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Forms of sulphur and their relationship with soil physical properties in Vertisol

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Abstract
Forms of sulphur and their relationships with soil physical properties and sulphur availability indices were investigated in soybean growing in Vertisols. The abundance of various forms of sulphur was in the decreasing order *i.e.* total S >organic S > heat soluble S> sulphate S> water soluble S. All forms of S showed significantly positive correlation with organic carbon and physic-chemical properties of soil. Silt content of the soil showed negative impact. Available sulphur showed significant and positive corrélation with soil aggregate size, mean weight diameter, infiltration rate, soil moisture content bulk density and pénétration résistance in Vertisol. Among soil properties, pH and electrical conductivity showed negative correlation with plant available sulphur in surface layer (0-30 cm), whereas, there was a positive correlation with organic carbon in the lower layer (30-60 cm) of soil profile.

Keywords: Triclosan, TCS, determination, detection, sensor

Introduction

Sulphur is the fourth major plant nutrient element. It is essential for synthesis of amino acids like cystine, cysteine and methionine which are the basic structural units of protein molecules. It activates certain enzyme systems and is a component of some vitamins. It resembles N for many functions in plants and is synergistic to nitrogen fixation and nodule development in legumes. It is required by plants in amounts similar to phosphorus for cell wall formation, protein synthesis, enzyme reaction and energy transfer. These soils are strongly to moderately acidic with high Fe and Al oxide contents, dominated by high active clay and exhibited multiple nutrient deficiencies including that of sulphur. Lack of indigenous sources of S, enhanced removal of S from the soil under intensive cropping systems and use of high analysis S-free fertilizers coupled with its leaching from root zone are largely responsible for increasing incidences of S deficiency in these soils (Sammi Reddy *et al.* 2001; Sarkar *et al.* 2007; Bose *et al.* 2008) [19, 20, 4]. In early 1990s, S deficiencies were reflected in about 130 districts of the country (Tandon 1991) [25]. Singh (2000) [21] reported that nearly 45% districts of the country exhibited more than 40% S deficiencies.

Oilseed crops are extensively grown in an area of 9.08 lakh ha of Jabalpur representing Vertisol, Entisols, Inceptisols and Alfisols and reported about 46.4 percent, 20.0 per cent and 8.3 percent deficiency in available S, respectively (Das *et al.* 2009; Basumatary *et al.* 2010; Das *et al.* 2011) [1, 3]. S deficiency in M.P. have been attributed to continuous use of high analysis S-free fertilizers, inclusion of high yielding varieties used in the intensive cropping system and restricted use of organic manures. Soils under high annual rainfall (>1500 mm) in Jabalpur enhances leaching of $S0_4$, leaving these soils deficient in S (Borkotoki and Das 2008) [6]. Because of the above factors, the areas earlier described as sufficient in available S have started showing S deficiency in some districts of M.P. Thus, to know the exact S supplying capacity of a soil, this present study was undertaken to know different forms of sulphur in relation to soil properties in Vertisol.

Soybean is rapidly emerging as the most important oil seed crop along with great potential as very rich protein food. Importance of soybean as a source of protein and oil is well established (Dwivedi *et al*., 2007) [8]. It can supply the much needed protein to human diets, soybean contains 35-40% protein, 19% oil, 35% carbohydrate (17% of which is a dietary fibre), 5% minerals and several other components including vitamins (Liu, 1997) [14]. Owing to its amino acids composition, the protein of soybean is called a complete protein. In India, soybean is grown in about 110.66 lakh hectare under diverse agro-climatic and soil conditions with average production of 86.43 lakh tonne. While in Madhya Pradesh it is cultivated in an area of 56.13

lakh ha and production about 44 lakh tonne which contributes about 60% production from around 55% of soybean grown area of the country (SOPA, 2015).

Material Methods

The study was conducted at the research field of Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur, situated at $23^{0}10$"N latitude and $79^{0}57$"E longitude and at an altitude of 393.0 meter above mean sea level in the South-Eastern part of the Madhya Pradesh. The soil of the experimental field is medium black belonging to Kheri series of fine montmorillonitic hepertherimc family of Typic Haplustert. The climate in the Jabalpur is generally pleasant and salubrious. The tropic of cancer passes through the middle of the district. It has sub-tropical climate characterized by hot dry summers and cool winters. Jabalpur lies in the "Kymore Plateau and Satpura hills" agro-climatic zone of Madhya Pradesh. The average maximum temperatures during the month of May-June varies between 42.5 to 46.4 ^{0}C and are the hottest month of the year, while the average minimum temperature ranges from 4.2 to 8.7 ^{0}C during December-January, which are the coldest month of the year. The average annual rainfall over the district is 1274 mm which is mostly received between June to September (summer monsoon) and a little rainfall (75 to 175mm) received during October to May. The average humidity of the region is about 73 per cent and average evaporation is 3.93 mm/day.

Experimental details

Design used	:	Randomized block design
Replication	:	04
Treatments	:	8
Plot size	:	17x10.8 m (183.6 m^2)
Space between replications	:	2m
Space between plots	:	1 m
Experimental area	:	146X58 m
Cropping sequence	:	Soybean-wheat

RDF soybean 20:80:20 kg ha^{-1} NPK

Table 1: Physico–chemical properties of soil at initiation of the Field study

S. No	Soil Properties	Value	Method Used
1.	Mechanical composition %		International Pippete Method (Piper, 1950) [17]
	Sand	25.3	
	Silt	18.9	
	Clay	55.8	
2	Terminal infiltration rate (mm hr^{-1})	12.7	Double ring infiltrometer method (Richards, 1954)
3.	Bulk density (Mg m^{-3})	1.34	Manually operated core sampler method (Richards *et al.*,1954)
4.	Cation exchange capacity [C mol (P^{+}) kg^{-1}]	30.15	Cation exchange capacity (CEC) with % clay and % OM using
5.	pH (1:2.5)	7.62	Glass electrode pH meter (Piper 1950) [17]
6.	Electrical conductivity (1:2.5) (dSm^{-1})	0.21	Electrical conductivity meter (Piper 1950) [17]
7.	Organic carbon (g kg^{-1})	6.40	Walkley and Black rapid titration method (1934)
8.	Available nitrogen (mg ka^{-1})	121.6	Alkaline permanganate method (Subbiah and Asija, 1956)
9.	Available phosphorus (mg ka^{-1})	8.7	Soils were extracted with 0.5 M $NaHCO_3$ and colour development by Ascorbic acid (Olsen *et al*., 1954) [16]
10.	Available potassium (mg ka^{-1})	154.2	Neutral normal ammonium acetate method by using flame photometer (Chapman and Pratt, 1965)

Table 2: Methods used for estimating different forms of sulphur in soil samples

Form of sulphur	Method	Reference
Total sulphur	Estimated by turbidimetrically using $Bacl_2$ from extract obtained after digesting the soil with HNO_3 and $HClO_4$ di - acid mixture.	[3]
Water soluble sulphur	Estimated turbidimetrically using de – ionized water as extracting solution	[11]
Heat soluble sulphur	Soil samples were hydrolyzed with the addition of distilled water and then evaporated to dryness on gently heating boiling water both. The sulphur in the solution was determined turbidimetrically	[11]
Sulphatesulphur	Extracted with 0.15% $CaCl_2$ using soil extractant ratio of 1:5 sulphur in soil extract was determined calorimetrically by developing $BaSO_4$ turbidity in the presence of sodium acetate – acetic acid buffer.	[3]
Organic sulphur	By subtraction of sulphate sulphur from total sulphur	-

Result and Discussion

Effect of integrated addition of fertilizers and manure on soil physical properties

Effect of continuous addition of integrated fertilizers and manure on physical properties (bulk density, penetration resistance, mean weight diameter, soil moisture content and fractions of water stable aggregates) of surface (0-15 cm) and sub-surface (15-30 cm) soils were evaluated after harvest of wheat crop grown in soybean-wheat sequence and the results thus obtained are presented separately under following heads:

Bulk density

The data pertaining to the effect of continuous imposition with and without integration of organic source on bulk density of soil at 0-15 cm and 15-30 cm depths are given in table 3. Data clearly indicated that bulk density in soil at both the depths was significantly affected by different treatments of nutrient application. Data further revealed that bulk density of surface and sub-surface soil layers was maximum (1.39 and 1.50 Mg m^{-3}) under control (T_8) treatment while, it was lowest in control (1.28 and 1.37 Mg m^{-3}). It was also evident from the data that bulk density of soil in sub-surface layer was higher as compared to surface soil layer in all the treatments. The results clearly indicated that integration of organic source with inorganic nutrients reduced the bulk density of soil and also the bulk density increased with soil depth irrespective of the nutrients application treatments.

Penetration resistance

Penetration resistance indicates the degree of compactness in soil. A significant effect of integrated nutrients application with and without integration of organic manure on penetration resistance was observed at 0-15 cm and 15-30 cm soil depths (table 3). Data further indicated that integration of FYM with inorganic fertilizers significantly reduced the penetration resistance over same levels of higher yield (T_6) treatments and other treatments as well. Highest penetration resistance was observed under control (T_8) (0.42 and 0.44 M Pa) for 0-15 and 15-30 cm soil depths, respectively. It was also evident from the data that sub-surface (15-30 cm) soil layer exert more resistance to penetration as compared to surface layer (0-15 cm). The data further showed that in surface layer penetration resistance varied from 0.34 M Pa (T_6 and T_7) to 0.42 M Pa (T_8), while in sub-surface layer values ranged from 0.35 M Pa (T_6) to 0.44 M Pain control (T_8) treatments.

Table 3: Effect of application of integrated nutrient application on soil bulk density

Treatment	Bulk density ($Mg\ m^{-3}$)		Penetration resistance (M Pa)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
50% NPK	1.34	1.44	0.39	0.41
100% NPK	1.35	1.44	0.38	0.40
150% NPK	1.35	1.43	0.38	0.41
100% NP	1.33	1.41	0.37	0.39
100% N	1.32	1.40	0.37	0.39
100% NPK + FYM	1.29	1.37	0.34	0.35
100% NPK (S FREE)	1.28	1.37	0.34	0.36
CONTROL	1.39	1.50	0.42	0.44
SEm $\pm$	0.020	0.022	0.012	0.013
CD (*p=0.05*)	0.060	0.067	0.036	0.040

Mean weight diameter

Data pertaining to mean weight diameter of soil aggregates are presented in table 4. Data clearly indicated that effect continuous addition of integrated nutrient application significantly affected the mean weight diameter at 0-15 and 15-30 cm soil depths. Mean weight diameter of soil aggregates under the treatments of only inorganic nutrients application were significantly smaller than those treatments received FYM at the rate of 5.0 t ha^{-1} in surface layer (0-15 cm), while the difference was not significant for sub-surface (15-30 cm) soil layer. Further it was observed that mean weight diameter of soil aggregates in surface layer was larger than the sub-surface layer and the least mean weight diameter of soil aggregates were obtained in control treatment at both the soil depths.

Soil moisture content

Data on soil moisture content in 0-15 cm and 15-30 cm soil depths as affected by integrated nutrient application after harvest of wheat crop has been given in table 4. It is clear from data that soil moisture content was significantly affected by integrated application of inorganic and organic sources of plant nutrients. It is also evident from data that soil moisture content in different treatments ranged from 21.93 (control) to 25.22 percent (T_6) in surface layer soil (0-15cm) and 24.33 (T_8) to 27.13 percent in T_6 (100% RDF with 5.0 t FYM ha^{-1}) treatment in sub-surface layer soil. Soil moisture content in sub-surface soil was higher than those of surface soils in different treatments. Results clearly indicated that addition of organic manure significantly increased the soil moisture content and also the moisture content is directly related to the soil depth.

Table 4: Effect of addition integrated nutrient application on mean weight diameter and soil moisture content

Treatment	Mean weight diameter (mm)		Soil moisture content	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
50% NPK	1.38	1.21	21.84	22.41
100% NPK	1.39	1.20	21.33	22.52
150% NPK	1.36	1.23	20.78	21.82
100% NP	1.37	1.25	20.30	21.67
100% N	1.35	1.24	20.11	21.62
100% NPK + FYM	1.51	1.38	24.63	25.02
100% NPK (S FREE)	1.49	1.35	23.34	24.16
CONTROL	1.21	1.12	19.58	21.37
SEm $\pm$	0.029	0.026	0.950	0.731
CD (*p=0.05*)	0.088	0.079	2.862	2.202

Water stable aggregates

Data pertaining to fractions of water stable aggregates of different size in surface (0-15 cm) and sub-surface (15-30 cm) soils as effect by integrated nutrient application after harvest of wheat crop are given in table 6 and 7, respectively. Data clearly indicated that different size fractions of water stable aggregates were significantly affected by integrated nutrient application in both surface and sub-surface soils.

It is evident from the data (table 6) that size of water stable aggregates in surface soil was improved due to integrated use of FYM (T_6) and inorganic fertilizers as compared to application of inorganic fertilizers (T_2) alone. However, the fraction of water stable aggregates of finer size was more in the treatments received only inorganic fertilizers. The data further showed that aggregates in the size fractions of >2, 2-1, 1-0.5, 0.5-0.25, 0.25-0.1 and < 0.1 mm were ranged from 1.53-3.65, 9.4-20.4, 28.5-37.7, 16.7-26.0, 6.06-18.7 and 15.53-21.45 percent, respectively in different treatments in surface soil.

Data pertaining to water stable aggregates of different size fractions in sub-surface soil as effect by integrated nutrient application (table 7) also indicated that percent fraction of larger aggregates were significantly more in those treatments received FYM along with inorganic fertilizers. While, the percent of finer aggregates fractions were higher in the treatments which received only inorganic fertilizers.

The data presented in tables 6 and 7 clearly revealed that integration of FYM with inorganic fertilizers significantly improved the quantity of larger water stable aggregates in both surface and sub-surface soil layers which have great importance for good aeration, better infiltration and water holding in soil.

Table 5: Effect of addition integrated nutrient application on infiltration rates of soil

Treatment	Initial (0-30 min) infiltration rate (mm hr^{-1})		Equilibrium (30-60 min) infiltration rate (mm hr^{-1})	
	Before sowing	After Sowing	Before sowing	After Sowing
50% NPK	34.3	35.2	11.6	12.1
100% NPK	34.7	35.6	11.4	12.4
150% NPK	34.9	35.5	11.5	12.3
100% NP	35.0	35.7	12.3	12.9
100% N	35.9	35.8	12.7	12.6
100% NPK + FYM	38.5	39.1	12.3	13.6
100% NPK (S FREE)	36.8	37.5	12.1	13.5
CONTROL	33.8	35.4	10.5	11.5
SEm ±	0.83	0.84	0.38	0.34
CD (*p=0.05*)	2.51	2.52	1.14	1.03

Table 6: Effect of addition integrated nutrient application on water stable soil aggregates

Treatment	Soil aggregates of different size (%) at 0-15 cm soil depth					
	> 2.0 mm	2.0-1.0 mm	1.0-0.5 mm	0.5-0.25 mm	0.25-0.10 mm	< 0.10 mm
50% NPK	1.86	14.11	29.34	19.66	9.69	22.62
100% NPK	1.87	12.78	30.10	20.14	10.11	23.01
150% NPK	1.86	18.75	27.98	19.30	11.16	20.96
100% NP	1.97	16.07	33.93	19.17	9.19	19.68
100% N	1.94	16.99	31.54	20.49	10.36	19.11
100% NPK + FYM	3.82	21.30	37.98	18.41	5.23	13.27
100% NPK (S FREE)	3.73	19.10	36.91	17.71	7.52	15.04
CONTROL	1.55	9.76	18.89	21.98	23.27	24.56
SEm ±	0.042	0.445	0.704	0.766	0.577	0.561
CD (*p=0.05*)	0.125	1.341	2.123	2.308	1.738	1.692

Table 7: Effect of addition integrated nutrient application on water stable soil aggregates

Treatment	Soil aggregates of different size (%) at 15-30 cm soil depth					
	>2.0 mm	2.0-1.0 mm	1.0-0.5 mm	0.5-0.25 mm	0.25-0.10 mm	< 0.10 mm
50% NPK	1.49	15.01	28.38	16.32	11.25	28.44
100% NPK	1.50	15.43	29.75	17.66	12.22	28.40
150% NPK	1.53	16.59	27.76	15.96	10.23	27.94
100% NP	1.56	16.43	29.21	14.94	9.20	28.68
100% N	1.62	15.99	28.51	14.26	10.47	28.37
100% NPK + FYM	2.79	17.98	31.87	9.96	9.66	29.93
100% NPK (S FREE)	2.71	16.63	30.34	9.90	8.49	29.86
CONTROL	1.19	7.98	22.81	21.43	10.03	36.57
SEm ±	0.059	0.721	0.861	0.669	0.574	0.808
CD (*p=0.05*)	0.177	2.173	2.595	2.015	1.731	2.435

Table 8: Effect of continuous addition of integrated nutrient use on soils physico-chemical properties on soil

Treatments	Physico-chemical properties of soil					
	pH		EC (dS m^{-1})		OC (g kg^{-1})	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
50% NPK	7.51	7.61	0.15	0.17	6.25	5.28
100% NPK	7.56	7.64	0.17	0.20	7.25	6.65
150% NPK	7.59	7.67	0.19	0.21	8.04	7.12
100% NP	7.55	7.63	0.17	0.19	6.70	5.75
100% N	7.47	7.58	0.16	0.17	5.32	4.82
100% NPK + FYM	7.55	7.60	0.18	0.19	9.31	7.93
100% NPK (S FREE)	7.57	7.61	0.16	0.17	6.74	5.57
CONTROL	7.56	7.59	0.15	0.16	4.98	3.87
SEm±	0.18	0.17	0.01	0.02	0.30	0.31
CD (P=0.05)	NS	NS	NS	NS	0.89	0.91

Soil pH

Initial value of the soil pH (0-20 cm) when the experiment started in 1972 was 7.6. However, the pH values as influenced by the integration of organic and inorganic fertilizers and manure of the different treatment are presented in table 7. The result revealed that the soil pH (0-15 cm) ranged between 7.47 to 7.59. The pH value at 15-30 cm depth ranged between 7.58 (100% N) to 7.67 (150% NPK) in various treatments. The value is slightly higher as compared to the pH values at surface. Treatment which includes for study intermediate between two and indicated that pH of the soil was not much affected by the imposition of treatments. Pramanik and Dolui (2001) [18] Bhatnagar *et al.* (2003) [2]. The total sulphur correlated positively and significantly with pH and clay, whereas organic sulphur showed a positive and highly significant correlation with organic carbon (Mandal *et al.* 1997) [15].

Soil EC

The result revealed that the EC of the soil at 0-15 cm depth ranged between 0.15 dSm^{-1} (50% NPK and control) to 0.19 dSm^{-1} (150% NPK) in various treatment and noticed that the continuous application of different doses of fertilizers and manure did not resulted in any significant effect on soil EC.

The EC value slightly higher as compared to those observed in 0-15 cm depth and ranged between 0.16 (control) to 0.21 dSm^{-1} (150% NPK). However, the differences were found to be non-significant. All the forms of sulphur except organic sulphur correlated positively and significantly with electrical conductivity. A positive and significant correlation of organic sulphur was observed with organic carbon and CEC. The electrical conductivity of soils had a greater impact on different forms of sulphur followed by CEC. (Gowrisankar and Shukla 1999) [9].

Organic Carbon

The data observed in table 7 showed that the organic carbon significantly increased with increase in the doses of fertilizers. The lowest value was noticed in control (4.98 g kg^{-1}) which was increased to 6.25, 7.25 and 8.04 g kg^{-1} respectively due to use of 50% NPK, 100% NPK and 150% NPK of RDF. The highest content 9.31 g kg^{-1} was observed in 100% NPK+FYM treatment. Hebsur *et al.* (2004) [10] Srinivasarao *et al.* (2004) [23]

Soil organic carbon content at 15-30 cm depth found to be lower as compared to the content found at 0-15 cm depth. However, it was found that with increasing level of fertilizer OC content of soil continued to increase and the values were found to be higher as compared to control. The lowest value was noticed 3.87 g kg^{-1} in control whereas inclusion of FYM along with 100% NPK (7.93 g kg^{-1}) treatment increased the OC content followed by 150% NPK (7.12 g kg^{-1}) treatment. However, 50% NPK and 100% NPK (5.28 and 6.65 g kg^{-1}) found lower as compared to 150% NPK (7.12 g kg^{-1}).

Total and sulphate sulphur had a significant positive correlation with organic carbon and a negative one with pH, whereas organic and non sulphate sulphur maintained a significantly positive relationship with organic carbon. All forms of sulphur had significant and positive relationships with each other. (Singh *et al.* 2000) [21].

Plant available sulphur showed significant positive correlation with organic and total sulphur fractions in the profiles. Among soil properties, pH and electrical conductivity showed negative correlation with plant available sulphur in surface layer (0-30 cm), whereas, there was a positive correlation with organic carbon in the lower layer (30-60 cm) of soil profile.

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