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Sulphur distribution in Inceptisol of Northern India and genotypic differences in sulphur uptake of rice

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Estimating site and depth wise distribution of major (S) fractions and their relationship with soil physicochemical properties are central to developing efficient S management strategies, especially in S deficient areas. Screening use of efficient genotypes also holds promise in this regard in environment like low land paddy ecosystem, which are known to be extremely hostile in the term of S availability for crop uptake. In the present investigation, distribution of total, organic, heat soluble, 0.15% calcium chloride extractable and sodium di-hydrogen phosphate extractable S were studied in a Inceptisol on one hand, while trying to screen a lowland paddy genotype with higher S uptake efficiency on the other. A wide horizontal variation in total S(261 to 670 mg kg^{-1}) was observed in surface soil. Different S fraction was positively correlated with soil organic carbon and clay content, whereas negative correlation of the S fraction was recorded with pH and calcium carbonate equivalent. Organic- S was the dominant fraction throughout the profile although its contribution to total S pool declined with depth. Irrespective of location and soil depth, sodium di-hydrogen phosphate extracted greater amount of S in comparison to heat soluble and calcium chloride extractable S. Paddy variety PD-4 performed better over the other in the term of growth, yield and nutrient uptake. Remarkable improvement in growth, yield and nutrient response of paddy was recorded to S application upto 40 kg ha^{-1}

Key words: Sulphur, paddy soils, soil physicochemical properties, growth, yield, nutrient uptake.

INTRODUCTION

The occurrence of sulphur (S) deficiencies in Indian soils has increased manifolds with increasing use of high analysis fertilizers with low S content, and greater crop removal of the nutrient from the ever increasing multiple cropping systems. Out of 142 million hectares arable land in India, at least 57 million hectares, that is, about 40°C of total, suffers from various degrees of S deficiency (Tripathi, 2003). Large areas of Uttar Pradesh in Northern India are known to be S-deficient. (Tiwari et al., 1997) found 64°C sulphur deficient area in Hardoi district of the state. There is multitude of factors governing crop availability of the nutrient. It is vital to have site specific estimation of different S- forms, their distribution and relationships with soil physicochemical properties for assessing degree of deficiency and also to suggest remedial measures. Lowland paddy soils as one of the major agricultural soils

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of India are suffering from S deficiencies to different degrees. This is due to seriously impeded supply of this. extremely important nutrient to the crop. Lowland paddy soils with continued submergence offers a unique ecosystem for retention, and mobilization of S largely governing its availability for crop uptake. Lowland paddy ecosystems have been extensively reported to show S deficiency (Rahman et al., 2007). External application of the nutrient through fertilizers has been shown to overcome the problem of S deficiency only partly due to uneven supply of the nutrient encountered in most of the cases. At the same time a great degree of variability has also been reported among crops and also varieties in their ability to withstand S deficiency stress (Hawkesford, 2000). This has highlighted the potential for screening genetically more suitable plant materials as a tool for ensuring higher productivity even in S deficient soils. With all these facts at the backdrop, the current study was carried out to assess the status and vertical distribution pattern of major forms of soil S vis-a-vis soil physicochemical properties and also to evaluate production response of 3 lowland paddy varieties towards graded levels of S.

MATERIALS AND METHODS

Study site

The experimental site was rice growing area of Saharanpur, Uttar Pradesh. It lies between 77°15' and 76°0' east longitude and 27° 10' and 29° 30' north latitude and is situated at the altitude of about 894 meters above mean sea level. The winter season is fairly cold and temperature occasionally drops to freezing, that is, 0°C during the month of January. The summers are appreciable hot with temperature touching 40°C. Desiccating winds during summer is also a common feature. The average annual rainfall fluctuates around 100 cm and the bulk of rains are received during monsoon season. Frequent winter showers are also common.

Delineation of status and vertical distribution of soil S forms and their relationship with soil physicochemical properties

Collection and analysis of soil samples

Soil samples were collected from 0-30 cm for surface study and from 30-60, 60-90, 90-120 and 120-150 cm for profile study during the month of May 2006. For surface study, 20 composite samples were collected from each of the 11 major rice growing area (blocks). For profile study, samples were collected from 2 selected locations in each block. All the soil samples were air dried, crushed with wooden roller, passed through a 2 mm sieve and stored in labelled polythene bags.

Soil pH was determined in a 1: 2 soil- water suspension with a standard pH meter. Electrical conductivity (EC) was determined following standard procedure (Bower and Wilcox, 1965). The mechanical analysis of soil was carried out following Bouyoucous hydrometer method (Black, 1965). Calcium carbonate equivalent (CCE) of the soil was determined by following procedure as outlined by (Piper, 1966). Soil organic carbon (SOC) was determined by Walkley and Black method, while available nitrogen (N) was determined by Macro- kjeldahl method (Jackson, 1967). Available phosphorus (P) was determined following (Olsen, 1954) Available potassium (K) was determined following neutral normal ammonium acetate method (Jackson, 1958). Total S in the soil was determined following Black (1965) and Kolthoff (1961). Organic sulphur was determined as per the procedure described by Bradsley and Lancaster (1965). Heat soluble sulphur was determined by the method as suggested by Williams and Steinbergs (1959). Sulphur extractable in 0.15% calcium chloride was determined by the method suggested by Williams and Steinbergs (1959). Sodium dihydrogen phosphate extractable sulphur determination was done as per the method suggested by Cooper (1968).

Production response of lowland paddy cultivars to graded levels of S

Experiment details

A field experiment was carried out consecutively for 2 years (2006 and 2007) with 3 cultivars of lowland paddy viz., IR- 64, PR- 108 and PD- 4. The crop was applied with 4 doses, that is, 0, 20, 40 and 60 kg of S. Twenty five days old seedlings were transplanted in July in the puddled plots each having a size of 5 m × 4 m. All the recommended agronomic practices were followed to raise the crop. Treatments were allocated maintaining 4 replications for each and the experiment laid out in split plot design. The paddy cultivars comprised the main plot treatment while the sub plot treatments were comprised of S doses. Elemental sulphur (85%) was used as the S source.

The experimental plots had the following soil characteristics: pH: 7.1; EC: 0.29 dsm^{-1}; $CaCO_3$: 1.7%; Organic carbon: 0.71%; available N, P, K contents of 131, 142 and 77 mg kg^{-1}; Total, organic, NaH_2PO_4 extractable, heat soluble and $CaCl_2$ extractable S contents of 603, 347.90, 43.5 and 41.6 mg kg^{-1}. The soil represented Inceptisols with loam texture.

Collection and analysis of soil samples

Five numbers of surface soil samples (0-30 cm) were collected from each plot at the start of the experiment and also after crop harvest. Soil samples were processed and analysed following procedures as mentioned above. Five plant samples were also collected from each plot. Plant tissue analysis was done following standard procedures for determining uptake of N, P, K (Jackson, 1973) and S (Chesnin and Yien, 1950). Chlorophyll content in fresh leaf samples were analysed following procedure as outlined by Bruinsma (1963). Other plant growth and yield parameters recorded were plant height, leaf area index (LAI), grain yield and straw yield.

Statistical analysis

The data collected from field and laboratory were analysed statistically using standard statistical programmes (Snedecor and Cochran, 1967).

RESULTS

Physicochemical properties of surface soils

Major physicochemical properties of surface soils in the 11 blocks under study are presented in Table 1. Data reveals that most of the soils were neutral to alkaline in reaction. Maximum soil pH (8.6) was recorded in Nagal and Saraswa block whereas the lowest (6.0) was recorded

Table 1. Physico-chemical properties of surface soil samples (0-30cm).

S/N	Block	pH	EC (dSm^{-1})	CCE (%)	Organic C (%)	Available N (mgkg^{-1})	Available P (mgkg^{-1})	Available K (mgkg^{-1})	Sand (%)	Silt (%)	Clay (%)	Texture class
1	Rampur Maniharan	6.2-8.2(7.0)*	0.18-0.40(0.28)	0.5-2.5(1.71)	0.45-0.87(0.66)	85-164(123.1)	9.5-19.2(13.1)	74-150(105.8)	30.2-64.0(45.9)	23.0-39.8(31.8)	13.0-30.0(21.8)	L
2	Nanauta	6.2-8.2(7.2)	0.20-0.40(0.28)	0.5-2.2(1.55)	0.45-0.85(0.63)	85-170(119.6)	7.5-17.3(13.1)	70-170(106.8)	32.0-52.0(41.1)	32.0-42.0(37.5)	16.0-28.0(21.2)	L
3	Deoband	6.3-7.8(7.0)	0.18-0.40(0.27)	0.5-2.5(1.50)	0.58-0.85(0.71)	109-170(137.3)	9.1-17.6(12.9)	77-187(114.7)	30.0-50.6(42.5)	31.0-42.0(34.1)	18.0-28.0(23.0)	L
4	Nagal	6.2-8.6(7.1)	0.19-0.45(0.28)	0.5-2.5(1.60)	0.49-0.73(0.60)	90-135(112.4)	8.9-17.6(13.2)	78-212(111.8)	30.0-55.0(43.1)	28.0-43.0(34.1)	17.0-28.0(22.7)	L
5	Balia Kheri	6.4-8.2(7.1)	0.18-0.40(0.29)	0.5-2.5(1.64)	0.47-0.70(0.57)	87-132(108.4)	9.0-17.8(12.8)	70-125(98.6)	30.0-55.0(43.4)	25.0-42.0(33.1)	15.0-28.0(22.6)	L
6	Gangoh	6.0-8.2(7.0)	0.17-0.43(0.27)	0.5-2.5(1.57)	0.50-0.88(0.75)	93-174(141.5)	9.3-17.6(21.3)	72-214(124.3)	28.0-54.0(40.6)	28.0-42.0(35.0)	18.0-28.0(23.6)	L
7	Nakur	6.5-8.2(7.2)	0.17-0.44(0.29)	1.0-3.0(1.85)	0.43-0.70(0.57)	77-128(107.2)	8.2-17.3(18.3)	81-132(102.8)	32.0-53.0(42.2)	29.0-41.1(34.0)	18.0-28.0(22.7)	L
8	Sarsawa	6.2-8.6(7.2)	0.17-0.45(0.29)	0.5-2.5(1.62)	0.44-0.86(0.63)	80-159(118.0)	9.5-18.2(13.3)	89-200(123.6)	30.0-58.1(46.2)	28.0-42.0(33.8)	15.0-28.0(20.0)	L
9	Punwarka	6.0-8.2(7.0)	0.17-0.40(0.27)	0.5-2.5(1.64)	0.45-0.80(0.58)	80-150(109.2)	11.0-18.2(13.7)	50-163(97.3)	27.8-60.2(44.6)	25.0-49.2(37.4)	14.8-23.0(17.9)	L
10	Muzafarabad	6.0-8.2(7.0)	0.17-0.40(0.26)	0.5-2.5(1.55)	0.58-0.88(0.72)	106-170(136.5)	11.5-19.6(14.6)	70-170(109.7)	28.0-52.0(41.4)	33.0-43.5(36.3)	17.5-28.5(22.0)	L
11	Sadholi Qadim	6.4-8.2(7.1)	0.18-0.40(0.28)	0.5-2.6(1.77)	0.41-0.78(0.61)	43-144(110.8)	11.3-19.0(14.0)	87-380(166.0)	26.0-56.0(40.5)	27.0-52.0(39.8)	17.0-22.0(19.6)	L

Data in parenthesis represents mean of 20 samples in each block; L= Loam.

in Gangoh, Punwarka and Muzaffarabad. The maximum electrical conductivity (EC) of 0.45 dSm^{-1} was observed in Nagal and Sarsawa while the minimum (0.17 dSm^{-1}) was in Gangoh, Nakur, Sarsawa, Punwarka and Muzaffarabad. The maximum value of calcium carbonate equivalent (CCE) was in Nakur (3.0%) and the minimum (0.5%) was in Rampur Maniharan, Nanauta, Deoband, Nagal, Baliakheri, Gangoh, Sarsawa, Punwarka, Muzaffarabad and Sadholi Kadim soils. Maximum SOC (0.88%) was observed in Gangoh and Muzaffarabad blocks while, the minimum (0.41%) was in Sadholi kadim soil. Maximum available nitrogen (174 mg kg^{-1}) was observed in Gangoh and minimum (43 mg kg^{-1}) was observed in Sadholi Kadeem block. The maximum soil available phosphours (19.6 mg kg^{-1}) was observed in Muzaffarabad while the minimum (7.5 mg kg^{-1}) was in Nanauta. The maximum soil available potassium (380 mg kg^{-1}) was observed in Sadholi Kadim whereas the minimum (50 mg kg^{-1}) was in Punwarka block. The maximum content of sand (64.0%) was in Rampur Maniharan and the minimum (26.0%) was in Sadholi Kadim. The maximum silt content (52.0%) was observed in Sadholi Kadim and the minimum (23.0%) was in Rampur Maniharan. The maximum (30.0%) as well as minimum (13.0%) clay content was observed in the Rampur Maniharan block. The soil textural class in all the blocks was found to be loam.

Different forms of sulphur in surface soils

The status of different S fractions in surface soils is presented in Table 2. Average maximum content of total sulphur (670.0 mg kg^{-1}) was observed in Rampur Maniharan and the minimum (261.0 mg kg^{-1}) was in soils of Muzaffarabad block. On an average, the maximum (435.5 mg kg^{-1}) and minimum (114.8 mg kg^{-1}) contents of organic S were observed in soils of Rampur Maniharan and Muzaffarabad blocks respectively. The maximum (50.7 mg kg^{-1}) and minimum (14.7 mg kg^{-1}) contents of 0.03 M sodium di-hydrogen phosphate extractable sulphur were observed in Rampur Maniharan and Sadholi Kadim soils respectively. The maximum (48.5 mg kg^{-1}) and minimum (14.0 mg kg^{-1}) average contents of heat soluble S were observed in soils of Deoband and Sadholi Kadim. The maximum (47.4 mg kg^{-1}) and minimum (11.6 mg kg^{-1}) average contents of 0.15% calcium chloride extractable sulphur were observed in soils of Deoband and Muzaffarabad. The soils in the present investigation showed higher status of sodium di-hydrogen phosphate extractable sulphur as compared to sulphur extracted by other two extractants (that is, heat soluble and calcium chloride extractable sulphur). The content of sodium di-hydrogen phosphate extractable sulphur was followed by heat soluble sulphur, whereas calcium chloride extractable sulphur recorded the least.

Correlations of sulphur fractions in surface soil with physicochemical properties

The type and magnitude of correlations of S-fractions in surface soil with soil physicochemical properties are presented in Table 3. Soil pH showed

Table 2. Different forms of sulphur (mg kg^{-1}) in Surface soil samples.

S/N	Block	Total-S (*)(**)	Organic-S (*)(**)	0.03 M sodium di-hydrogen phosphate ext.-S (*)(**)	Heat soluble-S (*)(**)	0.15% $CaCl_2$ ext. – S (*)(**)
1	Rampur Maniharan	457.0-70.0(580.2)	223.2-35.5(346.3)(59.68)	28.3-50.7(40.30)(6.94)	28.3-45.5(38.11)(6.56)	26.0-5.1(35.8)(6.17)
2	Nanauta	331.0-470.0(407.9)	191.9-338.1(257.5)(63.12)	22.0-42.3(29.9)(7.33)	20.1-38.0(27.9)(6.83)	16.7-37.7(26.3)(6.44)
3	Deoband	500.0-600.9(568.1)	277.1-377.3(334.2)(58.82)	30.2-49.5(39.9)(7.02)	29.0-48.5(36.2)(6-37)	23.2-46.6(33.9)(5.96)
4	Nagal	520.2-631.0(578.0)	274.0-435.2(358.3)(61.98)	30.0-49.8(40.1)(6.93)	27.0-47.6(37.6)(6.50)	23.2-47.4(34.9)(6.03)
5	Balia Kheri	370.6-557.0(444.2)	222.3-386.1(281.4)(63.34)	20.0-46.6(29.5)(6.64)	19.6-45.9(28.4)(6.39)	18.0-43.3(26.7)(6.01)
6	Gangoh	300.0-451.7(366.5)	180.3-293.0(249.4)(68.04)	18.6-36.6(39.7)(10.83)	15.0-36.1(25.0)(6.82)	13.8-35.2(23.1)(6.30)
7	Nakur	375.0-510.0(443.4)	227.8-350.5(296.2)(66.80)	22.0-39.9(45.5)(10.26)	20.0-39.8(27.8)(6.26)	20.0-38.4(26.6)(5.99)
8	Sarsawa	350.0-420.2(370.9)	205.2-294.9(220.0)(59.31)	21.7-28.8(25.5)(6.87)	18.0-27.6(22.9)(6.17)	17.2-27.3(21.7)(5.85)
9	Punwarka	367.9-460.7(409.1)	190.5-307.0(245.4)(59.98)	22.6-45.6(30.3)(7.40)	19.1-42.8(27.5)(6.72)	16.5-41.1(25.2)(6.15)
10	Muzaffaraba	261.0-334.0(298.6)	114.8-216.6(181.8)(60.88)	16.5-25.4(20.3)(6.79)	15.3-25.4(19.2)(6.43)	11.6-21.7(17.0)(5.69)
11	Sadholi Qadim	280.0-340.0(313.2)	154.3-211.9(183.9)(58.71)	14.7-30.0(22.4)(7.15)	14.0-28.9(20.9)(6.67)	12.0-25.0(19.1)(6.09)

*Mean of 20 samples;** Percent of total S.

significant negative correlation with all the S fractions except 0.03 M sodum di-hydrogen phosphate extractable sulphur, with whom a non significant negative correlation of pH was observed. EC was negatively correlated with all the S fractions. Maintaining the trend of soil pH, CCE also showed negative correlation with all the S fractions. Soil organic carbon (SOC) content was positively correlated with all the S fractions, rather strongly with total and 0.03 M sodum di-hydrogen phosphate extractable sulphur. Available N was correlated positively with all the S fractions, even rather strongly with total, organic and heat soluble S. Available P showed strong positive correlations with organic and 0.03 M sodum di-hydrogen phosphate extractable S, while a strong negative correlation was noticed with total-S. Available K was negatively correlated with all the S fractions. Sand content of soil was negatively correlated with all the S fractions. The correlations of silt content with different S fractions were found to be mostly negative and non-significant. Whereas strong found to be positive correlations were recorded between clay content and S fractions.

Depth wise variation in soil physicochemical properties

Soil physicochemical properties at various depths of profile are presented in Table 4. On an average, maximum soil pH were observed in Gangoh and Sadholi Kadim block. In all the blocks an increase in soil pH with depth was observed. EC did not show any definite trend in terms of variation with depth. CCE (%) varied from 0.5 to 3.95 and showed a tendency to increase with depth although failed to maintain a constant trend. Maximum SOC content (0.96%) at the surface layer was observed in Rampur Maniharan, whereas the minimum (0.48%) in Nakur block. At the lowest layer (120-150 cm), the maximum SOC content of 0.56% was recorded in Baliakheri, while the minimum (0.25%) was in Rampur Maniharan. Available N, P, K content showed remarkable decline with depth. The maximum contents of available N (184 mg kg^{-1}), P (22.5 mg kg^{-1}) and K (225 mg kg^{-1}) were recorded in Rampur Maniharan, Baliakheri and Sadholi Kadim block, respectively. A gradual increase in sand content, decline in clay content and an erratic trend in silt content with depth was observed in all the 11 blocks. Maximum sand (65.3%) content was observed in the bottom layer (120- 150 cm) in Rampur Maniharan. Maximum silt (50%) and clay (37.8%) contents were observed in the top layer in Nanauta and Gangoh blocks respectively. A wide variation in soil texture was also observed depending on both site and soil depth.

Sulphur fractions in the soil profile

The contents of various S fractions at different depths of the profile are presented in Table 5. There was an invariable decline in total S with depth, which might be ascribed to the fact that majority of the soil S is organic in origin and hence

Table 3. Correlation coefficients (*r*) between soil properties and forms of sulphur in surface soil samples.

Variable	Total-S	Organic-S	0.03 M NaH_2PO_4 ext.-S	Heat Soluble S	0.15% $CaCl_2$ ext.- S
pH	- 0.284**	- 0.337**	-0.115	- 0.215**	-0.185**
Ec	-0.257**	-0.302**	-0.092	-0.195**	-0.175*
$CaCO_3$	-0.281**	-0.309**	-0.072	-0.214**	-0.212**
Organic carbon	0.375**	0.081	0.421**	0.127	0.096
Av. Nitrogen	0.205**	0.270**	0.129	0.181**	0.163*
Av. Phosphours	-0.379**	0.228**	0.909**	-0.005	0.007
Av. Potassium	-0.108	-0.194**	-0.148*	-0.151*	-0.158*
Sand	-0.038	-0.309**	-0.401**	-0.125	-0.119
Silt	-0.129	-0.015	0.108	-0.058	-0.058
Clay	0.275**	0.480**	0.331**	0.246**	0.33**

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

Table 4. Physicochemical properties of soil profile.

Location/ Block	Depth (cm)	pH	EC (dSm^{-1})	CCE (%)	SOC (%)	Av. N (mg kg^{-1})	Av. P (mg kg^{-1})	Av. K (mg kg^{-1})	Sand (%)	Silt (%)	Clay (%)	Texture
Rampur Maniharan	0-30	6.8	0.17	1.1	0.96	184	21.5	148	40.0	29.9	30.0	CL
	30-60	6.9	0.18	2.7	0.56	104	19.3	110	45.8	28.4	25.8	SCL
	60-90	6.9	0.30	3.0	0.35	70	19.2	90	47.0	28.0	25.0	SCL
	90-120	7.1	0.24	3.6	0.35	69	18.5	89	50.0	25.0	24.9	SCL
	120-150	7.2	0.21	3.9	0.24	45	17.6	75	65.3	10.4	24.3	SCL
Nanauta	0-30	6.7	0.32	1.5	0.67	133	17.5	150	30.0	50.0	20.0	SL
	30-60	6.8	0.28	1.0	0.61	115	17.2	141	34.5	45.5	20.0	L
	60-90	6.9	0.58	2.0	0.60	108	16.6	135	40.8	41.2	18.9	L
	90-120	6.9	0.31	0.5	0.58	109	16.2	135	41.9	43.1	15.0	L
	120-150	7.1	0.20	2.5	0.51	92	15.5	151	43.0	45.0	12.0	L
Deoband	0-30	6.5	0.31	1.5	0.75	141	19.2	187	38.0	37.0	25.0	L
	30-60	6.7	0.40	1.0	0.71	140	18.5	170	40.8	37.2	22.0	L
	60-90	6.8	0.12	2.0	0.65	122	18.4	110	45.6	32.4	22.0	L
	90-120	7.1	0.45	3.0	0.57	102	17.2	128	48.0	32.0	20.0	L
	120-150	7.2	0.24	1.0	0.48	91.2	16.5	99	50.0	32.0	18.0	L
Nagal	0-30	7.1	0.17	1.5	0.61	121	17.2	86	38.0	32.0	30.0	L
	30-60	7.1	0.40	1.0	0.57	107	16.5	70	40.2	39.0	20.8	L
	60-90	7.2	0.23	3.8	0.42	78	16.3	65	42.2	38.6	19.1	L
	90-120	7.4	0.22	2.0	0.38	76	15.2	72	47.0	35.0	18.0	L
	120-150	7.6	0.18	2.5	0.38	68	15.0	63	47.9	35.1	17.0	L
Baliakheri	0-30	6.1	0.18	1.0	0.82	154	22.5	98	27.0	49.0	24.1	SL
	30-60	6.3	0.16	1.0	0.65	129	19.2	90	40.0	39.1	20.9	L
	60-90	6.3	0.20	1.5	0.65	117	17.6	81	43.0	40.0	17.0	L
	90-120	6.3	0.15	2.0	0.58	104	16.2	70	48.6	34.7	16.7	L
	120-150	6.5	0.14	2.0	0.56	96	14.2	70	54.9	32.8	12.3	SL
Gangoh	0-30	8.0	0.13	1.0	0.78	145	21.2	214	33.7	28.5	37.8	CL
	30-60	8.0	0.16	1.5	0.57	107	19.2	200	36.8	32.0	31.2	CL
	60-90	8.2	0.16	2.0	0.50	90	19.0	180	42.9	27.2	29.9	CL
	90-120	8.2	0.16	2.0	0.45	81	16.0	160	50.8	20.0	29.2	SCL

Table 4. Contd.

	120-150	8.2	0.12	2.5	0.32	60	15.0	155	54.5	26.2	19.3	SL
Nakur	0-30	7.1	0.19	2.5	0.48	96	21.5	96	40.6	32.1	27.3	CL
	30-60	7.2	0.17	1.5	0.47	94	19.2	90	42.5	35.0	22.3	L
	60-90	7.3	0.40	2.0	0.41	77	16.6	81	45.0	34.0	20.0	L
	90-120	7.4	0.23	1.0	0.35	63	15.7	70	51.0	34.0	15.0	SL
	120-150	7.5	0.22	0.5	0.30	56	14.2	69	57.9	27.1	15.0	SL
Sarsawa	0-30	7.1	0.30	1.0	0.65	122	17.2	200	40.0	35.0	25.0	L
	30-60	7.2	0.16	1.5	0.62	117	16.3	196	41.2	33.8	25.0	L
	60-90	7.5	0.16	1.0	0.58	114	14.8	175	46.7	32.0	21.0	L
	90-120	7.6	0.16	2.0	0.51	96	14.0	165	46.9	31.0	22.1	L
	120-150	7.7	0.12	1.0	0.40	76	13.0	160	47.0	30.0	22.0	L
Punwarka	0-30	6.2	0.32	1.5	0.85	169	19.6	155	44.2	20.8	35.0	SCL
	30-60	6.4	0.29	0.5	0.61	114	17.2	110	45.8	20.0	34.2	SCL
	60-90	6.6	0.33	2.0	0.51	96	13.6	90	45.6	20.0	33.4	SCL
	90-120	6.8	0.21	2.0	0.40	76	13.6	70	56.2	19.0	24.8	SCL
	120-150	6.9	0.23	1.0	0.37	70	13.0	63	60.0	20.0	20.0	SCL
Muzaffarabad	0-30	6.7	0.35	1.0	0.65	122	19.8	170	33.7	28.5	37.6	CL
	30-60	6.9	0.29	1.5	0.47	88	18.3	135	36.8	33.0	31.2	CL
	60-90	7.1	0.26	1.0	0.38	70	17.5	126	42.9	27.2	29.9	CL
	90-120	7.3	0.25	2.0	0.31	62	14.0	99	50.8	20.0	29.2	SCL
	120-150	7.8	0.21	2.3	0.25	49	14.0	80	54.5	26.2	19.3	SL
Sadholi Kadim	0-30	8.0	0.21	1.0	0.68	129	18.6	225	41.0	29.0	29.0	CL
	30-60	8.1	0.22	1.5	0.62	116	16.5	200	42.0	33.0	25.0	L
	60-90	8.2	0.22	2.0	0.48	90	15.6	151	44.1	33.9	22.0	L
	90-120	8.2	0.19	2.0	0.38	76	14.9	120	51.2	21.8	27.0	SCL
	120-150	8.4	0.20	2.5	0.36	68	12.8	90	60.0	28.0	22.0	SL

SL, Sandy loam; L, loam; CL, clay loam; SCL, sand clay loam; CCE, Calcium carbonate equivalent; EC, electrical conductivity; SOC, soil organic carbon.

the decline in organic matter with depth is bound to have significant bearing on the S content. The decline in organic S content with depth and the % contribution of organic S to total S as observed with depth. Maximum contents of total (650.6 mg kg^{-1}) and organic (393.6 mg kg^{-1}) S were recorded at the top layer (0-30 cm) in Rampur Maniharan, whereas the lowest (60.3 mg kg^{-1} of total and 30.1 mg kg^{-1} of organic S) were in Muzaffarabad block. Maximum contribution of organic S to total S (65.11%) was observed in the top layer (0-30 cm) in Muzaffarabad, while the minimum (47.9%) was in the bottom layer (120-150 cm) in the Gangoh block. In most of the sites studied, 0.03 M sodium di-hydrogen phosphate extractable S content tended to decline with depth while showing gradual increase in its contribution to total S. Maximum content of 0.03 M sodium di hydrogen phosphate extractable S (48.1 mg kg^{-1}) was recorded in 30-60 cm depth in Deoband, while the minimum (10.0 mg kg^{-1}) was in 120-150 cm layer in the Nakur block. The maximum content of heat soluble S (47.2 mg kg^{-1}) was recorded at 30-60 cm depth in Nagal, while the minimum (9.2 mg kg^{-1}) was at 120-150 cm depth in Gangoh block.

Correlations of S fractions with soil physicochemical properties in the profile

When averaged across the depth, soil pH showed significant negative correlations with different S fractions (Table 6). EC could show noticeable positive correlation only with heat soluble and 0.15% $CaCl_2$ extractable S. Considering the whole profile, CCE was only weakly correlated with the S fractions – positively with 0.03 M sodium di hydrogen phosphate and 0.15% $CaCl_2$ extractable S and negatively with total, organic and heat

Table 5. Variation in contents (mg kg^{-1}) of S fractions with depth.

Location/ Block	Depth (cm)	Total S	Organic S	% of Total S	0.03M sodium di-hydrogen phosphate ext. S	% of Total S	Heat soluble S	% of Total S	0.15% $CaCl_2$ ext. S	% of Total S
Rampur Maniharan	0-30	650.6	393.6	60.50	35.7	5.50	32.7	5.02	26.0	4.00
	30-60	422.2	233.0	55.18	30.3	7.17	27.4	6.46	24.0	5.68
	60-90	327.6	174.0	53.11	30.3	9.15	26.2	8.00	26.0	7.93
	90-120	215.2	110.0	51.15	24.1	11.19	23.2	10.78	21.0	9.75
	120-150	130.6	62.6	47.93	14.9	11.40	14.3	10.94	13.0	10.00
Nanauta	0-30	450.6	292.8	65.00	30.0	6.65	27.0	6.00	23.0	5.10
	30-60	370.2	207.3	56.00	31.0	8.37	25.0	6.75	21.5	5.80
	60-90	215.6	111.6	51.76	18.0	8.34	17.2	8.00	15.3	7.10
	90-120	200.2	100.1	50.00	27.0	13.50	20.0	10.00	20.2	10.08
	120-150	175.0	87.2	49.82	40.0	22.85	35.0	20.00	30.0	17.14
Deoband	0-30	600.3	330.8	55.11	33.0	5.50	30.2	5.04	27.0	4.50
	30-60	525.2	315.1	60.00	48.1	9.16	44.0	8.37	40.0	7.61
	60-90	420.6	218.7	52.00	47.1	11.20	40.3	9.60	35.0	8.32
	90-120	250.2	127.6	51.00	29.5	11.82	26.4	10.57	26.0	10.39
	120-150	250.0	120.0	48.00	39.1	18.03	47.0	18.80	41.4	16.56
Nagal	0-30	620.2	374.6	60.40	43.3	6.99	40.9	6.60	40.0	6.47
	30-60	554.2	326.4	58.90	38.2	6.90	47.2	8.15	42.8	7.72
	60-90	430.4	219.9	51.10	42.9	9.99	40.0	9.30	39.3	9.13
	90-120	370.2	188.4	50.90	38.0	10.29	34.2	9.23	31.7	8.57
	120-150	190.6	92.2	48.38	32.3	16.89	29.7	15.58	25.7	13.50
Baliakheri	0-30	535.0	319.9	59.79	28.0	5.23	26.7	5.00	24.0	4.48
	30-60	360.2	205.3	57.00	26.2	7.27	23.9	6.63	22.6	6.27
	60-90	270.6	144.5	53.39	32.8	12.12	27.6	10.20	24.3	9.00
	90-120	180.2	88.9	49.33	23.7	13.15	20.2	11.20	18.0	10.00
	120-150	130.6	63.5	48.62	23.5	18.00	21.4	16.38	19.59	14.93
Gangoh	0-30	420.6	252.3	60.00	32.6	7.75	32.0	7.60	28.2	6.70
	30-60	350.2	187.8	53.62	24.4	6.96	23.1	6.60	24.9	7.09
	60-90	235.6	134.0	56.87	23.3	9.90	21.5	9.12	20.1	8.53
	90-120	160.6	86.7	54.00	16.0	9.96	14.9	9.27	14.6	9.09
	120-150	100.2	48.0	47.90	10.2	10.17	9.2	9.18	8.5	8.48
Nakur	0-30	500.0	300.0	60.00	31.0	6.20	27.0	5.40	25.0	5.00
	30-60	337.0	229.8	68.81	17.6	5.22	17.0	5.05	17.0	5.05
	60-90	263.5	149.0	56.54	18.0	6.83	16.2	6.14	14.6	5.55
	90-120	210.0	100.8	48.00	15.1	7.20	16.1	7.66	15.1	7.20
	120-150	163.2	78.3	47.97	10.0	6.12	11.3	6.92	8.6	5.26
Sarsawa	0-30	370.2	223.2	60.31	28.6	7.72	22.9	6.18	15.5	4.18
	30-60	330.3	198.5	60.09	22.7	6.87	20.1	6.01	14.2	4.30
	60-90	250.6	146.3	58.37	18.0	7.18	17.0	6.78	14.0	5.58
	90-120	215.3	119.2	55.36	20.0	9.28	15.9	7.33	14.8	6.87
	120-150	170.6	83.4	48.88	27.2	15.94	13.3	7.80	9.0	5.27
Muzaffarabad	0-30	330.2	215.0	65.11	25.4	7.70	25.4	7.69	16.5	5.00

Table 5. Contd.

	30-60	250.4	152.7	60.09	17.7	7.08	17.5	7.00	17.0	6.78
	60-90	180.2	103.8	57.60	30.2	16.75	24.8	13.76	21.2	11.76
	90-120	100.0	58.0	58.00	13.5	13.55	12.0	12.00	11.8	11.80
	120-150	60.3	30.1	50.00	16.2	26.86	14.4	23.88	12.0	19.90
	0-30	335.2	184.3	55.00	18.4	5.42	16.7	5.00	13.4	4.00
	30-60	260.6	136.8	52.50	23.8	9.13	22.9	8.78	19.7	7.56
SadholiKadim	60-90	222.0	109.8	49.45	21.8	9.88	19.9	8.96	18.2	8.19
	90-120	160.2	78.4	48.95	25.8	16.10	22.4	13.98	20.8	12.98
	120-150	90.6	44.2	48.78	16.3	18.00	14.6	16.11	13.8	15.23

Table 6. Coefficients of correlation (*r*) of S- fractions with soil properties pooled over different depths.

Variable	Total-S	Organic-S	0.03M NaH_2PO_4 ext.-S	Heat Soluble	0.15% $CaCl_2$ ext.-S
pH	- 0.462**	- 0.482**	- 0.316**	- 0.321**	-0.291**
Ec	0.125	0.085	0.176	0.192*	0.218*
CCE	-0.160	-0.191	0.020	-0.017	0.051
Organic carbon	0.733**	0.748**	0.386**	0.394**	0.340**
Av. Nitrogen	0.773**	0.786**	0.415**	0.420**	0.367**
Av. Phosphours	0.725**	0.738**	0.429**	-0.449**	0.436**
Av. Potassium	0.259**	0.270**	0.041	0.027	-0.048
Sand	-0.575	-0.591**	-0.171	-0.188	-0.148
Silt	0.317**	0.309**	0.086	0.099	0.048
Clay	0.353**	0.385**	0.171	0.177	0.181

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

soluble S. As observed in the surface soil, SOC and available N content invariably showed positive correlation with all the S fractions in the whole profile too. Available P also showed strong positive correlation with all the S fractions, barring only heat soluble S with which it was negatively correlated. Available K content was also positively correlated with almost all the S fractions, rather strongly with total and organic S, the only exception being 0.15% $CaCl_2$ extractable S, with which it showed negative correlation. Sand content was negatively correlated with all the S fractions on other hand. Silt and clay contents were positively correlated with all the S fractions, rather strongly with total and organic S.

Productivity of lowland paddy with graded S levels

The mean values of crop growth and yield attributes pooled over two years of experimentation are presented in Table 7. Differential growth and yield responses of the varieties are prominent. PR-108, the tallest among 3 varieties tested also recorded significantly greater chlorophyll content besides having a slightly higher LAI. On the other hand, in terms of grain test weight, grain yield and straw yield, variety PD- 4 performed remarkably better than the other 2 varieties. Irrespective of the varieties, a gradual improvement in all the growth and yield attributes were recorded with increase in S level from 0 to 60 kg ha^{-1}, Sulphur applied at 60 kg ha^{-1} could enhance growth and yield performance of the crop only marginally over its application at 40 kg ha^{-1}; however, a significant improvement was recorded over its application at 20 kg ha^{-1}.

The differences in plant height among the varieties irrespective of S application rates perhaps indicated towards genotypic variation of the trait. Irrespective S level, maximum plant height (75.70 cm) was recorded with PR-108**.** However, increase in S level brought a steady increase in plant height irrespective of cultivator, the maximum (78.30 cm) being recorded with S application 60 kg $ha\text{-}^{1}$. Significant genotypic variations were also noticeable regarding all other growth and yield trial except grain test weight, which shows only marginal differences among the three verities tested. There was also increase in LAI, chlorophyll content and grain test weight with every increment in S level recording maximum values of 5.70, 2.75 and 23.62 g, respectively with sulphur application at 60 kg ha^{-1} (Table 7). Irrespective of S level, PD-4 performed better than the other cultivars in terms of grain and straw yield. Every

Table 7. Growth and yield attributes of the crop.

Treatments	Plant height (cm)	Leaf area index	Chlorophyll content	Grain test weight (g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})
Varieties						
IR-64	67.9	5.21	2.53	21.91	53.39	70.27
PR-108	75.7	5.57	2.64	22.55	56.66	71.70
PD-4	70.9	5.52	2.49	23.54	60.15	75.57
SM±	0.177	0.002	0.007	0.035	0.043	0.143
CD	0.925	0.011	0.003	1.596	0.227	0.747
Sulphur level						
S_0	61.8	5.04	2.27	21.45	51.02	65.24
S_{20}	70.8	5.40	2.52	22.46	56.04	71.63
S_{40}	75.0	5.60	2.66	23.13	58.98	75.31
S_{60}	78.3	5.70	2.75	23.62	60.90	77.86
SM±	1.455	0.050	0.019	0.019	1.167	0.157
CD	5.701	0.198	0.074	0.076	4.570	6.167

Table 8. Nutrient uptake response of paddy.

Treatments	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})		S uptake (kg ha^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Varieties								
IR-64	56.46	20.62	15.83	5.66	19.06	51.59	4.165	5.666
PR-108	59.39	21.64	16.93	5.81	20.19	54.11	4.244	5.780
PD-4	62.12	22.47	17.77	6.07	21.16	56.24	4.849	6.594
SM±	0.058	0.026	0.011	0.024	0.023	0.040	0.010	0.019
CD	0.305	0.136	0.059	0.127	0.125	0.211	0.057	0.097
Sulphur level								
S_0	54.37	20.65	14.89	5.28	17.11	50.59	3.69	5.06
S_{20}	59.22	20.99	16.63	5.76	20.05	53.34	4.26	5.86
S_{40}	61.02	21.51	17.60	6.08	21.17	55.58	4.71	6.36
S_{60}	62.68	23.14	18.23	6.28	22.23	56.41	5.02	6.78
SM±	0.770	0.287	0.233	0.089	0.270	0.770	0.062	0.078
CD	3.018	1.266	0.912	0.352	1.061	3.017	0.242	0.305

increment so brought about increase in yield. Averaged across cultivars, maximum grain (60.90 q ha) and straw (77.86 q ha) yield was recorded with 60 kg ha^{-1} of S.

Crop removal of nutrients including S

The nutrient uptake by grain and straw of the paddy cultivars is presented in Table 8. Out of the 3 paddy varieties tested, PD-4 occupied the first position followed by PR-108 and IR-64 in terms of uptake of all the nutrients by both grain and straw. The highest N, P, K and S uptake through grain as observed with PD-4 was 62.12, 17.77, 21.16 and 4.85 kg ha^{-1}, respectively.

Similarly, the maximum N, P, K and S uptake through straw also observed with PD-4 was 22.47, 6.07, 56.24 and 6.59 kg ha^{-1}, respectively (Table 7). Application of S could contribute remarkable improvement in crop uptake of N, P, K and also S over control having no S application. A gradual improvement in uptake of all the nutrients including S was recorded with increase in S dose. Maximum uptake of N, P, K and S through grain as recorded with S application at 60 kg ha^{-1} was 62.68, 18.23, 22.23 and 5.02 kg ha^{-1}, respectively. Similarly, maximum uptake of N, P, K and S through straw also recorded with S application at 60 kg ha^{-1} was 23.14, 6.28, 56.41 and 6.78kg ha^{-1}, respectively. S applied at 60 kg ha^{-1} affected a significant boost in nutrient uptake over its application at 20 kg ha^{-1}; however only marginal improvement was noticed over S application at 40 kg ha^{-1}.

DISCUSSION

Surface soil characteristics

The neutral to alkaline range of soil pH in the study area was also reported by Kumar (1999). The lower EC values might have stemmed from the fact that the soils of the district are well drained and soluble salts are mostly washed out by rivers Ganga and Yamuna and their tributaries to the plains of the neighbouring districts. The observed values were quite comparable to those reported by (Kumar, 1999). The level of CCE recorded in the study is in agreement with those reported by (Sharma and Gangawar, 1997). The SOC values are within the range as reported by Kumar (1999). The maximum SOC contents Gangoh and Muzaffarabad blocks might be due to these areas being densely planted with agro-forestry systems. The available N values in different blocks were almost at par with those reported by Kumar (1999). The low availability of soil P might he due to poor P reserve in organic pool. Almost similar availability of soil P and K in the study area was also reported by Tripathi et al. (2005).

Soil physico-chemical properties within a profile

The increase in soil pH with depth within a profile might be due to leaching of calcium carbonate and exchangable sodium on exchange complex which was also observed by Sharma et al. (1985) in soils of Moradabad and Mahajan (2003) in soils of Rampur Maniharan, Saharanpur. Erratic variation in EC with depth is perhaps caused by involvement of a number of factors. The observed values of CCE, which increased with depth despite showing an erratic trend, were well within the range as reported by Sharma and Gangwar (1997). As anticipated, SOC content invariably declined with depth, the values conforming to Mahajan (2003). The remarkable decline in available N, P, K contents with depth might have been caused, at least partially, by reduction in SOC. A similar variation in N, P, K contents with depth was also observed by Kharub (2006).

Variation in contents of soil sulphur fractions

At surface

The observed values of total sulphur were within the range of 19.0 to 3836.0 mg kg^{-1} in India as reported by Marsonia et al. (1986). The values were also well within the range as reported by (Singh, 2005). Considering the normal range of 100 to 500 mg kg^{-1} of total S in agricultural agricultural soils (Stevenson, 1986) the total S values recorded in the current study may be rated as medium to very high. The values of 0.03 M sodium di-hydrogen phosphate extractable sulphur and heat soluble S as recorded in the present study were well within the range as reported for Alfisols, Inceptisols and Mollisols of Moradabad district by Sharma and Gangwar (1997). Similarly, the contents of 0.15% calcium chloride extractable sulphur as recorded in the current study conform to the range suggested by Sharma and Gangwar (1997) although they were slightly higher than the values reported for Inceptisols and vertisols of Madhya Pradesh by Bhatnagar and Bhaduria (2006). The higher status of sodium di-hydrogen phosphate extractable sulphur over heat soluble and calcium chloride extractable sulphur might be due to the better extraction capacity of sodium di-hydrogen phosphate which extracts readily soluble sulphate plus part of adsorbed sulphate plus part of organic sulphur whereas, heat soluble sulphur represented readily soluble sulphur plus part of adsorbed sulphate and calcium chloride could extract only the readily soluble sulphur (Brook, 1979). The heat soluble sulphur was more than calcium chloride extractable sulphur because heating of soil sample resulted in liberation of sulphate sulphur covalently held by organic matter and conversion of unoxidized sulphur compounds to inorganic forms. The heat soluble sulphur was the sum of inorganic sulphur and sulphur released due to heating. The increase in extraction due to heating might be explained on the basis of three favourable factors of hydrolysis, that is, water, high temperature and duration of heating. Both the time of heating: and degree of temperature was effective in increasing the sulphate solubility (Bhardwaj and Pathak, 1969).

Within the profile

The decline in total S with depth might be ascribed to the fact that majority of the soil S is organic in origin and hence the decline in organic matter with depth is bound to have significant bearing on the S content. The decline in organic S content and the % contribution of organic S to total S with depth as observed in this study provides testimony to this. Similar observations were also made by Mahajan (2003). In most of the sites studied, 0.03 M sodium di hydrogen phosphate extractable S content tended to decline with depth while showing gradual increase in its contribution of total S. The values observed in the present study were found to be lower than those reported by (Sharma et al., 2000). Heat soluble S content also declined with depth in all the places barring Punwarka, Deoband and Nanauta block where no definite trend could be recorded. However, there was constant improvement in content of heat soluble S to total S with depth. The heat soluble S contents recorded in the present study were lower than those reported by Sharma et. al. (2000), while they were in agreement with values reported by Dwivedi et al. (1983). In general, 0.15% $CaCl_2$ extractable S also showed a tendency to decline with depth barring a few exceptions, while its contribution to total S increased constantly with depth. The values were well within the range as reported by Sharma et al. (2000). The decline in 0.03 M sodium di hydrogen phosphate extractable, heat soluble and 0.15% $CaCl_2$ extractable S with depth might be due to decline in total S content with depth. On the other hand, improvement in contribution of these 3 fractions of S to total S might be due to drastic decline in the contribution of organic S to total S with depth.

Correlations of soil physico-chemical properties with S fractions

At surface (0-30 cm)

The negative correlation of soil pH with different S fractions might have been governed by the degree of H^+ and OH ions present on soil Miscelle depending on pH. H ions being positively charged may attract soil sulphate ions while the negatively charged OH^- ions repel them. The sodium di-hydrogen phosphate extractable sulphur is not affected by ionic concentration and hence might have shown non- significant correlation with pH of the soil. This was in conformity to the findings of Sharma and Gangwar (1997). The weak and negative correlation of EC with different S fractions was in agreement with findings of Pandey et al. (1989), Sharma and Gangwar (1997) and (Kumar, 1999). The negative correlations of CCE with S fractions were also reported by Sharma and Gangwar (1997). SOC being the prime source of S, its positive correlations with different S fractions was rather anticipated. This was in agreement with findings of Sharma and Gangwar (1997) and Kumar (1999). The same reason may be cited for positive correlation of available N with different S fraction. The positive correlations of available P with organic S and 0.03 M sodium di-hydrogen phosphate extractable S might be attributed to better extraction capacity of the extractants to facilitate release of phosphate bound S from the total S pool. Similar correlation of available P with organic S was also reported by Kumar (1999). The negative correlation between available phosphorus and total sulphur may be due to the poor extractant capability or due to complex bond of sulphur end phosphorus in organic pool. The negative correlation of sand content with all the S fractions perhaps reflected leaching of soluble S bearing salts from lighter soils. Similar relationship was also reported by Sharma and Gangwar (1977). The significant positive correlation as observed between S fractions and clay contents might be due to increase in holding capacity of soils and formation of organic complex which is supposed to form a reserve pool for S since sulphate S and other forms of S are in dynamic equilibrium and related significantly to each other. Similar correlation between clay content and S fractions was also reported by Sharma and Gangwar (1997), Kumar (1999) and Singh et al. (2009).

Across depths (30-150 cm) in a profile

The negative correlation of soil pH with different S fractions observed upon averaging across depth in a profile might be due to changes in H and OH ion concentrations as discussed earlier for the surface soil. The staggered correlation of parameters such as EC and CCE with different S fractions perhaps indicates towards relative dominance of one factor among many. It was interesting to note the positive correlations of SOC, available N and available P with nearly all the S fractions (barring the negative correlation of available P with heat soluble S) which perhaps indicates towards the importance of organic matter as source of S, N and P irrespective soil depth although the contribution of organic matter tends to decline with depth. The positive correlation between available K and most of S fractions perhaps indicates towards the effects of organic matter and mineralogy in governing availability of these nutrients The negative correlation of available K with 0.15% $CaCl_2$ extractable S might have stemmed, at least partially from poor extraction ability of the extractant. Negative correlation of sand content with different S fractions underlines the adverse effects of this lighter soil fraction in either supplying or retaining S. On the other hand, positive correlations of silt and clay contents with different S fractions perhaps highlight the importance of these heavier soil fractions in maintaining S status at satisfactory level. The strong positive correlation of organic S with clay content is also indicative of the benefical role played by the clay-organic matter complex in ensuring a steady flow of available S from a formidable and stable S pool.

Lowland paddy productivity

The differential response of the lowland paddy cultivars towards graded S levels are due to genotypic variabiltv. The increase in plant height irrespective of varieties with every increment in S application rate however shows the beneficial impact of the nutrient This is in conformity with the findings of Singh and Singh (2002) where significant increase in plant heights of paddy varieties Swarna and PR-108 with gradual increase in S level from 0 to 40 kg ha' was reported. The increase in LAI and chlorophyll content with every increment in S dose is perhaps testimony to the key role played by S in plant metabolic activities. Such increase in LAI with gradual increase in S doses from 0 to 45 kg ha' was also reported by Chandel et al. (2003). The increase in grain test weight with enhanced S dose might he an indicator for enrichment of paddy grains with nutrient components viz., proteins etc., whose formation and constitution is critically dependent on optimum supply of S. The increase in grain and straw yield with every increment S dose has perhaps stemmed from better crop growth attributes achieved with enhanced levels of S. This was in agreement with the findings of Chandel et al. (2002), where marked improvement in paddy grain and straw yield with increased S levels from 0 to 45 kg ha^{-1} was reported. However the lack of significant boost in paddy growth and yield with S applied at 60 over kg ha^{-1}; its application at 40 kg ha^{-1} was observed in this study has perhaps indicated the latter to be the more economical dose for optimizing productivity of paddy.

Nutrient uptake by lowland paddy

The maximum uptake of all the nutrients by the variety PD-4 was well anticipated as it performed best in terms of all the growth and yield parameters including grain and straw yield. The gradual improvement in uptake of all the major nutrients including S with increasing S levels perhaps reflects inherent deficiency of available S in soil although on the basis of soil test value the most easily available form (0.15% $CaCl_2$ extractable) of sulphur in the experimental site corresponds to medium range. This is also indicative of complementary effects of S on these nutrients. Reduction in root hydraulic conductivity resulting in nutrient, starvation from root to shoot in S stressed condition has also been reported by Karmoker et al. (1991). The N uptake by paddy grains was nearly 3 fold higher as compared to paddy straw especially under S application perhaps contributing more accumulation of proteins in grains. Similar enhancement in N uptake in response to increasing S levels was also reported by Sakal et al. (1999). Progressive improvement in S, P and K uptake with increasing S levels as was observed with N offers enough reasons for better growth and yield of the crop with increasing rate of S application. The increase in uptake of P and K by paddy with increase in sulphur levels was also reported by Singh et al. (1994) and Sakal et al. (1999), respectively. Significant improvement in nutrient uptake upto 40 kg S ha^{-1} followed by only marginal increase with 60 kg S ha^{-1} gain underlined the previous S level as the most economical for optimal performance of the crop.

Conclusions

After thorough perusal of the data generated in the present investigation, the following conclusions could be drawn. The soil of the study site was mostly neutral to alkaline in reaction and was having physicochemical properties well within the range as reported earlier for the area. Total S content of the site was medium to high/ very high in range. Organic S was the major contributor to total S pool throughout the profile although the contribution of organic S declined with depth. On an average, the contents of sodium di-hydrogen phosphate extractable S was higher than heat soluble and calcium chloride extractable S, irrespective of location and soils depth. Soil pH and calcium carbonate equivalent was negatively correlated with contents of different S fractions. Significant positive correlations of soil organic carbon and clay content with different S fractions reflected the beneficial role played by soil organic matter and clay- organic matter complex in maintaining a higher S status in soil. In most of the sites studied; sodium di hydrogen phosphate extractable, heat soluble and calcium chloride extractable S showed gradual decline in content and constant improvement in percent contribution to total S with increase in depth.

Great genetic variability was recorded amongst the 3 paddy cultivars regarding production as well as nutrient uptake efficiencies. Out of the 3 varieties tested, variety PD-4 performed best in terms of growth, yield and uptake of nutrients. Growth and yield response of the crop (irrespective of varieties) which improved with every increment of S application was better only marginally with S application at 60 kg ha^{-1} than with S applied at 40 kg ha^{-1}. Variety PD- 4 was also responsible for maximum crop removal of nutrients irrespective of S levels. Crop removal of N, P, K and S increased with increase in S application rate. However, the highest dose of S (60 kg ha^{-1}) could affect only nominal increase in crop removal of the nutrients over that obtained from S applied with 40 kg ha^{-1}. Thus, taking into account the growth and yield performance of the crop along with the nutrient uptake pattern, S applied at 40 kg ha^{-1} seems more economical than its application at 60 kg ha^{-1} to ensure optimum productivity of paddy.

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