

## Sulphur Fractions, Distribution, and Correlations with Soil Attributes in the Gopalpur and Ishwardi Soil Series of Bangladesh

SHARMIN AKTAR HASI<sup>1,2</sup>, SAMIUL AHSAN<sup>1</sup>, JAGADISH CHANDRA JOARDAR<sup>1</sup>,  
MD. SADIQUL AMIN<sup>1</sup> and MILTON HALDER<sup>1\*</sup>

<sup>1</sup>Soil, Water and Environment Discipline, Khulna University, Khulna, Bangladesh.

<sup>2</sup>Department of Soil Science, Govt. Brojomohun College, Barishal, Bangladesh.

### Abstract

The deficiency of soil sulfur (S) is a prevalent issue in Bangladesh soils, posing a significant obstacle to enhancing crop yield and overall productivity. This study aimed to evaluate the distribution of different sulfur fractions across various soil depths in the Gopalpur and Ishwardi soil series, along with their relationships with other soil parameters. In both soil series, the sulfur fractions were ordered as follows: organic > adsorbed > available forms, with organic sulfur being the most abundant. Additionally, soil attributes such as pH, organic carbon, texture, and EC were assessed to understand their relationships with sulphur fractions. Results indicate significant variations in sulphur distribution between the two soils series, with organic sulphur dominating in Gopalpur soils and sulphate-sulphur prevailing in Ishwardi soils. Correlation analysis reveals strong associations between sulphur fractions and soil attributes, highlighting the influence of soil properties on sulphur dynamics. These findings provide valuable insights into sulphur cycling in agricultural soils of Bangladesh and underscore the importance of soil management practices for optimizing sulphur availability and crop productivity.



### Article History

Received: 03 April 2024

Accepted: 27 June 2024

### Keywords

C:S Ratio;  
Distribution;  
Soil Depth;  
Soil Parameters;  
Sulphur Fractions.

### Introduction


Sulphur, one of the primary minerals, has long been recognized as a nutrient essential for plant growth. Its importance in plant growth is widely established. Sulphur is essential for physiological and metabolic processes in plants. It is also a component of specific vitamins and enzymes that

are crucial for the plant's life cycle. Sulphur can be found in soil as free and adsorbed sulphate, as well as in a variety of organic and inorganic compounds. The organic S is the major portion of soil S, which comes from soil organic matter.<sup>1</sup> It is widely accepted that most of the agricultural crops suffer due to Sulphur deficiency.<sup>2,3</sup> This deficiency

**CONTACT** Milton Halder ✉ [milton@swe.ku.ac.bd](mailto:milton@swe.ku.ac.bd) 📍 Soil, Water and Environment Discipline, Khulna University, Khulna Bangladesh.



© 2024 The Author(s). Published by Enviro Research Publishers.

This is an  Open Access article licensed under a Creative Commons license: Attribution 4.0 International (CC-BY).

Doi: <https://dx.doi.org/10.12944/CWE.19.2.17>

is due to multiple factors such as lower content of S deposition from atmosphere, trade off soil S due to enhanced crop productivity, and very less content of S in the inorganic fertilizers that apply in the field.  $SO_4^{2-}$  is the suitable form for plants to absorb from soil, which constitutes about < 5% of the total soil S. Sulfate deposition from the atmosphere and organic S mineralization often offer ample quantities of S to meet plant requirements.<sup>4</sup> However, present S supplies via atmospheric sources are < 10000 g/ha but this amount of S is generally considered below the threshold limit of S requirement for plants (400,000 g/ha).<sup>5</sup>

S availability for plants can play a crucial role for S requirement of crop in locations with low S inputs from the environment or fertilizers. Sulphur deficiency has received enough attention as a major limiting issue. The main causes of S deficiency in Bangladesh are intensive cropping with high yielding varieties for various crops, soil remaining waterlogged for most of the years due to wet land rice culture, shift toward virtually S free fertilizer,

and depletion of soil organic residues (agricultural crop residues, forestry residues, and organic waste materials, can be utilized as feedstock for biofuel production) from the field due to fuel shortage.<sup>6</sup> The study was carried out to investigate the correlation between various fractions of soil S and edaphic properties of Gopalpur and Ishwardi soil series of Bangladesh.

## Materials and Methods

### Soil Sample Collection

The study area belonging to the Gangetic alluvium tidal floodplain soil is located at Phultala upazila in Khulna (Figure 1; between 21.38°N and 23.1°N Latitude and 88.58°E longitude). Three soil samples were collected horizontally from freshly exposed pits of Gopalpur and Ishwardi soil series were kept in clean air-protected polyethylene bags. Soils, four representatives, were sampled at different vertical depths from each pit. Soil samples were collected from 0-13 cm, 13-18 cm, 18-29 cm and 29-50 cm depths.

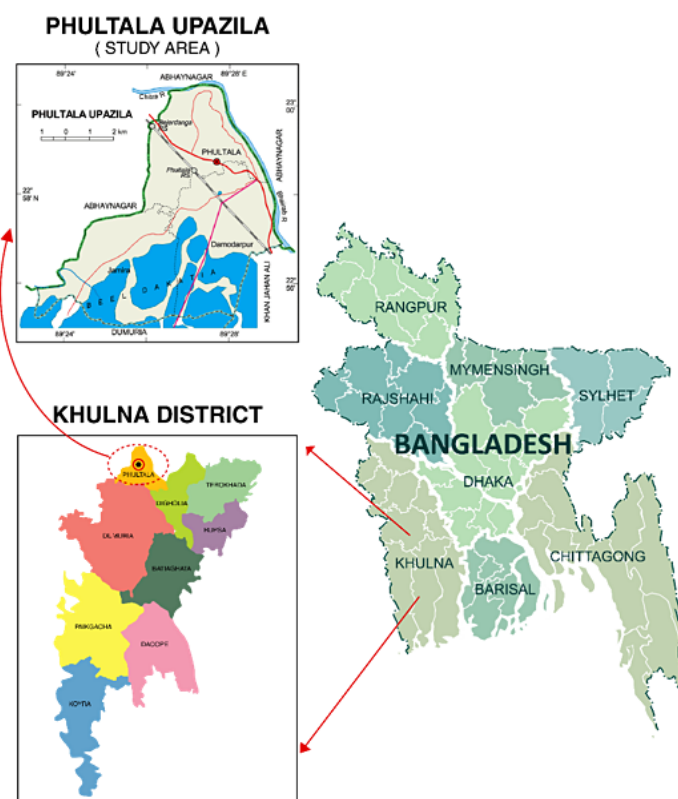


Fig.1: The map of Gopalpur and Ishwardi soil series sampling area

### Processing of Soil Sample

The collected soil samples were air dried, and the larger particles were gently crushed using a wooden hammer. A 2 mm sieve was used to sieve a portion of the crushed soil. The sieved soils were gathered in a plastic pot and leveled properly. Chemical analysis was performed in the laboratory of Soil, Water and Environment Discipline, Khulna University.

### Laboratory Analyses

The soil samples were characterized by the following standard procedures. Soil samples were extracted by using different extractants for characterizing different forms of S. Other parameters such as textural class, pH, EC, and organic carbon (OC) were also determined. Each sample was replicated thrice. The textural analysis of the samples were carried out by the procedure outlined by Gee and Buder.<sup>7</sup> The soil pH and conductivity were estimated by using a pH meter and EC meter, respectively (Hanna instruments, model pH-211). 1:2.5 ratio of soil: water was followed for determining soil pH.<sup>8</sup> Soil EC was calculated by EC meter (Hanna instruments, model EC-214), where soil- water ratio was 1:5.<sup>9</sup> The wet digestion procedure of Walkley and Black's to estimate soil organic matter was followed.<sup>10,8</sup> Available S was extracted using 0.01M CaCl<sub>2</sub>. The soil S, which was adsorbed to clay minerals was determined by subtracting available S from the S extracted with 500 mg/kg phosphate solutions.<sup>11</sup> Total S was extracted by using HNO<sub>3</sub>-HClO<sub>4</sub> acid digestion mixture.<sup>12</sup> Organic S was calculated by using the formula,

$$\text{Organic S} = \text{Total S} - (\text{Available S} + \text{Adsorbed S}) \dots(1)$$

The S in the filtrate was determined using spectrophotometer at 420 nm wavelength.<sup>13</sup>

### Data Analysis

The statistical analyses were done by using Microsoft Excel, and MINITAB 16.0.

## Results and Discussion

### Soil Properties

The pH of the Gopalpur soils series ranged from very slightly alkaline to medium alkaline and varied with depth. The lowest value was 7.64 at 0-13 cm depth and increased with depth, reaching 8.42 at 29-50 cm depth. Similar findings were observed in Gopalpur soil collection.<sup>6,14</sup> The vertical pH distribution of the

Ishwardi soils tested ranged from 7.70 to 8.58, with a mean of 8.20. Similar to the Gopalpur soil series, the lowest and greatest pH values were found at depths of 0-13 cm and 29-50 cm, respectively. The soils are very slightly alkaline to medium alkaline, as indicated by the lowest value of 7.70 and the highest value of 8.58. This could be explained by changes in the oxidation-reduction conditions in floodplain soils, as well as a weaker buffering mechanism in those profiles. Rahman<sup>15</sup> also reported similar findings.

For both soil series, the maximum value of soil EC was reported at depths 0-13 cm, with a decreasing tendency with increasing depth. Both soils were non-saline (0-2 dS/m) in character (Table 1). Similar findings have also been reported in.<sup>14</sup>

The OC content was found to be higher at 0-13 cm depth for both soil series and declined as the depth of the soil profile increased because of organic carbon content decreases with increasing depth from the surface. The OC range for the Gopalpur soil series was 0.5-1.8%, whereas it was 0.42-1.57% for the Ishwardi soil series. In the Gopalpur series, Rahman<sup>15</sup> found 2.1% OM in the surface soil. According to Bhuiyan *et al.*,<sup>16</sup> the OM content of several soil series in Bangladesh ranged from 0.86 to 4.47%, with a mean value of 1.89%.

Silt ranges particles dominate the particle size of soil samples. Except for surface soil, the textural class of the Gopalpur soil series is predominantly silty clay loam (Table 1). The texture of the surface soil is silt loam. The percentages of clay and sand particles ranged from 20 to 38% and 10 to 22%, respectively. In the Ishwardi soil series, the vertical distribution of sand ranged from 10% to 18%. With increasing depth, the percentage of sand in both soil series dropped. The percentage of silt in the Ishwardi soil series showed an erratic tendency, but it declined with depth in the Gopalpur series. The vertical distribution of clay in the Ishwardi soil series investigated ranged from 34% to 46%. In the Ishwardi soil series, the greatest value 46% was achieved at a depth of 28-39 cm, and the lowest value 34% was found at a depth of 29-50 cm (Table 1). In the Ishwardi soil series, the percentage of clay changed randomly with depth, but it raised in the Gopalpur soil series. The textural class was silty clay up to a depth of 29 cm, and silty clay loam at a depth of 29-50 cm.

**Table 1: The vertical distribution of soil characteristics in Gopalpur and Ishwardi series**

Soil series	Depth (cm)	pH	EC (dS/m)	OC (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
Gopalpur	0-13	7.64	1.15	1.8	22	58	20	silt loam
	13-18	8.08	1.12	0.8	18	54	28	silty clay loam
	18-29	8.4	0.91	0.7	16	49	35	silty clay loam
	29-50	8.42	0.98	0.5	12	48	36	silty clay loam
	Mean	8.19	1.04	0.96	15.6	52.2	31.4	
Ishwardi	0-13	7.7	1.34	1.57	18	40	42	silty clay
	13-18	8.31	0.95	0.57	13	42	45	silty clay
	18-29	8.28	0.97	0.45	12	58	46	silty clay
	29-50	8.58	0.88	0.42	10	44	34	silty clay loam
	Mean	8.2	1.04	0.75	13.6	45.8	41.4	

**Sulfur Fractions**

**Available S**

In Gopalpur soil series, the range of available S was 0.57 to 2.75 mg/kg, while the average was 1.82 mg/kg. Surface soil had the highest value of 2.75 mg/kg. The concentration of plant available S in soil was reduced with increasing soil vertical depth (Table 2). In the Ishwardi soil series, the plant available S concentration was 3.65 mg/kg in average, which ranged from 1.04 to 9.47 mg/kg. Surface soil yielded the highest result of 9.47 mg/kg identical to the Gopalpur soil series. Greater OC content in surface soil layers could explain the higher available S content. This result is corroborated with the results of Kumar *et al.*,<sup>17</sup>

**Adsorbed S**

In the Gopalpur soil series, adsorbed S content ranged from 0.95-8.77 mg/kg, while the average was 3.94 mg/kg. Surface soil had the highest S value of 8.77 mg/kg. Adsorbed S was shown to decrease as soil depth increased. The adsorbed S content of the Ishwardi soil series ranged between 4.55 and 12.69 mg/kg, with an average S content of 7.41 mg/kg. Surface soil yielded the highest result of 12.69 mg/kg. This could be owing to the increased clay content with depth, as observed by Misra *et al.*,<sup>18</sup> Also, several factors can influence the adsorbed S content such as physical properties, chemical composition, pH, temperature, ionic strength, redox conditions etc.

**Table 2: Depth wise distribution of different S fractions in Gopalpur and Ishwardi soil series**

Depth cm	Gopalpur soil series				Ishwardi soil series			
	Fractions of S (mg/kg)							
	Available	Adsorbed	Organic	Total	Available	Adsorbed	Organic	Total
0-13	2.75	8.77	852	864	9.47	12.69	853	875
13-18	2.27	5.00	945	953	1.71	6.97	876	884
18-29	1.70	1.03	985	988	2.18	4.55	669	676
29-50	0.57	0.95	1106	1108	1.23	5.45	399	406
Mean	1.82	3.94	972	978	3.65	7.41	699	710

**Organic S**

The organic S content of the Gopalpur soil series increased with soil depth, ranging from 852-

1106, while the average result was 972 mg/kg (Table 2). This could be owing to in deeper soils, there's typically more space for organic matter

accumulation. Organic sulfur is often found in organic matter, such as decaying plant and animal material. So, deeper soils might have more organic matter, leading to higher organic sulfur content. The organic S content of the Ishwardi soil series dropped as soil depth increased, ranging from 399 to 876 and the average was 699 mg/kg (Table 2). The sulfur of organic matter is considered as organic S is an important source of available S for plants uptake and growth following mineralization from organic to inorganic form (sulphate) through microbial decomposition of organic matter<sup>19</sup>. The amount of the drop in organic S corresponded to the decrease in soil OC content. Intensive root activity, as well as incorporation of crop residue and different organic amendments substantially applied on the top soil resulting enhanced OC in the top soil, and thereby leading to greater content of organic S in the top soils layer. Srinivasarao *et al.*,<sup>19</sup> reported similar results.

#### Total S

The total S concentration of the Gopalpur soil series ranged between 864 and 1108, while the average level was 978 mg/kg. The greatest value, 1108 mg/

kg, was found at the shallowest depth of the soil profile. The total S content of the Ishwardi soil series ranged between 406 and 884, with an average content of 710 mg/kg. The maximum value of 884 mg/kg was recorded at a depth of 13-18 cm in the soil profile (Table 2). Total S in the soil depends on various factors. These factors include soil organic matter concentration, precipitation, position of the location on the earth surface, and parent rock.

According to Larson *et al.*,<sup>20</sup> the total soil S content is also affected by the type of fertilizer used (mineral or organic manure), and soil changes have been found to be proportionate to the number of organic wastes provided. Total soil S is declined with increasing soil vertical distance, which could be attributed to a drop in OC content. The concentrations of different fractions of soil S are also influenced by clay content, range of soil pH, soil CaCO<sub>3</sub>, SOM.<sup>21</sup> Moreover, soil S availability is also impacted by agricultural operation and management coupling with different fractions of soil S. The different fractions of soil S influenced the S availability through their dynamic equilibrium in the liquid phase of soil.<sup>22</sup>

**Table 3: Pearson's correlation matrix among the studied soil properties**

	pH	EC	OC	Sand	Silt	Clay	Av S	Ad S	Org S	Total S
EC	-0.91**	1								
OC	-0.95***	0.82*	1							
Sand	-0.89**	0.72*	0.89**	1						
Silt	-0.20	-0.06	0.10	0.33	1					
Clay	0.36	-0.18	-0.49	-0.63	-0.47	1				
Av S	-0.70	0.86**	0.66	0.45	-0.37	0.19	1			
Ad S	-0.77*	0.78*	0.71*	0.47	-0.27	0.01	0.82*	1		
Org S	-0.22	0.25	0.19	0.40	0.06	-0.12	0.09	-0.26	1	
Tot S	-0.25	0.27	0.22	0.41	0.06	-0.12	0.04	-0.23	0.42	1

Here, Av S= available S, Ad S= adsorbed S, Org S= organic S, and Tot S= total S. \*, \*\*, \*\*\* indicate values are significant at 0.05, 0.01, 0.001 level, respectively.

#### Relationship Among Soil Properties

As part of the investigation, a correlation matrix was performed to assess whether any association exists between the various soil characteristics regardless of soil series or soil depth (Table 3). There was a considerable positive association between total S and organic S, as well as available S and adsorbed S (Table 3). Organic S and total S exhibited a

positive but insignificant connection with available S. Organic S and total S had a negative but negligible connection with adsorbed S (Table 3). All fractions of S (available S, adsorbed S, organic S, and total S) were associated positively with EC, OC, sand, and clay, but negatively with pH and silt content in soil (Table 3). According to Aulakh and Dev,<sup>23</sup> pH less than 6.4 had substantially greater absorbed S. Soil

pH did not have a significant relationship with total S.<sup>24</sup> The organic S fraction in soil presents as range of materials such as microbial derived materials as well as turnover materials of degraded plants parts, soil macro and micro animals leftovers.<sup>25,26</sup>

### Carbon: Sulphur Relationship

The mean OC: organic S ratio for the Gopalpur soil series was 9.87, while it was 10.76 for the Ishwardi soil series. Similarly, the OC: total S ratio for the Gopalpur and Ishwardi soil series was 9.82 and 10.59, respectively (Fig. 2). The C:S ratios, which we found in this study were compared with the findings reported by Balanagoudar and Satyanarayana<sup>27</sup> in Karnataka soils and Sharma *et al.*,<sup>28</sup> for various

Alfisol, Inceptisols, and Mollisols. According to the findings, the organic fraction is the most prevalent of the S fractions in the soils investigated. The S release as available S for plant growth from organic matter through decomposition by microbial activity is determined by hydrological parameters such as soil moisture content, redox potential, pH, texture, structure etc. A greater portion of soil S is present as organic S in soil organic matter. The SO<sub>4</sub>-S in soils solution is greatly maintained by mineralization under optimal settings of hydrological and thermal. Overall, the available S concentration in these soils' surface layers is less than the threshold limit value (10 mg/kg), hence S treatment is required to increase crop production levels.

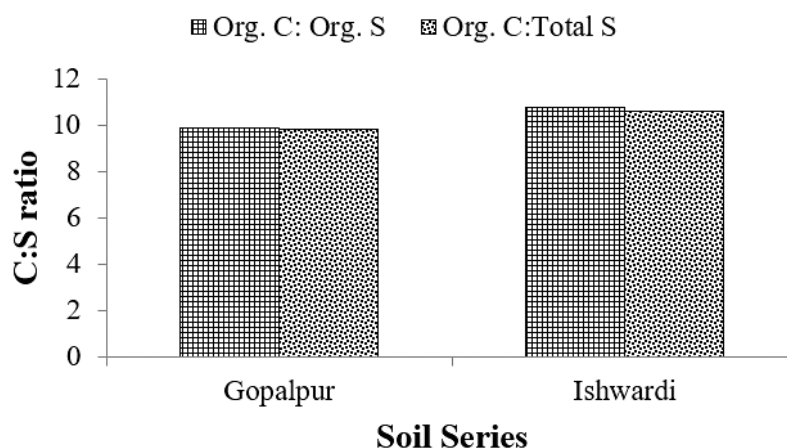


Fig. 2: Ratio of OC to organic S and total S fractions of two soil series (mean of all layers)

### Conclusion

The fractions and distribution of various forms of S (available S, adsorbed S, organic S, and total S) in the Gopalpur and Ishwardi soil series of Gangetic Alluvium Floodplain soil in Bangladesh were investigated. The average quantity of different fractions of S in soil profile in the Gopalpur soil series ranged from 864-1108 mg/kg for total S, 852-1106 mg/kg for organic S, 0.95-8.77 mg/kg for adsorbed S, and 0.57-2.75 mg/kg for available S. In contrast, the mean values of distinct S fractions in the Ishwardi soil series ranged from 406-884 mg/kg for total S, 399-876 mg/kg for organic S, 4.55-12.69 mg/kg for adsorbed S, and 1.04-9.47 mg/kg for available S. The various S fractions were present in the following order: organic > adsorbed > available form, with organic being the most abundant. The available S

content in these soils' surface layers is less than the critical limit value (10 mg/kg). The Gopalpur soil series had elevated levels of organic and total S, whereas the Ishwardi soil series had increased levels of available and adsorbed S. Organic S of both series accounted for 97–99% of total S. Both soil series had low OC content, were non-saline, and had a pH ranging from very slightly alkaline to medium alkaline. Plant available S showed a significant positive correlation with adsorbed S in soil profiles. Organic S had a substantial positive connection with total S. The average OC: organic S ratio for the Gopalpur soil series was 9.87, compared to 10.76 for the Ishwardi soil series. Similarly, the OC: total S ratio for the Gopalpur and Ishwardi soil series was 9.82 and 10.59, respectively.

The amount of available and absorbed S reduced as soil profile depth increased. The Ishwardi soil series had higher levels of both available S and adsorbed S compared to the Gopalpur soil series. The Gopalpur soil series had a higher abundance of the organic form of S compared to the Ishwardi soil series. Continuous cropping without replenishing S and using unbalanced fertilizer nutrients leads to a faster depletion of S reserves. The combination of inorganic fertilizers containing S sources and organic manures is essential for maintaining and preserving soil fertility with regards to S levels.

#### Acknowledgement

The article submitted for this journal is entirely of the candidates' own investigations and no part of the article or results have not been published for any journal, nor is it being concurrently submitted for any journal.

#### Funding Sources

No fund was received for the present work.

#### Conflict of Interest

There is no conflict of interest between authors.

#### Authors' Contribution

Sharmin Aktar Hasi wrote the first draft of manuscript, Samiul Ahsan helped in laboratory works, Jagadish Chandra Joardar, Md. Sadiquul Amin, and Milton Halder designed the work, edited and revised the final version of manuscript.

#### Data Availability Statement

All the datasets throughout the study have been incorporated in the manuscript

#### Ethics Statement

Neither any animals were involving nor harm during the study.

#### References

- Russell E.J. Soil conditions and plant growth. *Longmans, Green & Co., London*. 1952;
- Blair G. Sulphur fertilizers: A global perspective. Proceedings no. 498. International fertilizer society, York, U.K. 2002;
- Zhao F.J, McGrath S.P, Blake-Kalff M.M.A, Link A and Tucker M. Crop responses to sulphur fertilization in Europe. *Proceedings no. 504. International fertilizer society, York*. 2002;
- Radojevic M and Bashkin V.N. Practical environmental analysis. *Royal society of chemistry, Cambridge UK*. 1999;
- McGrath S.P, Zhao F.J and Blake-Kalff M.M.A. History and outlook for sulphur fertilizers in Europe. Proceedings no. 497. International fertilizer society, York, U.K. 2002;
- Rahman M.N, Sayem S.M, Alam M.K, Islam M.S and Mondol A.T.M.A.I. Influence of sulphur on nutrient content and uptake by rice and its balance in old Brahmaputra floodplain soil. *Journal of Soil and Nature*. 2007;1(3): 5-10.
- Gee, G.W. and Bauder, J.W. (1986) Particle-Size Analysis. In: Klute, A., Ed., *Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods*, Agronomy Monograph No. 9, 2nd Edition, *American Society of Agronomy/Soil Science Society of America, Madison, WI*, 383-411.
- Jackson M.L. Chemical composition of soils. In: Bear, F.E (ed). *Chemistry of soil*, 2nd ed. *Oxford and IBH publishing company, New Delhi*. 1962; 71-141 pp.
- USDA (United States Department of Agriculture) 2004. Soil survey laboratory manual, soil survey investigation report no. 42, version 4.0, USDA-NRCS, Nebraska, USDA.
- Piper C.S. Soil and plant analysis. *International Public Inc., New York*. 1950;
- Ensminger L.E. Some factors affecting the adsorption of sulfate by Alabama soils. *Soil Science Society of America*. 1954;18: 259-264.
- Vogel A.I. *A Textbook of Quantitative Inorganic Analysis*, 3rd Edition. 1961; p 230.
- William C.H and Steinbergs A. Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. *Australian*

- Journal of Agriculture Research*. 1959;10: 340–352.
14. Ahmed I.U, Faiz S.M.A, Rahman S, Anwar Hussain A.K.M and Bhuiyan N.I. Effect of nitrogen and residual sulphur on the growth, yield and N-S composition of rice. *Journal of the Indian Society of Soil Science*.2004;37: 323-327.
  15. Rahman M.A. Integrated use of fertilizer and manure for crop production in wheat-rice and rice-rice cropping patterns. *Ph.D. thesis, Dept. of Soil Sci., Bangladesh Agriculture University, Mymensingh, Bangladesh*. 2005;
  16. Bhuiyan N.J, Shah A.L and Panaullah G.M. Effect of NPK fertilization on the grain yield of transplanted rice and soil fertility-a long-term study. *Bangladesh Journal of Soil Science*. 1991;22(1&2): 41-50.
  17. Kumar R, Singh K.P and Singh S. Vertical distribution of sulphur fractions and their relationships among carbon, nitrogen and sulphur in acidic soil of Jharkhand. *Journal of the Indian Society of Soil Science*. 2002;50(3): 502-505.
  18. Misra U.K, Das C.P and Mitra G.N. Forms of sulphur in some soils of Orissa in relation to relevant soil properties. *Journal of Indian Society of Soil Science*. 1990;38: 61-69.
  19. Srinivasarao Ch, Ganeshamurthy A.N, Masood Ali, Singh R.N and Singh K.K. Sulphur fractions, distribution, and their relationships with soil properties in different soil types of major pulse-growing regions of India. *Communications in Soil Science and Plant Analysis*. 2004;35: 2757-2769.
  20. Larson W.E, Clapp C.E, Pierce W.H and Mochoran V.B. Effects of increasing amounts of organic residues on continuous corn: II. Organic carbon, nitrogen, phosphorus, and sulphur. *Agronomy Journal*. 1972;64: 205-208.
  21. Xiao H, Li N and Liu C. Source identification of sulfur in uncultivated surface soils from four Chinese provinces. *Pedosphere*. 2015;25: 140-149.
  22. Azmi N.Y, Seema and Manish K. New technique for sequential fractionation of soil sulphur. *International Journal of Current Microbiology and Applied Sciences*. 2018;3397-3405.
  23. Aulakh M.S and Dev, G. Profile distribution of sulphur in some soil series of Sangrur district, Punjab. *Journal of Indian Society of Soil Science*. 1976;24: 308–313.
  24. Dolui A.K and Saha S.G. Studies on sulphur status of some soils of West Bengal, India. *Indian Journal of Agricultural Chemistry*. 1983;16(2): 259-265.
  25. Eriksen J, Murphy M.D and Shung E. The soil sulphur. In: Schung E. (ed.): Sulphur in agroecosystems. *Kluwer academic publishers, Dordrecht*. 1998; 39-73.
  26. Solomon D, Lehmann J, Tekalign M, Fritzsche F and Zech W. Sulphur fractions in particle size separates of the sub-humid Ethiopian highlands as influenced by land use changes. *Geoderma*. 2001;102: 41-59.
  27. Balanagoudar S.R and Satyanarayana T. Correlations of different forms of sulphur with soil properties and with organic carbon and nitrogen in some Vertisols and Alfisols. *Journal of the Indian Society of Soil Science*. 1990;38: 641–645.
  28. Sharma Y.K, Gangwar M.S and Srivastava P.C. Sulphur fractions and carbon, nitrogen and sulphur relationships in Alfisols, Inceptisols and Mollisols in some parts of western Uttar Pradesh. *Journal of the Indian Society of Soil Science*. 2000;48: 477–485.