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Effect of Different Sulphur Sources on Sulphur Fractionation in a Red Sandy Loam Soil

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The aim of the present study was to examine the different forms of sulphur fractions in post-harvest soil of cabbage crop to determine the S status of red sandy loam soil, Thondamuthur block, Coimbatore district.
Study Design: The design used in the present study was Factorial randomized block design with 20 treatments replicated thrice.
Place and Duration of Study: A field experiment was carried out in a farmer's field of red sandy loam non-calcareous soil, deficient in sulphur which was located at Viraliyur village of Thondamuthur block, Coimbatore district during February to May 2021 of rabi season.
Methodology: A field experiment was carried out in sandy loam sulphur deficient soil with cabbage as test crop fertilized with NPK along with different sulphur sources viz., elemental sulphur, potassium sulphate, gypsum and single super phosphate @ levels of 0, 20, 40, 60 and 80 kg ha^{-1} replicated thrice in a Factorial Randomized Block Design. S fractions of water-soluble S, inorganic S, organic S, available S and residual S were estimated in post-harvest soil.
Results: The results revealed that the total sulphur differed from 278.1 to 339.4 mg kg^{-1}. Among the sulphur fractions, inorganic S (39%) accounts highest proportion of total S followed by organic S (38.3%), water-soluble S (9.19%) and available S (4.12%). The order was, Inorganic S > organic S > sulphate S > water soluble S.

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Conclusion: This study indicated that all the sulphur fractions are strongly associated with S sources, levels and properties of red sandy loam soil of Coimbatore district under cabbage cultivation.

Keywords: Sulphur fractions; sulphursources; soil properties; red sandy loam soil.

1. INTRODUCTION

Sulphur (S) is the ninth and least abundant necessary macronutrient in plants, after carbon, oxygen, hydrogen, nitrogen, potassium, calcium, magnesium, and phosphorus. It plays an important role in improving crop growth and involved in plant metabolism therefore, it is termed as the fourth major plant nutrient [1]. It is a vital element for plants, and the soil constitutes the primary source of S [2]. Deficiency of sulphur is widespread in soil and occurs in 120 out of 400 districts in India [3]. Inorganic SO_4-S (S imbedded in colloids, dissolved in the soil solution, and precipitated SO_4-S) is readily available to plants and accounts for about approximately 5% of total S [4]. Sulphur fertilization is important to enhance the productivity and quality of cabbage.

In red soil, availability of sulphur was high due to low pH and high iron and aluminium oxide concentration, which absorbs more sulphate S than black soils [3]. There are about three factors which includes physical, chemical and biological factors that affect sulphate in soil. Sulphur in soil - plant system undergoes 3 major transformations ie., mineralization, immobilization and oxidation which determine its gains and losses through leaching, gas evolution and adsorption under different agroclimatic conditions [5]. By regulating S release and dynamics in soil, the depth distribution of different sulphur forms and their interactions determine the S supplying power of soil by influencing its release and distribution [6]. Many information regarding sulphur dynamics in temperate soils are available but there is only limited information about the dynamics of S pools for tropical soils [7].

In most soils, sulphate (SO_4) is the most common form of inorganic S, while some reduced S forms (elemental S, thiosulphate, or sulphide) can also be found in anaerobic soils. Researchers have examined a lot of work on the key processes of sulphur cycling, which mainly focus on the releasing pattern of sulphur. Some of the researchers includes [8,9] studied the distribution and accumulation of sulphur in soil system [10,11], the mineralization and immobilization of organic sulphur by [12], the dissimilatory reduction process of sulphate and its coupling mechanism with carbon, nitrogen and iron studied by [13,14]. Understanding of various types of sulphur is essential for determining the long-term availability of sulphur and to formulate effective sulphur fertiliser recommendations. The information regarding distribution of various sulphur forms in sandy loam soils is limited, hence the present investigation was proposed to determine the sulphur fractions present in the soil due to added sulphur fertilization.

2. MATERIALS AND METHODS

A field experiment was conducted in a farmer's field at Viraliyur, Thondamuthur, Coimbatore district, with cabbage hybrid Saint as test crop in a S deficient soil to study the sulphur fractions. The soil chosen for the study was red sandy loam in texture having deficient S, with slight alkaline soil reaction, non-saline, non-calcareous and having low available nitrogen, potassium and organic carbon content but high available phosphorus. Totally twenty treatment combinations were replicated thrice in a factorial randomized block design using different sulphur sources *viz*., Elemental sulphur, Potassium sulphate, Gypsum and SSP with the levels of 0, 20, 40, 60, 80 kg S ha^{-1} respectively. Post-harvest surface soil samples were collected treatment-wise at 0-30 cm depth from the field after the harvest of cabbage (90th day), processed and analysed for different fractions of sulphur by sequential extraction as outlined by [15]. Initial soil characteristics of experimental soil were listed below (Table 1) and field layout (Fig. 1).

2.1 Water Soluble Sulphur

Five grams of soil was extracted with 25 ml of distilled water (1:5 of soil: water ratio) and centrifuged for about 10 minutes and filtered. After collecting the filtrate, sulphur was estimated by using turbidimetry method [16].

Table 1. Basic initial properties of the soil

Soil properties	Mean	Category
pH	7.65	Slightly alkaline
EC (dSm^{-1})	0.19	Non-saline
OC (%)	0.51	Medium
Available S (mg kg^{-1})	9.45	Deficient

S1R2L1	S3R3L1	S4R1L1	S2R2L1
S1R3L1	S3R1L1	S4R2L1	S2R1L1
S1R1L1	S3R2L1	S4R3L1	S2R3L1
S1R2L3	S3R1L2	S4R2L4	S2R1L5
S1R1L3	S3R3L2	S4R1L4	S2R2L5
S1R3L3	S3R2L2	S4R3L4	S2R3L5
S1R2L5	S3R3L4	S4R1L2	S2R1L3
S1R3L5	S3R1L4	S4R3L2	S2R2L3
S1R1L5	S3R2L4	S4R3L2	S2R3L3
S1R3L4	S3R1L5	S4R1L5	S2R2L2
S1R1L4	S3R3L5	S4R2L5	S2R3L2
S1R2L4	S3R2L5	S4R3L5	S2R1L2
S1R1L2	S3R1L3	S4R2L3	S2R3L4
S1R2L2	S3R2L3	S4R3L3	S2R2L4
S1R3L3	S3R3L3	S4R1L3	S2R1L4

Fig. 1. Field layout

2.2 Available Sulphur

The soil residue obtained after the extraction of water-soluble sulphur was treated with 25 ml of 1% NaCl, centrifuged for 30 minutes and filtered. After collecting filtrate S was determined turbidimetrically [16].

2.3 Inorganic Sulphur

Inorganic sulphur was extracted by adding 25 ml of 1% HCl solution to the soil residue obtained from previous extraction, kept for shaking 10 minutes and filtered. The soil was leached with distilled water for free of chloride. After extraction of S fraction, sulphur was estimated turbidometrically [16].

2.4 Organic Sulphur

The residue from the HCl extraction (2g oven dried) was treated with H_2O_2 until the effervescence stops, it was centrifuged and filtered. From the collected extractant, S was analysed by using turbidimetry method [16].

2.5 Total Sulphur

Total sulphur content was determined separately by acid digestion method as per the procedure given by [17]. Five grams of finely ground soil was mixed with 3 ml of 69% Nitric acid and heated on steam bath. Then, 3 ml of 60% Perchloric acid and 7 ml of Phosphoric acid were added and heated on sand bath at 190-210ºC until white fumes were visible. Two ml of 37% Hydrochloric acid was added after cooling and heated again until white fumes visible. The digest was transferred quantitatively and volume was adjusted to 100 ml using 1N HCl and were analysed by using turbidimetry method [16].

2.6 Residual Sulphur

The residual fraction of soil S represents the unaccounted S not extracted by any of the previous sequential extractants, hence, this fraction was calculated from the difference between total S and sum of all fractions. After extraction of all forms of S fractions, sulphur in the different extracts was estimated turbidometrically [16].

2.7 Statistical Analysis

The data obtained from experiment were subjected to statistical analysis using AGRESS software version 7.01. The level of significance used was $P < .05$. Critical difference (CD) values were calculated for the $P < .05$ whenever “F” test was found significant.

3. RESULTS AND DISCUSSION

Applied sulphur enters into various forms mainly organic and inorganic, water soluble and sulphate S. Knowledge on proportion of sulphur at varied depths gives an overall management of S and thereby to select appropriate nutrient management strategy to produce higher economic growth in a cropping system through long-term fertiliser use [18].

3.1 Water - Soluble Sulphur

The water - soluble sulphur in soil varied from 11.5 to 38.2 mg kg^{-1} significantly (*P*=.05) (Fig. 2). Water- soluble sulphur fraction exert a significant interaction on sulphur treatment. Highest mean value of 29.0 mg kg^{-1} of water-soluble sulphur was recorded in SSP applied soil followed by potassium sulphate having the mean value of 27.8 mg kg^{-1} and the lowest mean value of 23.4 mg kg^{-1} was observed in elemental sulphur applied soil. This water-soluble S fraction increases with increasing levels of sulphur fertilization. Mean value of water-soluble sulphur accounts for around 6.72 to 9.19% of total sulphur which was shown in Table 2. According to [19] water soluble S has a substantial association with all kinds of S. Water-soluble and sulphate S have no correlate with organic carbon, implying that this form of S has a poor link to the soil's organic portion. It exhibits a significantly negative correlation with pH and $CaCO_3$ and positive correlation with organic carbon, due to the influence of organic matter on sulphur availability which was reported by [20]. In comparison to all other fractions of sulphur, the water-soluble S level in the soils during the current analysis was determined to be the lowest. These findings were similar to [21].

3.2 Inorganic S

The Inorganic sulphur content in soil was significantly(*P*=.05) influenced by S nutrition from different sources and the content ranged from 84.7 to 158.6 mg kg^{-1}(Fig. 3). Increasing levels of sulphur increased the inorganic S. Among the different levels of sulphur, the highest inorganic sulphur content of 158.6 mg kg^{-1} was recorded in the soil applied with 80 kg ha^{-1} of S, followed by 60 kg S ha^{-1} and the lowest content of 84.7 mg kg^{-1} was recorded in the treatment without S. Among the sources of S, application of elemental sulphur (130.6 mg kg^{-1}) recorded the maximum inorganic sulphur content which was followed by gypsum (126.7 mg kg^{-1}), potassium sulphate (122.7 mg kg^{-1}) and SSP (119.7mg kg^{-1}). Among different fractions, inorganic S fraction registered about 35 to 40.4% (Table 2). Sub-soil sulphur moved towards and accumulates within the top soil. The addition of increased amount of inorganic sulphur results in cumulating comparatively higher quantity of total-S in soil. The findings of the current analysis were similar to those reported by [22].

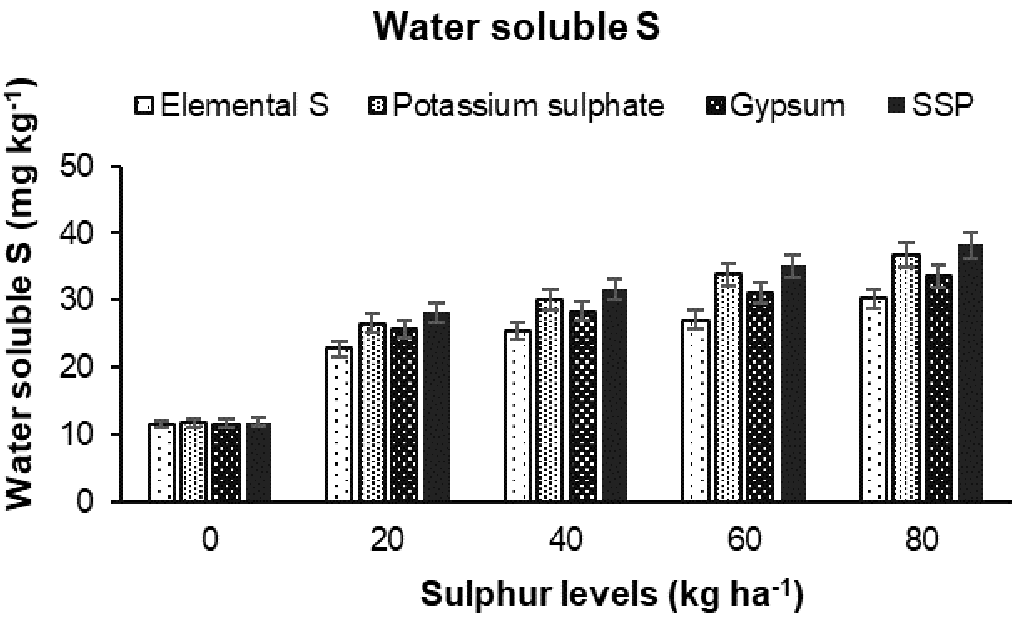

Fig. 2. Effect of sulphur fertilization on water soluble sulphur fractions in red sandy loam soil
Mean ± S.E.M = Mean values ± Standard error of means of water-soluble S

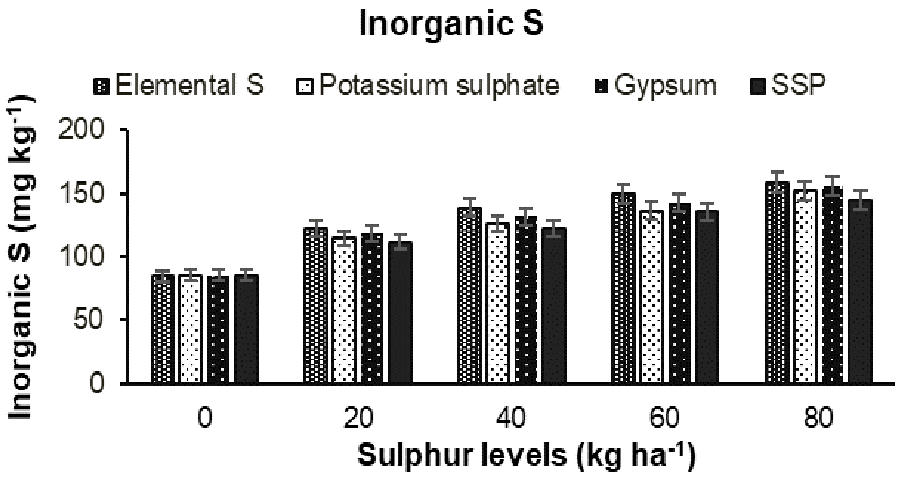

Fig. 3. Effect of sulphur fertilization on inorganic sulphur fractions in red sandy loam soil
Mean ± S.E.M = Mean values ± Standard error of means of Inorganic S

3.3 Organic S

Organic S was significantly(*P*=.05) influenced by S addition and it ranged from 73.64 to 152.8 mg kg^{-1} (Fig. 4) It was noted that, increasing rate of S treatment through K_2SO_4 at different graded levels increased organic S in soil to some extent. The percentage of organic S ranged from 30.6 to 41.5% (Table 2). The highest organic sulphur was observed in soil supplemented with 80 kg ha^{-1} of S through potassium sulphate applied soil (152.8 mg kg^{-1}) followed by 80 kg ha^{-1} of S as SSP (139.7 mg kg^{-1}) whereas the lowest activity was recorded in control treatment (74.01mg kg^{-1}). Out of different sulphur sources tested, potassium sulphate having the highest organic S of 121.2 mg kg^{-1} followed by SSP (116.6 mg kg^{-1}), gypsum (113.1 mg kg^{-1}) and elemental sulphur (112.0 mg kg^{-1}). Except for the adsorbed fraction, organic S maintained a significant and positive connection with all fractions of S, showing their significance in keeping organic matter bound S in a dynamic equilibrium. [23] investigated that the organic S was found to be the major fraction in soils. This discrepancy in organic S content was contributed by soil texture, organic carbon content, and the acquisition of a large amount of soil organic matter and clay. These findings are consistent with the findings of [24] in Assam soils and [25,24,26] also found similar findings.

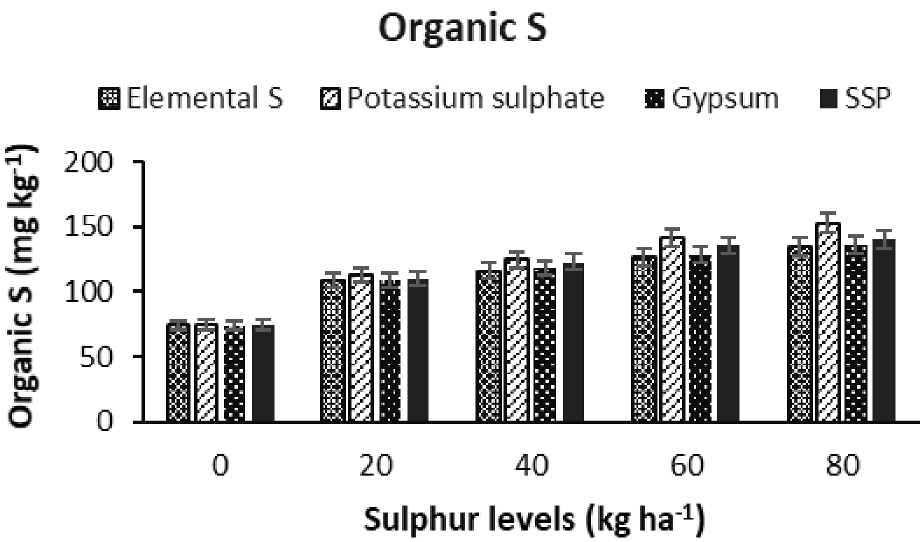

Fig. 4. Effect of sulphur fertilization on organic sulphur fractions in red sandy loam soil
Mean ± S.E.M = Mean values ± Standard error of means of organic S

3.4 Sulphate S

Sulphate sulphur was significantly(*P*=.05) varied from 7.67 to 18.3 mg kg^{-1} for surface soils (Fig. 5). Maximum range of available S (14.3 mg kg^{-1}) was observed in soil collected from elemental sulphur treatment. Percent sulphate S of soil is present from 3.17 to 4.70% (Table 2). Minimum range of sulphate S (12.1 mg kg^{-1}) was found in SSP applied soil. [25] reported similar findings, showing that available S was strongly and inversely linked with pH, therefore available S increased with decrease in pH. [27] also reported similar findings. Amount of available-S is directly related with crop growth and yield. Similar relationship was in accordance with [28].

3.5 Total Sulphur

In addition to all other fractions, total sulphur was also significantly(*P*=.05) influenced by S fertilization and showed a same trend in increasing the sulphur content due to different sources and levels of S. Increasing levels of S, increased the total S and the values varied from 241.0 to 389.5 mg kg^{-1}. Among the different levels applied, sulphur application at 80 kg ha^{-1} of elemental sulphur was found superior compared to other levels having total S of 389.5 mg kg^{-1} and the lowest value was observed in control of potassium sulphate (241.0 mg kg^{-1}). Among different sources, elemental S recorded the highest total S (340.2 mg kg^{-1}) followed by gypsum (329.5 mg kg^{-1}), potassium sulphate (312.2 mg kg^{-1}) and the lowest value was observed in SSP treatment (307.4 mg kg^{-1}). [15] found more or less identical total-S values in the R.A.U. research farm, Pusa, with varying fertility levels (231.21 to 397.26 mg kg^{-1}) Comparative increase in total S content with increase in organic C and clay content which were detailed by [29] in alluvial soil. In contrast, total S decreased with soil depth, and that may be due to the decrease in the organic C content. Hence, total S exhibits significantly positive relation with organic carbon, clay content and free iron oxides, indicating that there is a strong collaboration of these soil properties with total sulphur. As a result, all S fractions in these soils were in a state of dynamic equilibrium. [30] also observed the existence of several relations among various fractions of S.

3.6 Residual Sulphur

The residual fraction of sulphur in red soil was ranged from 10.5 to 71.3 mg kg^{-1}. The highest residual S was noticed in elemental sulphur application (59.9 mg kg^{-1}) followed by gypsum applied soil having 50.8 mg kg^{-1} and less residual S was monitored in potassium sulphate applied soil of 27.6 mg kg^{-1}. Residual S varied from 33.97 to 43.84 mg kg^{-1} which was reported by [31]. This sulphur fraction was calculated by taking the difference of total S and sum of all fractions.

3.7 Correlation Co-Efficient (r) between Sulphur Fractions in Red Sandy Loam Soil

Correlation among different sulphur fraction includes water-soluble S, inorganic S, organic S, sulphate S, total S and residual S was carried out @ 1% significant level (Table 3). Sulphur fertilization had a significant effect on all the sulphur fractions. Water soluble sulphur had a significant and positive correlation with inorganic

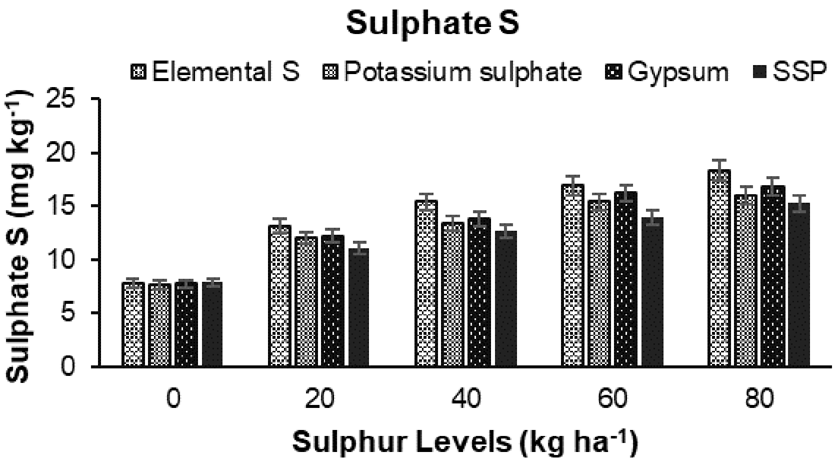

Fig. 5. Effect of sulphur fertilization on sulphate sulphur fractions in red sandy loam soil
Mean ± S.E.M = Mean values ± Standard error of means of sulphate S

S (r = 0.871**), organic S (r = 0.975**), sulphate S (r =0.835**), total S (r = 0.820**) and negatively correlated with residual S (r = -0.775**). Inorganic S was positively correlated with organic S (r = 0.935**), sulphate S (r =0.991**), total S (r = 0.982**) and negatively correlated with residual S (r = -0.467*). Organic S had a significant and positive correlation with sulphate S (r =0.912**), total S (r = 0.891**) and had a negative correlation with residual S (r = -0.715). Sulphate S had a positive and significant influence on total sulphur having r = -0.411. Total sulphur is positively correlated with all the sulphur fractions except for residual S (r = -0.328).

Table 2. Percentage of various sulphur fractions with respect to total sulphur in post-harvest surface soil of cabbage

Sources	Levels	Water Soluble S (%)	Inorganic S (%)	Organic S (%)	Sulphate S (%)
Elemental sulphur	L1	4.77	35.0	30.6	3.21
	L2	6.76	36.1	32.1	3.90
	L3	7.00	38.2	32.0	4.24
	L4	7.31	40.4	34.2	4.56
	L5	7.76	40.7	34.7	4.70
	Mean	6.72	38.1	32.7	4.12
Potassium sulphate	L1	4.84	35.3	30.9	3.18
	L2	8.93	38.5	37.9	4.03
	L3	9.74	40.6	40.3	4.34
	L4	9.84	39.5	41.0	4.47
	L5	10.0	41.2	41.5	4.35
	Mean	8.67	39.0	38.3	4.08
Gypsum	L1	4.80	35.3	30.5	3.17
	L2	7.98	36.9	34.0	3.74
	L3	8.11	37.7	33.9	3.85
	L4	8.48	38.9	35.1	4.21
	L5	9.07	42.1	36.8	4.32
	Mean	7.69	38.2	34.0	3.86
SSP	L1	4.88	35.0	30.6	3.23
	L2	9.80	38.7	38.3	3.85
	L3	10.2	39.4	39.7	4.08
	L4	10.4	40.0	40.0	4.11
	L5	10.7	40.4	39.1	4.27
	Mean	9.19	38.7	37.5	3.91
SEd	S	0.40	0.57	0.72	0.21
	L	0.44	0.63	0.80	0.23
	SxL	0.88	1.27	1.60	0.46
CD (P=0.05)	S	0.80	1.15	1.45	0.42
	L	0.89	1.28	1.62	0.47
	SxL	1.79	2.57	3.24	0.93

**SEd-standard error of difference and CD-critical difference*
S-Sulphur source, L-Sulphur Levels and SxL- Interactions

Table 3. Correlation co-efficient (r) between different sulphur fractions in red sandy loam soil

	Water soluble S	Inorganic S	Organic S	Sulphate S	Total S	Residual S
Water soluble S	1					
Inorganic S	0.871**	1				
Organic S	0.975**	0.935**	1			
Sulphate S	0.835**	0.991**	0.912**	1		
Total S	0.820**	0.982**	0.891**	0.984**	1	
Residual S	-0.775**	-0.467*	-0.715**	-0.411	-0.328	1

Significant at 5% level Significant at 1% level*

4. CONCLUSION

From the above experiment, it is concluded that Sulphur fertilizers had a substantial influence on distinct soil fractions in the soil. All the sulphur fractions are positively correlated among themselves except for residual S. Knowledge of different types of sulphur forms in soils and how their availability is influenced by different soil qualities in soil fertility of red sandy loam soil where cabbage is grown was deliberated.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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