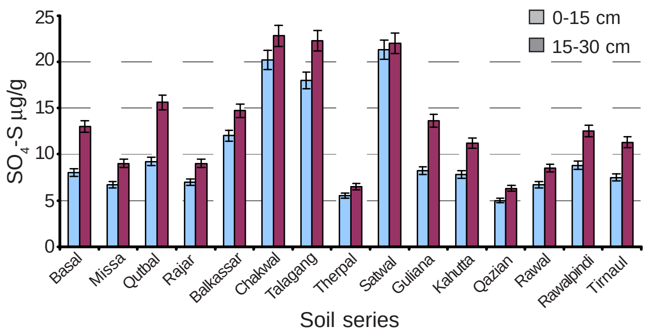

Fig. 1. Plant available sulphur (SO_4-S) content in soils of Pothwar plateau, Punjab, Pakistan.

addition of S by the canal/ tubewell waters. The crop production Pothwar area depends on rainfall, therefore, the soils did not receive any S from canal/ tubewell waters, except whatever, little is present in rainwater as compared to irrigated areas where, canal and tubewell water add considerable amount of S to soils (Bhatti, 1980). The soils of this area remain fallow during heavy summer rains (monsoon) in order to conserve moisture for subsequent crop that might also increase leaching losses of SO_4 to deeper depths with rapidly percolating water; many lysimeter studies had shown that more leaching of SO_4 occurred in fallow than cropped soils and it was minimum during growing period of crop (Shepherd and Bennett, 1998; Kirchmann *et al.*, 1996).

Lower S content in the upper depth as compared to the lower depth in all the soils might be due to eluviations or leaching of SO_4 from the upper part of the soil to lower depths particularly in the well drained soils under high rainfall conditions (Rawalpindi area). Havlin *et al.* (2004) advocated less than 10% of the total S in surface soil.

Relationships between plant available S (SO_4-S) and soil properties. The simple linear correlation and regression analysis highlighting the pattern of association among SO_4-S and other soil characteristics are presented in Table 3 and 4, Fig. 2 and 8 are discussed as under:

The particle size analysis and textural classes of the soil under study, presented in Table 4, showed that soils were generally medium to course textured. Sandy loam and silt loam were the dominant textural classes with relatively high amounts of sand and silt. Soil SO_4-S exhibited positive correlation with silt ($r = 0.001$) and clay ($r = 0.77$**) and negative correlation ($r = -0.41$) with sand particles of the soils under study (Fig. 2 and 3). These results are supported by Tiwari and Sakal (2002). The highly significant and strong correlation ($r = 0.77$**) between SO_4-S and clay, indicated that amount of clay contributes to the soil S because it might adsorb SO_4 strongly, as compared to silt and sand fractions. Solomon *et al.* (2001) reported 1.5-2.0 times greater amount of inorganic S in the clay as compared to silt separates in soils. SO_4 adsorbed to clay is subsequently slowly released to soil solution thus preventing SO_4 leaching losses from the surface soils (Scherer, 2001), while, high sand contents in soil might encourage leaching losses of SO_4 due to their low adsorption capacity.

Strong positively correlation ($r = 0.77$**) between SO_4-S and EC_e indicated that S in soil increased as EC_e increased. The fact is that EC_e is related to the concentration of soluble cation and anions present in soil; so, increase in anions like SO_4 increases EC_e of the soil. Similar relationships were also reported by Ghosh and Agrawal (2005) and Tiwari and Sakal (2002) in Indian soils. Sulphur exhibited negative correlation ($r = -0.49$) with soil pH; it decreased as pH increased (Fig. 4). These results are supported by the studies of Bandyopadhyay and Chattopadhyay (2000). The alkaline (pH 8.0-8.5) and calcareous nature of Pothwar soils might encourage the adsorption of cations on exchange sites and as a result, anions like SO_4 are subsequently released into the soil solution where, it might be leached with downward percolating water in well drained soils of the area.

Table 3. Physicochemical characteristics of soils of Pothwar*

Soil series	Sand (%)	Silt (%)	Clay (%)	EC_e dS/m	pH	$CaCO_3$ (g/100 g)	SOC (g/100 g)	TN (g/100 g)	EP (µg/g)	SO_4-S (µg/g)	C:S ratio	N:S ratio
Basal	41.5	47.0	11.5	0.38	8.0	7.50	2.12	0.25	4.15	10.7	197.7	22.9
Missa	37.5	54.0	8.5	0.42	8.2	13.15	2.43	0.26	4.75	7.9	307.0	32.9
Qutbal	45.5	41.0	13.5	0.35	7.9	5.20	2.88	0.28	5.15	12.4	231.9	22.2
Rajar	52.0	41.0	7.0	0.36	7.9	11.35	2.23	0.24	4.55	8.0	278.1	29.4
Balkassar	40.5	39.0	20.5	0.58	7.6	3.40	3.72	0.34	6.15	13.4	278.0	25.4
Chakwal	31.5	42.0	26.5	0.53	7.7	3.60	4.05	0.38	7.40	21.5	188.4	17.7
Talagang	41.0	36.5	22.5	0.63	7.6	3.25	3.35	0.39	5.10	20.2	165.8	19.1
Therpal	69.0	21.0	10.0	0.40	7.7	7.45	2.23	0.23	3.40	6.0	370.8	37.5
Satwal	52.0	28.0	20.0	0.49	7.8	5.25	3.86	0.38	5.30	21.7	177.6	17.3
Guliana	39.5	42.5	18.0	0.36	7.9	9.55	3.26	0.33	5.15	11.0	298.6	29.8
Kahutta	47.0	34.5	18.5	0.39	8.1	5.25	3.05	0.32	5.40	9.5	321.1	33.7
Qazian	63.5	24.0	12.5	0.29	7.9	5.60	1.94	0.22	3.95	5.7	340.4	37.7
Rawal	45.0	39.5	15.5	0.34	7.7	8.25	2.90	0.27	4.50	7.6	381.6	35.5
Rawalpindi	43.0	38.0	19.0	0.41	7.9	7.30	3.20	0.33	5.00	10.7	299.1	30.4
Tirnaul	32.0	51.0	17.0	0.33	7.9	10.7	2.95	0.30	4.35	9.4	313.8	31.9
Mean	45.37	38.6	16.0	0.42	7.9	7.1	2.94	0.3	5	11.7	276.7	28.2
SD	10.38	9.09	5.49	0.1	0.2	3	0.65	0.06	1	5.3	69.3	7.0
CV	0.23	0.24	0.34	0.23	2.2	0.4	0.22	0.19	0.2	0.5	17.9	1.8
Min	31.5	21.0	7.0	0.29	7.6	3.3	1.94	0.22	3.4	5.7	165.8	17.3
Max	69.0	54.0	26.5	0.63	8.2	13.2	4.05	0.39	7.4	21.7	381.6	37.7

*=average of two soil depths 0-15 and 15-30 cm; SOC = soil organic carbon; C:S = carbon:sulphur ratio; TN= total nitrogen; N:S = nitrogen : sulphur ratio; EP = extractable-P

Table 4. Relationship between soil characteristics (x) and SO_4-S contents (y) in different soil types of Pothwar (n =15)

Soil characteristics	r	Regression equations	R^2
Sand	- 0.41	y = 21.20 - 0.20x	0.17
Silt	0.00	y = 11.70 + 0.00x	0.00
Clay	0.77**	y = - 0.30 + 0.75x	0.60
EC_e	0.77**	y = - 5.90 + 42.46x	0.59
pH	- 0.49	y = 131.42 -15.28x	0.25
$CaCO_3$	- 0.60*	y = 19.20 -1.06x	0.36
Organic C	0.82**	y = - 7.80+ 6.63x	0.67
Total N	0.88**	y = - 12.65 + 81.65x	0.77
Extractable P	0.72**	y = 8.21- 4.02 x	0.52

r=simple linear correlation coefficient; R^2=multiple reg. coefficient of determination; *=significant at P=0.05 (> 0.52); **=highly significant at P=0.01(> 0.64)

The soils of Pothwar plateau inherited $CaCO_3$ contents from their parent materials because most soils have originated from fine grained loess material containing calcite. The significant negative correlation (r = -0.60*) of S with $CaCO_3$ indicated that SO_4 in calcareous soil (Fig. 5) may form insoluble compounds with $CaCO_3$ and become less available. These results are in line with those of Havlin *et al.* (2004) and Trivedi *et al.* (2000).

Strong positive correlation (r = 0.82**) between SO_4-S and organic C exhibited the importance of organic C to S availability in soil (Fig. 6). However, the low (<5.0 mg/g) organic C content (Table 2) with little addition of farmyard manure (FYM) and no recycling of crop residues in the soils under study indicated that the amount of S generated from this source cannot be appreciable. These results support other findings (Hedge and Murthy, 2005; Srinivasarao *et al.*, 2004; Trivedi *et al.*, 2000; Ahmad *et al.*, 1994). Since S is an integral constituent of soil organic matter, the enrichment with S generally determines the S supplying capacity of soils. In the fifteen soil series analysed, C:S ratio showed much variations (Table 2) and ranged from 165 to 381; the lowest was observed in Talagang while, the highest was recoded in Rawal soil.

The C:S ratio (with respect to the C levels) tend to be more variable; it has been reported in the range of 143:1 in alkaline soils of Oregon, USA (White, 2005); 92:1 in Eastern Australia (Havlin *et al.,* 2004) and 100:1.2 in Alfisols of India (Sharma and Jaggi, 2001). However, the C:S ratio of 100:1 was described as a reasonable representative by Brady and Weil (2002). The rather wide C:S ratios in all soils under study suggested that these soils contained less proportion of both organic C and S contents.

Sulphur exhibited highly significant positive correlation with N ($r = 0.88^{**}$) and P ($r = 0.72^{**}$) in soils under study. Sulphur

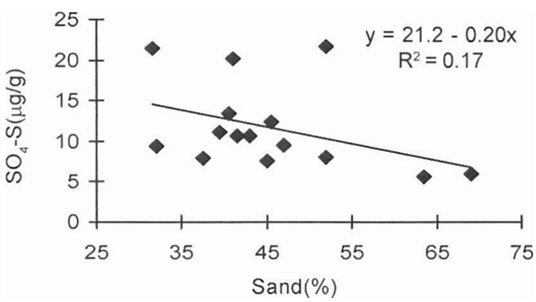

Fig. 2. Correlation between SO_4-S and sand fraction.

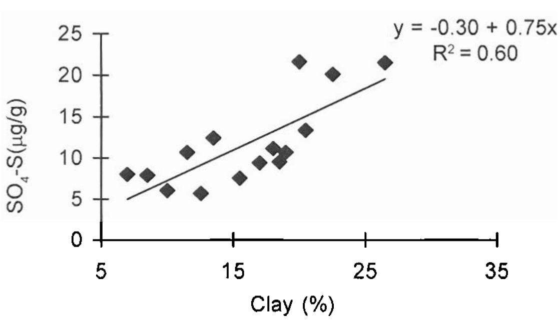

Fig. 3. Correlation between SO_4-S and clay fraction.

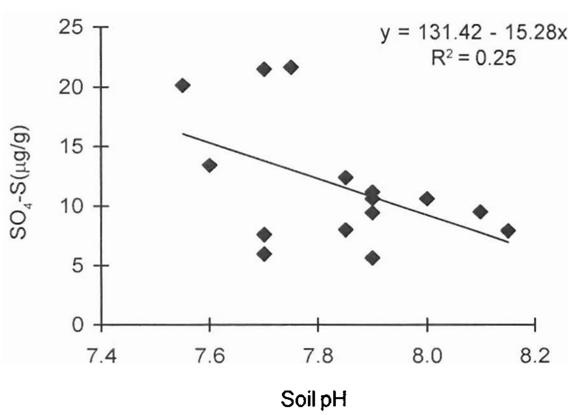

Fig. 4. Correlation between SO_4-S and pH.

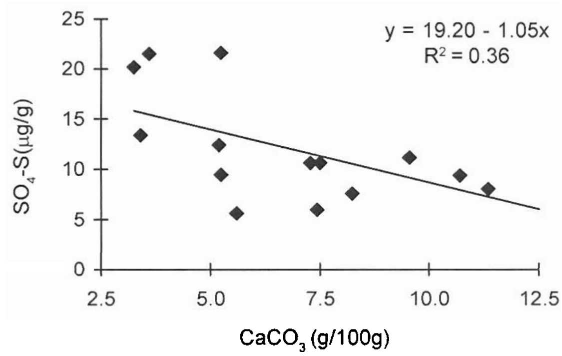

Fig. 5. Correlation between SO_4-S and $CaCO_3$.

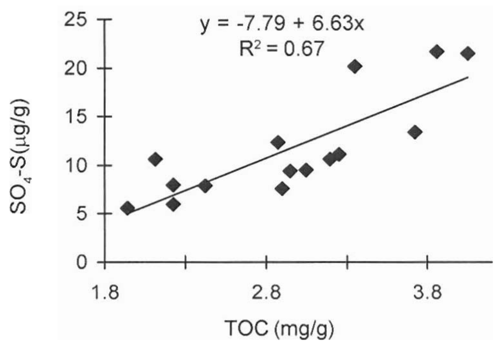

Fig. 6. Correlation between SO_4-S and total organic C.

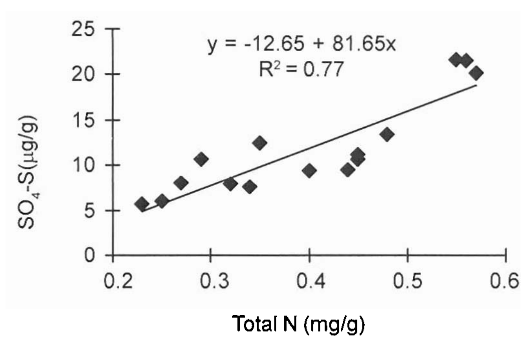

Fig. 7. Correlation between SO_4-S and total N.

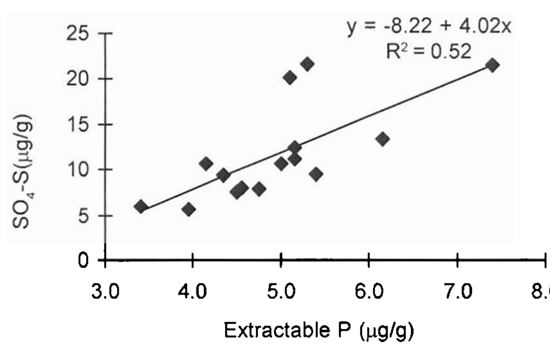

Fig. 8. Correlation between SO_4-S and extractable P.

in soil decreased as NP concentration decreased (Fig. 7 and 8). It may be due to coarse texture and calcareous nature of Pothwar soils, which caused low availability of these plant nutrients. The high N:S ratios (Table 3) in the soils might be due to more use of N fertilizers like urea in the soils. Farmers of Pothwar region practice low agricultural input because of uncertainty of rainfall; N alone accounted 90 percent of the total consump-tion of all the three major nutrients (NPK) in Rawalpindi area during 2004-05 (NFDC, 2005). Application of high rates of N fertilizer on marginally S deficient soils can result in faster depletion of S from the soil, with little or no increase in the yield (Malhi and Gill, 2002). Maximum rapeseed yield responses to N and S were observed only when the availability of N and S was in approximate balance (7:1).

Sulphur and P both form insoluble compounds in the presence of $CaCO_3$ in the soil and get converted into insoluble fractions in alkaline calcareous soils at higher soil pH. Similar results were reported by earlier workers (Ghosh and Agrawal, 2005; Kaistha *et al.,* 2002) in case of Indian soils.

Overall influence of soil characteristics on SO_4-S availability are presented through regression analysis and equations (Table 4) while, the corresponding relations are presented in Fig. 2-8. It indicated that effect of all the parameters on soil S was not similar ($P<0.05$). Some soil characteristics had more influence on plant available S than others. Higher coefficient of determination values ($R^2 >50$) for clay content, EC_e, organic C, N and P depicted close association of these characteristics with SO_4-S, while, sand content, soil pH and $CaCO_3$ had less impact ($R^2 < 50$) on soil S content. Higher association of clay content ($R^2= 59$) to soil S as compared to sand ($R^2 = 17$) indicated presence of clay to be more important for adsorption and availability of S than other soil fractions. However, among all soil characteristics, organic C and N had the most pronounced effect ($R^2> 65$) on S availability which emphasized the importance of organic C to plant nutrients availability particularly S. Therefore, to get better yields of crops particularly oilseed in Pothwar soil, management of organic C is very important through crop residue incorporation and FYM addition.

Conclusion

The results revealed that majority of soils in Pothwar were deficient in plant available sulphur. All the soils of Attock district and most of the Rawalpindi district were found to be deficient while, most soils of Chakwal area had sufficient plant available S content. The problem was found very prominent in areas with light textured soils, low organic matters and under medium to high rainfall conditions, which might encourage leaching losses of SO_4-S to lower soil depths. A significant, positive relationship between organic C content and SO_4-S contents suggested that organic matter content inspite of being low, may have contributed to the increase in S availability in soil.

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