

Vertical distribution of forms of sulphur in relation to physicochemical properties of lateritic soils of Eastern India

ABSTRACT

Sulphur (S) deficiency is widespread in Indian soils, and it has been emerging as a major problem in rice-growing lateritic soils of West Bengal. The vertical distribution of S forms and their relationships with soil physicochemical properties were examined in 50 rice-growing locations of West Bengal, India, for the current study. Most soils were sandy clay loam to clay loam, with low to medium levels of organic carbon, and strongly acidic to moderately acidic. A decrease in organic carbon across the depths was evident. Among the sulphur forms, organic S was dominant, and the contribution of water-soluble S was least throughout the soil profile. The studied sulphur forms followed the order: total S > organic S > heat soluble S > adsorbed S > sulphate S > water soluble S. Except for adsorbed S, most forms decreased with soil depth. The correlation study revealed that soil pH were positively and significantly correlated with water soluble ($r = 0.431^{**}$) and sulphate S ($r = 0.325^*$) in surface soils, with sulphate S both in mid-surface ($r = 0.450^{**}$) and subsurface soils ($r = 0.423^{**}$). Organic carbon showed a positive correlation with all the S forms throughout the profile. Both clay and silt content positively affected S forms, while sand content showed a negative relationship. Positive correlation among all the S forms observed along soil depth, except for a negative correlation between adsorbed S and sulphate S. This investigation will be helpful for sulphur management to optimize crop yields in lateritic soils.

Keywords: Sulphur forms, correlation, soil depth, soil properties, lateritic soil

1. INTRODUCTION

For Indian agriculture, sulphur is currently regarded as one of the most essential nutrients for the growth and development of plants (Rathore et al., 2015, Sakal and Singh, 1997). Sulphur, which ranks after nitrogen, phosphorus, and potassium as the fourth most important nutrient for plants, is also crucial for humans and other animals (Sakal and Singh, 1997). Sulphur's significance as a secondary plant nutrient is well known and it is essential for the nutrition of cereals, oil seed and pulse crops due to its high requirement (Ramya et al., 2023;

33 Pandey et al., 2022, Verma et al., 2022, Havlin et al., 2004). Sulphur plays an important role
34 in the formation of chlorophyll and improves the activity of the ATP-sulphurylase enzyme
35 (Tewari et al., 2010). It is associated with the formation of biologically important
36 compounds like thiourea, plant regulators, thiamin, biotin and glutathione (Hedge and
37 Sudhakar, 2007). In addition to being involved in the metabolic and enzymatic processes of
38 all living cells, it is crucial for the synthesis of proteins and amino acids, especially those
39 containing sulphur (Tandon and Messick, 2002). Therefore, maintaining an ideal level of
40 sulphur in the soil is crucial for maximizing crop production and its quality.

41 Sulphur application had a significant impact on the yield-related characteristics of crops
42 (Singh et al., 2022). Aside from nutrient sources, the soil is the primary source of S (Scherer,
43 2009). A significant factor in determining the amount of sulphur absorbed by crops is the
44 status of other major nutrients, particularly nitrogen and phosphorus and other physico-
45 chemical properties of soil (Singh et al., 2022, Paul and Mukhopadhyay, 2015, Hembram et
46 al., 2012). Therefore, even under excellent management practises and regardless of all other
47 nutrient applications, the absolute yield potential of a crop cannot be obtained in soils that
48 are lacking in S content (Singh et al., 2022).

49 Crop production is considered to be globally constrained by sulphur deficiency. There are
50 numerous reports of sulphur deficiencies throughout the world (Scherer, 2009). On average,
51 41 percent of Indian soils have reported S deficiency (Sharma et al., 2014, Singh et al. 2006).
52 Reports indicated that, S deficiency was widespread in red-lateritic, coarse-textured alluvial,
53 leached acidic hill soils and black clayey soils (Shukla et al., 2020). It is more pronounced in
54 alfisols than vertisols (Singh et al., 2022). The results of different investigations indicated
55 that, soils of West Bengal are extensively deficient in sulphur, which is particularly
56 noticeable in coarse-textured lateritic soils and entisols (Das et al., 2021, Kundu et al., 2020,
57 Chattopadhyay and Ghosh, 2006). Use of high analysis fertilizers with less or zero sulphur
58 content, reduced or no use of organic manures, followed by crop uptake with high yielding
59 varieties and adsorption of S in acid soils are the major reasons of sulphur deficiency in crop
60 production (Shukla et al., 2017, Borkotoki and Das, 2008). Though the efficiency of sulphur
61 is only 8–10% (Hegde and Murthy, 2005, Tiwari and Gupta, 2006), the severity of this
62 deficiency varies according to these regions' physico-chemical characteristics of soil as well
63 as the climatic conditions (Das et al., 2021, Hembram et al., 2012, Ganeshamurthy, 1999).

64 As 90% of the total S is present in organic form, it is preferable to study the various forms of
65 S rather than the available ones to determine a soil's capacity to supply S (Das et al., 2012,
66 Basumatari et al., 2010). The availability of sulphur is influenced by a number of soil
67 conditions, and as a result, the status of various forms of sulphur in soils varies greatly with
68 soil type (Trivedi et al., 2000, Arora and Takkar, 1988). Both inorganic and organic forms of
69 sulfur are found in soil. Sulphur exists in soil in different forms, viz, water soluble S,
70 sulphate S, organic S, adsorbed S, heat soluble S and total S. Due to different losses, mainly
71 through leaching, sulphate sulphur only makes up a small portion of total sulphur (1.25 to
72 17.7%), especially in soils with a coarse texture (Singh et al., 1993). The sulphur-supplying
73 capacity of a soil is determined by the types of sulphur and how they interact with soil
74 characteristics to affect the release and its dynamics (Basumatari et al., 2012). As sulphur
75 exists in different forms, the knowledge of these forms of sulphur in soils together with their
76 distribution in the root zone is of much relevance in assessing the sulphur-supplying capacity
77 of the soils (Kundu, 2006). The information on the vertical distribution of different S
78 fractions under rice-based cropping systems is scanty, particularly in the lateritic soils of
79 West Bengal. In view of this, the present study was undertaken to assess the vertical status of
80 different forms of S and identify the relationship between the S forms and soil physico-
81 chemical properties.

82 **2. MATERIALS AND METHODS**

83 *2.1. Sampling and analyses of soil*

84 A total of one hundred fifty soil samples were collected from fifty representative locations of
85 rice-based cropping systems in lateritic zones of West Bengal, India. The investigation
86 covered five different blocks, namely Bolpur, Illembazar, Dubrajpur, Sainthia and Md. Bazar
87 and sampling was done at three different depths: the surface (0–20 cm), mid-surface (20–40
88 cm), and subsurface (40–60 cm) from each location. The processed samples were analyzed
89 for physico-chemical properties, including mechanical analysis, pH, organic carbon (OC)
90 and cationic exchange capacity (CEC). The analysis was carried out in the soil testing
91 laboratory run by the department of soil science and agricultural chemistry at Visva-Bharati
92 University in West Bengal, India, in 2019–20 using the established protocols. The
93 hydrometer method was followed for mechanical analysis, whereas soil pH was evaluated
94 using 1:2.5 soil: water suspension (Jackson, 1973). Soil organic carbon content was
95 determined by the Walkley and Black method (1934). The method outlined by

96 Schollenberger and Simons (1945) was used to determine the cation exchange capacity
97 (CEC). Different extraction methods recommended by various scientists were used to
98 evaluate the various forms of S (Table 1).

99 3. RESULTS AND DISCUSSION

100 3.1. Physico-chemical characteristics of soils

101 The findings of some important physico-chemical properties of the soils studied are
102 presented in Table 2. A careful analysis of the outcomes showed that, sand fraction (%) in
103 the surface (0–20 cm) soils under investigation varied from 21.24 to 76.56 with a mean value
104 of 50.04, whereas the silt fraction (%) varied from 4.72 to 36.16 with a mean value of 17.99.
105 Clay (%) content ranged from 12.72 to 51.60, with an average value of 31.89. On the basis
106 of relative proportion of different soil separates, the textural class of most of the soils studied
107 varied from sandy clay loam to clay loam. With increasing depth, clay content increased
108 while silt and sand content decreased. The average values pH values ranged from 4.12 to
109 5.61, 5.14 to 6.59, 5.10 to 6.34, 4.54 to 5.88 and 4.22 to 5.59 in surface soils of Bolpur,
110 Illembazar, Dubrajpur, Sainthia and Md. Bazar blocks respectively. The highest pH (6.98)
111 was observed in sample analyzed from the lower layer of the Dubrajpur block, whereas the
112 lowest pH (4.12) observed in the surface soils of the Bolpur block. The majority of the
113 samples analyzed fall into the strongly acidic to moderately acidic category. Similar findings
114 also reported by Kundu (2006), Ghosh et al. (2005). The variation in soil pH might be
115 ascribed to the difference in the parent material from which soil developed, vegetation,
116 topography, climatic conditions and management practices (Ghosh et al., 2005). The organic
117 carbon content (%) of surface soils (0–20 cm) varied from 0.32 to 0.67 (0.48 ± 0.11), 0.34 to
118 0.73 (0.51 ± 0.15), 0.15 to 0.58 (0.38 ± 0.15), 0.44 to 0.73 (0.59 ± 0.11) and 0.52 to 0.76
119 (0.65 ± 0.09) respectively, in soils from Bolpur, Illembazar, Dubrajpur, Sainthia and Md.
120 Bazar blocks.

121 From the average values, it can be seen that most of the soils under investigation fall into the
122 low-to-medium category in organic carbon content. A decrease in organic carbon across the
123 depth showed all the blocks under study. Similar findings also reported by Chattopaddhyay
124 and Ghosh(2009).The average CEC of the total examined soils was $9.39 \text{ C mol (P}^+) \text{ kg}^{-1}$,
125 with a range of 5.40 to $23.32 \text{ C mol (P}^+) \text{ kg}^{-1}$. The increase in CEC with depth may be due to
126 an increase in the clay content of the soil (Lambooy, 1984).

127

128 **3.2. Forms of sulphur and its relationship with soil physico-chemical properties**

129 The results of distribution of different forms of sulphur under study area (Table 3 to 5) and
130 its interaction with important physico-chemical properties of the soils (Table 6) are
131 presented here.

132 **3.2.1. Water soluble sulphur (Ws-S)**

133 In the surface layer, the water soluble sulphur (Ws-S) ranged from 1.04 to 3.39, with a mean
134 value of 2.22 mg kg⁻¹; in the mid-surface layer, it ranged from 0.72 to 2.25, with a mean of
135 1.34 mg kg⁻¹; and in the bottom layer, it ranged from 0.21 to 1.22, with a mean value of 0.56
136 mg kg⁻¹. Surface soils of the Sainthia block had the highest amount of water-soluble sulphur,
137 whereas the subsurface layer of the Illambazar block had the lowest amount. Water soluble
138 sulphur contributes a small fraction of total sulphur (< 1 %). The relatively low
139 concentration of this fraction might be due to the leaching of sulphate from soil layers.
140 Similar observations were also made by Suri et al. (2021). In comparison to subsurface soil,
141 surface soil had a higher concentration of water soluble sulphur. The decrease in Ws-S with
142 depth was also found by Sankhyan et al. (2015). The average values of water soluble sulphur
143 are in agreement with the observations of Kumar and Singh (1999), Bandyopadhyay and
144 Chattopadhyay (2001), Ghosh et al. (2005).

145 Water soluble sulphur (Ws-S) was found to have a significant and positive correlation with
146 organic carbon, CEC, silt and clay content, whereas it was significantly and positively
147 correlated with pH ($r= 0.431^{**}$) in the surface layer. A negative and non significant
148 correlation was observed between Ws-S and sand content in all three depths. In the lower
149 depth soil CEC showed a positive and significant correlation ($r= 0.387^{**}$). Similar
150 observations also reported by Ghosh et al., (2005), Rajkonwar et al., (2016), Kundu et al.,
151 (2020), Suri et al., (2021). The positive correlation with organic carbon may due to the
152 importance of organic matter on sulphur availability which was reported by Borkotoki and
153 Das (2008), Paul and Mukhopadhyay (2015) and Bandyopadhyay and Chattopadhyay
154 (2001).

155 **3.2.2. Organic Sulphur (Org-S)**

156 Crop plants primarily obtain S from organic sources and it's the major contributor of total S,
157 but this S must first be converted to sulphate through mineralization. The organic sulphur
158 (Org-S) content in surface soils under study varied, ranging from 98.11 to 203.78 with an

159 average value of $142.83 \text{ mg kg}^{-1}$ whereas in mid-surface and subsurface soils it ranged from
160 31.61 to $125.27 \text{ mg kg}^{-1}$ and 12.08 to 78.95 mg kg^{-1} respectively. The highest mean values of
161 organic sulphur in surface (0–15 cm depth) obtained in Sainthia ($160.78 \text{ mg kg}^{-1}$) and Md.
162 Bazar ($158.64 \text{ mg kg}^{-1}$) may be due to the high organic carbon content of these blocks.
163 Similar observations also reported by Chattopaddhyay and Ghosh (2009). In comparison to
164 subsurface soil, surface soil has a higher concentration of organic sulphur. The decrease in
165 organic carbon may be accountable for this tendency in organic sulphur (Balanagoudar and
166 Satyanarayana 1990, Singh et al. 1993, Srinivasarao et al. 2004).

167 The surface soils showed a significant and positive correlation with organic carbon
168 ($r=0.636^{**}$), silt ($r=0.327^{**}$) and clay content ($r=0.383^{**}$). However, it showed a negative
169 and significant correlation with sand ($r= -0.386$). The soil pH showed a negative correlation
170 with Org-S throughout the layer. The mid-surface and subsurface soils correlated
171 significantly and positively with CEC ($r=0.349^{**}$ and $r= 0.364^{**}$). These results are in
172 conformity with earlier reports of Das et al.(2011), Paul and Mukhopadhyay(2015),
173 Rajkonwar et al. (2016) and Suri et al. (2021). The results indicated that Org-S content of the
174 soil greatly affected by organic carbon content and soil texture (Kundu, 2006, Das et al.,
175 2006, Kour et al., 2010, Das et al., 2012, Singh, 2015).

176 **3.2.3. Sulphate sulphur (Sulph-S)**

177 From a nutritional perspective, the sulphate fraction of S is crucial, and it may serve as a
178 useful indicator for evaluating the availability of S to plants. This fraction constituted more
179 than Ws-S to total S. The average sulphate sulphur content in surface soils varied from 7.89
180 $\pm 0.95 \text{ mg kg}^{-1}$, $8.08 \pm 1.11 \text{ mg kg}^{-1}$, $7.59 \pm 1.89 \text{ mg kg}^{-1}$, $8.12 \pm 1.24 \text{ mg kg}^{-1}$, and $5.26 \pm$
181 1.15 mg kg^{-1} respectively in the soils of Bolpur, Illembazar, Dubrajpur, Sainthia and Md.
182 Bazar blocks. It varied from 2.29 to 8.21 mg kg^{-1} and from 1.07 to 2.79 mg kg^{-1} in the mid-
183 surface and subsurface, respectively, in the soils under investigation. Similar to water soluble
184 and organic fraction, sulphate sulphur fraction decreased with increasing depth. The higher
185 levels of sulfate S in surface soils may have resulted from increased microbial and plant
186 activity, which led to an accumulation of organic matter. These findings are in good
187 agreement with Srinivasarao et al. (2004), Ghosh et al. (2005), Chattopaddhyay and Ghosh
188 (2009) and Kour et al. (2010).

189 This form of S exhibited a positive and significant relationship with soil pH ($r = 0.325^*$), ($r =$
190 0.450^{**}), and ($r = 0.423^{**}$) at the surface, mid-surface and subsurface respectively. Similar

191 findings were also reported by Kour et al. 2010. This form of S possessed a positive and
192 significant relationship with OC ($r = 0.305^*$) in surface soils and with CEC in all three
193 depths. Both clay and silt content showed a positive correlation with this form, while a
194 negative correlation was noted with sand content. The considerable positive association
195 between sulphate S and both clay and organic carbon shows that these soils' ability to supply
196 sulphur depends heavily on both of these factors. These findings line up with those of
197 Bandyopadhyay and Chattopadhyay (2001), Ghosh et al. (2005), Kour and Jalai (2008),
198 Chattopadhyay and Ghosh (2009), Rajkonwar et al. (2016), and Suri et al. (2021).

199 **3.2.4. Adsorbed Sulphur (Ads-S)**

200 Adsorbed S in all the soils under study varied widely and ranged from 10.06 to 32.97 mg kg⁻¹
201 at different soil depths and constituted on average 11.30 % of total S (Table 2). Unlike
202 other fractions, this form of S increases with increasing soil depth. In subsoil, it ranged from
203 14.12 to 32.97 mg kg⁻¹ whereas in surface soil, it varied from 10.06 to 26.96 mg kg⁻¹. Similar
204 findings also reported by Srinivasarao et al.(2004). According to Mishra et al. (1990), an
205 increase in clay content with depth may be the cause of the increase in adsorbed S. It may be
206 due to retention of sulphate on the surface of sesquioxides and on the edges of kaolinitic type of
207 clays (Barrow, 1977).

208 In all three soil layers (0–20 cm, 20–40 cm, and 40–60 cm), adsorbed S correlated negatively
209 with pH and significantly negatively with sand ($r = -0.311^*$, $r = -0.282^*$ and $r = -0.428^{**}$).
210 Sulphate adsorption is a pH-dependent process, and it was evident that raising soil pH would
211 cause a decline in the amount of sulphur in this form due to lesser sulphate adsorption in
212 soils and concurrent leaching losses (Dolui, 1997, Basumatary and Das, 2012). Adsorbed S
213 was positively correlated with silt content and positively and significantly with clay content
214 in surface ($r = 0.368^{**}$), mid-surface ($r = 0.308^*$) and in subsurface soils ($r = 0.506^{**}$). The
215 organic matter content of the soil also showed a positive and highly significant correlation
216 with adsorbed S, the values are $r = 0.331^*$, $r = 0.566^{**}$ and $r = 0.534^{**}$ in surface to
217 subsurface layers, respectively. The adsorption of sulphate on the finer fractions of soil and
218 organic matter could account for the positive relationship of adsorbed S with those fractions
219 and the dominant role organic matter plays in sulphate sorption in these soils (Gowrisankar
220 and Shukla, 1999). These findings are consistent with reports by Kour et al.(2010)
221 Rajkonwar et al. (2016), and Srinivasarao et al. (2004).

222 **3.2.5. Heat soluble sulphur (Hs-S)**

223 This portion of S, also known as mineralizable S, accounts about 13.17 % of total S in
224 surface soils. In comparison to water soluble S, sulphate-S, and adsorbed-S, heat soluble S
225 content was higher in the soils under study. Among the blocks, the surface soils of Md. Bazar
226 block observed the highest amount of heat soluble S (68.08 mg kg^{-1}) while the lowest value
227 observed in subsurface soils of Bolpur block (10.06 mg kg^{-1}). These findings are similar to
228 findings of Singh et al. (2006), Kundu et al. (2020). Higher amount of heat soluble S is
229 attributed to release of additional amount of S from organic as well clay minerals on wet and
230 dry heating of the soil during extraction.

231 A significant positive correlation between heat soluble S and organic carbon was observed
232 for all three depths, with values; of $r = 0.599^{**}$, $r = 0.588^{**}$ and $r = 0.504^{**}$ respectively.
233 The heat soluble S also showed positive correlation with CEC, silt and clay content, whereas
234 negative correlation with sand content. In subsurface soils, a significant and positive
235 correlation was observed with CEC ($r = 0.308^*$) and clay content ($r = 0.422^{**}$), but a
236 negative and significant correlation with sand content ($r = -0.374^{**}$). These results are in
237 concurrence with the findings of Sharma and Jaggi (2001), Basumatary et al. (2008),
238 Borkotoki and Das (2008), Paul and Mukhopadhyay (2015), Rajkonwar et al. (2016).

239 **3.2.6. Total S (Tot-S)**

240 Total S content, which indicates the reserve pool of this element in soil, ranged from 205.98
241 to $545.04 \text{ mg kg}^{-1}$ in surface soils. Among the blocks, by considering the average values of
242 three depths, soils from the Md. Bazar block recorded the highest content of total S (249.81
243 mg kg^{-1}) while the lowest was found in the Dubrajpur block ($206.74 \text{ mg kg}^{-1}$). The average
244 values in the surface layers varied from 314.53 ± 84.80 , 389.24 ± 113.43 , 291.49 ± 76.56 ,
245 390.79 ± 101.45 and $403.38 \pm 75.04 \text{ mg kg}^{-1}$ in soils of Bolpur, Illembazar, Dubrajpur,
246 Sainthia and Md. Bazar blocks. Wide variation in total S may be due to variation in soil pH,
247 organic carbon and clay content. Similar results also reported by Kumar et al. (2002),
248 Srinivasarao et al. (2004), Ghosh et al. (2005), Kundu (2006), Paul & Mukhopadhyay
249 (2015), Suri et al. (2021).

250 Total S has significant positive correlation with organic carbon ($r = 0.584^{**}$), significant and
251 negative correlation with sand content ($r = -0.283^*$) in surface layers, whereas it has a
252 significant positive correlation with organic carbon ($r = 0.333^*$), CEC ($r = 0.431^{**}$) and clay
253 content ($r = 0.383^{**}$) in mid-surface layers. Similar relationships were also observed in
254 subsurface layer, indicating the strong association of these soil properties with total S and

255 implying that most of the sulphur is greatly influenced by organic matter. The results are in
256 accordance with Bhogal et al. (1996), Rai et al. (2000), Bandyopadhyay and Chattopadhyay
257 (2001), Srinivasarao et al.(2004), Kour and Jalai (2008), Borkotoki and Das (2008), Kour et
258 al. (2010), Paul and Mukhopadhyay (2015), Rajkonwar et al. (2016), Roshini et al. (2021)
259 and Suri et al. (2021).

260 ***3.3. Inter-relationship between forms of sulphur lateritic soils of West Bengal***

261 Among fractions, water soluble sulphur had a significant and positive correlation with
262 organic S and sulphate S in both surface ($r = 0.442^{**}$ $r= 0.440^{**}$), and mid-surface ($r =$
263 0.440^{**} and $r= 0.370^{**}$) layer soils (Table 7). It was also noted that organic sulphur
264 exhibited a significant positive relationship with adsorbed sulphur ($r=0.489^{**}$), heat soluble
265 sulphur ($r=0.531^{**}$) and total sulphur ($r=0.781^{**}$) in surface soils. The adsorbed sulphur
266 showed a negative correlation with water soluble sulphur and sulphate S. Total sulphur
267 exhibited a positive relationship with all other sulphur forms, indicating that all fractions of
268 sulphur in these soils maintained a dynamic equilibrium. Similar relationships among
269 various forms of S were also reported by Srinivasarao et al. (2004), Ghosh et al. (2005),
270 Kundu (2006), Borkotoki and Das (2008), Basumatari et al. (2010), Paul and
271 Mukhopadhyay(2015) and Roshini et al. (2021).

272 **4. CONCLUSIONS**

273 Understanding the vertical distribution of various forms of S in soils and their relationship
274 between soil physico-chemical properties will be useful for managing it to maximise crop
275 yields in the rice-growing lateritic soils of West Bengal, India. The investigation revealed
276 that, except for adsorbed S, most forms decreased with soil depth. The largest and smallest
277 components of the total S were the organic and water soluble forms. The analysis of the data
278 showed that the different forms of sulphur were in the following order: total S > organic S >
279 heat soluble S > adsorbed S > sulphate S > water soluble S. Their availability was impacted
280 by the amount of organic matter, the texture of the soil, and the reaction of the soil. The
281 inter-relationships between the forms within them revealed that all sulphur fractions in these
282 soils maintained a dynamic equilibrium.

283

284 **7.0 REFERENCES**

- 285 Arora CL, Takkar PN. Influence of soil characteristics on the forms and availability of
286 sulphur in some Entisols and Inceptisols. *J. Indian Soc. Soil Sci.* 1988; 36:496- 499.
- 287 Balanagoudar SR, Satyanarayana T. Depth distribution of different forms of sulphur in
288 Vertisols and Alfisols. *J. Indian Soc. Soil Sci.* 1990; 38(4):634-640.
- 289 Bandyopadhyay PK, Chattopadhyay GN. Different forms of sulphur in relation to soil
290 properties in some Alfisols and Inceptisols of Birbhum district of West Bengal.
291 *Agropedology* 2001; 12:82-85
- 292 Barrow NJ. Studies on extraction and on availability to plants of adsorbed plus soluble
293 sulphate. *Soil Sci.* 1967; 104:242–249.
- 294 Basumatari A, Das KN, Borkotoki B. Interrelationship of Sulphur with soil properties and its
295 Availability Index in some Rapeseed- growing Inceptisols of Assam. *J. Indian Soc. Soil Sci.*
296 2010; 58:394-402.
- 297 Basumatary A, Das KN. Forms of sulphur and their relationship with soil properties in some
298 soils of North Bank Plain zone of Assam. *Agropedology* 2012; 22:43-49.
- 299 Basumatary A, Talukdar MC, Ramchiary S. Sulphur forms and their Relationship with Soil
300 properties in B. Rapeseed- growing Soils of Upper Assam. *Int. J. Tropical Agric.* 2008;
301 26:69-72.
- 302 Bhogal NS, Choudhary KC, Sakal R. Distribution of different forms of sulphur in
303 Calciorthents of North Bihar. *J. Indian Soc. Soil Sci.* 1996; 44(1):65-69.
- 304 Black CA. *Methods of Soil Analysis. Part-II. Agronomy Series. No. 9, American Society*
305 *Agronomy, Inc., Madison.* 1965.
- 306 Borkotoki B, Das KN. Forms of Sulphur and their relationship with soil properties in
307 Entisols, Inceptisols and Alfisols of Assam *J. Indian Soc. Soil Sci.* 2008; 56:186-191
- 308 Chattopadhyay GN, Ghosh GK. Vertical distribution of forms of sulphur in some profiles
309 of Birbhum district of West Bengal. *J. Interacademia* 2009; 13(1):28-35.
- 310 Das S, Khanam R, Ghosh Bag A, Chatterjee N, Hazra GC, Kundu D, Pal B, Mohiuddin G
311 Spatial distribution of sulphur and its relationship with soil attributes under diverse agro-
312 climatic zones of West Bengal, India. *J. Indian Soc. Soil Sci.* 2021; 69(4):401-410.

- 313 Das, I., Ghosh, K., Ray, S. C., Mukhopadhyay, P. K., Ghosh, S. K. 2006. Status and
314 distribution of sulphur vis-a-vis taxonomic class-wise distribution of sulphur in selected soil
315 series of Inceptisols in West Bengal. *J. Indian Soc. Soil Sci.* 54(3): 368-371. 26.
- 316 Das, K. N., Basumatari, A., and Borkotoki, B. 2011. Interrelationship of forms of Sulphur
317 with its availability indices and soil properties in Entisols of Assam. *J. Indian Soc. Soil Sci.*
318 59: 134-140.
- 319 Das, K. N., Basumatari, A., and Borkotoki, B. 2012. Forms of sulphur in some Rapeseed-
320 growing Soils of Assam. *J. Indian Soc. Soil Sci.* 60: 13-19.
- 321 Dolui AK, Jana SC. Sulphate sorption–desorption characteristics of some Inceptisols. *J.*
322 *Indian Soc. Soil Sci.* 1997; 45:265-270.
- 323 Evans CA, Rost CO. Total organic sulfur and humus sulfur in Minnesota soils. *Soil Sci.*
324 1945; 59:125–137.
- 325 Fox RL, Olson RA, Rhoades HF. Evaluating the sulphur status of soils by plant and soil
326 tests. *Soil Sci. Soc. Am. Proc.* 1964; 28:243-246.
- 327 Freney JR. Determination of water-soluble sulfur in soils. *Soil Sci.* 1958; 86:241–242.
- 328 Ganeshamurthy AN, Saha JK. Sulphur status of soils of agro-ecological regions of India.
329 *Fert. News* 1999; 44:57–60.
- 330 Ghosh GK, Chattopadhyay GN, Chattopadhyay S. Availability and forms of sulphur in red
331 and lateritic soils of Birbhum district of West Bengal. *Indian J. Agric. Sci.* 2005; 75 (6):358-
332 60.
- 333 Gowrisankar D, Shukla LM. Sulfur forms and their relationship with soil properties in
334 Inceptisols of Delhi. *J. Indian Soc. Soil Sci.* 1999; 47(3):437– 442.
- 335 Havlin JL, Beaton JD, Tisdale SL, Nelson WL. *Soil fertility and fertilizers. An introduction*
336 *to nutrient management.* 7th ed. Person Education, Singapore. 2004; p. 221.
- 337 Hedge DM, Sudhakar BSN. Correcting sulphur deficiencies in soils and crops. *Indian J. Fert.*
338 2007; 3(1):65-79.
- 339 Hembram S, Mukhopadhyay P, Patra PK. Distribution of available S in some soil series of
340 West Bengal growing rice and pulses. *Int. J. Bio-resour. Stress Manage.* 2012; 3(3):332-335.

- 341 Jackson JL. Soil Chemical Analysis; Prentice Hall of India Pvt. Ltd., New Delhi, India;
342 1973, p. 498.
- 343 Kour S, Arora S, Jalali VK, Mondal AK. Soil sulfur forms in relation to physical and
344 chemical properties of midhill soils of North India. *Commun. Soil Sci. Plant Anal.* 2010.,
345 41(3): 277-289.
- 346 Kour S, Jalai VK. Forms of sulphur and their relationship in soils of different agroclimatic
347 zones of Jammu region. *J. Indian Soc. Soil Sci.* 2008; 56:309-312.
- 348 Kumar R, Singh KP, Singh S. Vertical distribution of sulfur fractions and their relationships
349 among carbon, nitrogen, and sulfur in acidic soils of Jharkhand. *J. Indian Soc. Soil Sci.*
350 2002; 50(3):502–505.
- 351 Kumar S, Singh V. Forms of sulphur in soils of younger alluvial plains of Rajasthan. *Int. J.*
352 *Trop. Agric.* 1999. 17(1-4): 173-175.
- 353 Kundu MC. Distribution of different forms of sulphur in rice growing soils of Nadia district
354 of West Bengal. *Plant Archives* 2006; 6(1):257-259.
- 355 Kundu R, Adhikary S, Padhan D, Das A, Dutta J. Extractable fractions of sulphur in major
356 soils of India. *Chem. Sci. Rev. Lett.* 2020; 9:138-145.
- 357 Lambooy AM. Relationship between cation exchange capacity, clay content and water
358 retention of Highveld soils. *S. Afr. J. Plant Soil* 1984; 1 (2):33-38.
- 359 Mishra UK, Das CP, Mitra GN. Forms of sulfur in some soils of Orissa in relation to
360 relevant soil properties. *J. Indian Soc. Soil Sci.* 1990; 38:61-69.
- 361 Pandey SB, Sachan R, Patel V, Bhawan R. Effect of sulphur, potassium and PSB on growth
362 parameters, root architecture and quality of mustard (*Brassica juncea* L.). *Int. J. Plant Soil*
363 *Sci.* 2022; 34(24):122-127.
- 364 Paul SC, Mukhopadhyay P. Distribution and availability of sulphur in some terai soils under
365 subtropical zone of eastern India. *Int. J. Agric. Environ. Biotechnol.* 2015; 8(2):347-357.
- 366 Rajkonwar B, Basumatary A, Barua NG. Forms of sulphur and their relationship with soil
367 properties in soils of Jorhat district of Assam. *Ann. Plant Soil Res.* 2016; 18(2):127-132.
- 368 Ramya T, Dawson J. Influence of potassium and sulphur on yield, economics and quality of
369 summer sunflower (*Helianthus annuus*. L). *Int. J. Plant Soil Sci.* 2023; 35(7): 12-16.

- 370 Rathore SS, Shekhawat K, Kandpal BK, Premi OP, Singh SP, Singh GC, Singh D. Sulphur
371 management for increased productivity of Indian mustard: A review. *Ann. Plant Soil Res.*
372 2015; 17(1):1-12.
- 373 Roshini S, Jegadeeswari D, Chitdeshwari T, Sankari A. Effect of different sulphur sources
374 on sulphur fractionation in a red sandy loam soil. *Int. J. Plant Soil Sci.* 2021; 33(22):87-95,
375 2021.
- 376 Sakal R, Singh AP. Sulfur in balanced fertilization in eastern India. In proceedings of the
377 Symposium on Sulfur in Balanced Fertilization. Sulfur Institute- Fertilizer Association of
378 India/ International Fertilizer Industry Association, New Delhi. 1997.
- 379 Sankhyan NK, Kumar P, Sharma GD, Rana MC. Spatial and vertical distribution of sulphur
380 in acidic soils of Western Himalayas. *Indian J. Ecol.* 2021; 48(2):489-495.
- 381 Scherer HW. Sulphur in soils. *J. Plant Nutr. Soil Sci.* 2009; 172:326-335.
- 382 Schollenberger CJ, Simon RH. Determination of exchange capacity and exchangeable bases
383 in soil-ammonium acetate method. *Soil Sci.* 1945; 59:13-24.
- 384 Sharma RK, Jaggi RC. Relationship of forms and availability indices of sulphur with
385 properties of soils of Kangra, Himachal Pradesh. *J. Indian Soc. Soil Sci.* 2001; 49:698-702.
- 386 Sharma U, Subehia SK, Rana SS, Sharma SK, Negi SC. Soil sulphur fractions and their
387 relationship with soil properties and rice (*Oryza sativa* L.) yield under long-term integrated
388 nutrient management in an acid Alfisol. *Res. Crops* 2014; 15 (4):738-745.
- 389 Shukla AK, Behera SK, Singh VK, Prakash C et al. Premonsoon spatial distribution of
390 available micronutrients and sulphur in surface soils and their management zones in Indian
391 Indo-Gangetic Plain. *Plos one* 2020; 15:e0234053.
- 392 Singh S, Singh KP, Rana NK, Sarkar AK. Forms of sulphur in some Ranchi soils of
393 Chotanagpur. *J. Indian Soc. Soil Sci.* 1993; 41:562–563.
- 394 Singh V, Sharma YK, Singh V, Mahajan P. Suitability of extractants for available sulfur and
395 relationship of sulfur fraction with some soil properties in paddy soils of western UP.
396 *Environ. Ecol.* 2009; 27:1698–1703.
- 397 Singh VK, Sirothia P, Patel VK. Interaction effect of the phosphorus and sulphur levels on
398 growth and yield attributes of linseed (*Linum usitatissimum*) crop under rainfed condition.
399 *Int. J. Plant Soil Sci.* 2022; 34(22):433-440.

400 Srinivasarao, C., Ganeshamurthy, A. N., Ali, M., Singh, R. N., and Singh, K. K. 2004.
401 Sulphur fractions, distribution, and their relationships with soil properties in different soil
402 types of major pulse-growing regions of India. *Commun. Soil Sci. Plant Anal.* 2004; 35(19-
403 20):2757-2769.

404 Suri D, Sharma VK, Kumar P, Upadhyay RG, Nazir G, Anjali K. Sulphur dynamics under
405 different land uses of outer himalayan region of Himachal Pradesh. *Environ. Conserv. J.*
406 2021; 22(3):265-270.

407 Tandon HLS, Messick DL. *Practical sulfur guide*, 20. Washington, D.C.: The Sulfur
408 Institute. 2002.

409 Tiwari KN, Gupta BR. Sulphur for sustainable high yield agriculture in Uttar Pradesh.
410 *Indian J. Fert.* 2006; 1: 37-52.

411 Trivedi SK, Bansal KN, Tomar RAS, Verma RS. Vertical distribution of forms of sulphur in
412 some profiles of Morena and Bhind districts of Madhya Pradesh. *J. Indian Soc. Soil Sci.*
413 2000; 48: 238-241.

414 Verma S, Singh A, Swayamprabha Pradhan S, Kumar V, Kumar V. Effect of sulphur
415 nutrition on the production potential of Brassica spp.: A Review. *Int. J. Plant Soil Sci.* 2022;
416 34(24):880-887.

417 Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic
418 matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* 1934;
419 37(1):29-38.

420 Williams CH, Steinberg A. Soil sulphur fractions as chemical indices of available sulphur in
421 some Australian soils. *Aust. J. Agric. Res.* 1959. 10: 340-352.

422

423

424

425

426

427

428

429

430

Tables

431 **Table 1 :Extraction methods of different forms of sulphur**

Sl. No.	Forms	Condition; Extraction procedure
1	Water soluble sulphur (Ws-S)	Water soluble S extracted by shaking with distilled water as proposed by Freney (1958).
2	Organic sulphur (Org-S)	Organic S was determined by digestion with hydrogen peroxide (Evans and Rost, 1945) and subsequent extraction with NaCl solution (Williams and Steinbergs, 1959).
3	Sulfate sulphur (Sulph-S)	Sulfate S can be extracted with 0.15% calcium chloride (CaCl ₂) as suggested by Williams and Steinbergs (1959).
4	Adsorbed sulphur (Ads-S)	Adsorbed S by extracted with potassium (K) dihydrogen phosphate (500 ppm P) as suggested by Fox et al., (1964).
5	Heat Soluble sulphur (Hs-S)	Heat Soluble S extracted from the soil by special heat treatment and with 0.1% NaCl solution as described by Williams and Steinbergs (1959)
6	Total sulphur (Tot-S)	Total sulphur content can be determined by diacid digest method (hydrofluoric acid and perchloric acid) as given by Black (1965).

432

433

434

435

436

437

Table 2: Physico-chemical characteristics of lateritic soils of Birbhum District, West Bengal

Locations	Sand (%) at depth			Silt (%) at depth			Clay (%) at depth			pH at depth			OC (%) at depth			CEC [C mol (P+) kg ⁻¹]		
	(cm)			(cm)			(cm)			(cm)			(cm)			at depth (cm)		
	0–20	20–40	40–60	0–20	20–40	40–60	0–20	20–40	40–60	0–20	20–40	40–60	0–20	20–40	40–60	0–20	20–40	40–60
Bolpur																		
Range	29.12–	26.40–	24.4–	4.72–	6.72–	6.72–	12.72–	16.16–	18.88–	4.12–	4.35–	5.11–	0.32–	0.22–	0.11–	6.90–	7.82–	10.11–
	76.56	75.84	73.84	30.72	28.72	26.72	48.16	51.6	55.6	5.61	5.84	6.15	0.67	0.38	0.24	19.22	21.64	23.32
Mean	57.47	54.83	51.34	14.32	14.18	13.76	28.21	30.99	34.9	4.97	5.27	5.58	0.48	0.29	0.15	11.19	12.64	14.11
SD	18.79	18.61	18.31	8.83	7.87	7.21	11.23	11.74	12.16	0.52	0.46	0.35	0.11	0.06	0.04	4.08	4.25	4.43
Illambazar																		
Range	24.40–	20.40–	19.12–	6.72–	6.0–	4.0–	22.88–	27.60–	31.60–	5.14–	5.71–	6.17–	0.34–	0.21–	0.10–	6.40–	6.90–	7.90–
	68.4	65.12	62.4	26.72	26.72	22.72	51.6	52.88	54.88	6.59	6.78	6.94	0.73	0.63	0.29	13.7	15.2	17.8
Mean	50.27	46.8	44.29	17.36	17.1	15.56	32.37	36.1	40.15	5.92	6.26	6.58	0.51	0.39	0.2	10.18	11.01	12.5
SD	17.13	17.38	16.95	8.75	8.92	9.26	10.11	10.11	8.85	0.46	0.38	0.25	0.15	0.14	0.07	2.87	3.2	3.67
Dubrajpur																		
Range	21.24–	22.40–	21.12–	8.0–	6.0–	6.72–	21.44–	26.16–	30.88–	5.10–	5.49–	5.79–	0.15–	0.11–	0.08–	6.20–	8.20–	10.20–
	68.56	66.4	62.4	36.16	33.28	34	51.6	53.6	54.16	6.34	6.74	6.98	0.58	0.39	0.24	14.6	16.8	19.30
Mean	46.06	44.51	41.55	20.18	18.25	18.52	33.76	37.25	39.93	5.69	6.4	6.64	0.38	0.24	0.14	9.3	11.35	13.49
SD	20.02	17.3	16.7	10.37	8.23	8.81	10.88	10.12	8.79	0.5	0.37	0.34	0.15	0.09	0.05	2.75	2.79	2.8
Sainthia																		
Range	25.68–	23.68–	22.40–	10.72–	10.72–	12.0–	14.16–	16.88–	19.60–	4.54–	5.22–	5.89–	0.44–	0.22–	0.11–	6.20–	8.40–	10.8–
	75.12	72.4	68.4	32.72	32	30.72	51.6	52.88	59.6	5.88	6.41	6.58	0.73	0.47	0.26	11.3	14.5	14.8
Mean	47.22	44.34	41.76	20.5	20.56	19.76	32.28	35.1	38.48	5.18	5.85	6.51	0.59	0.36	0.18	8.89	10.76	12.84
SD	18.52	17.38	17.21	7.4	7.08	6.75	12.4	11.38	12.69	0.46	0.45	0.35	0.11	0.07	0.06	1.96	2.19	1.43
Md. Bazar																		
Range	26.40–	27.68–	24.40–	2.72–	4.72–	6.0–	25.60–	26.16–	28.16–	4.22–	4.55–	5.12–	0.52–	0.24–	0.12–	5.40–	6.90–	8.60–
	71.68	69.12	65.12	30	28.72	24	50.88	52.88	57.6	5.59	6.26	6.85	0.76	0.58	0.32	11.5	13.8	14.6
Mean	49.18	47.27	44.47	17.98	17.18	16.03	32.84	35.55	39.5	4.87	5.46	5.94	0.65	0.41	0.2	7.42	9.22	10.78
SD	16.82	16.39	16.09	9.82	8.33	7.03	8.38	9.26	10.21	0.44	0.48	0.48	0.09	0.1	0.06	2.05	2.26	2.09

441

442

Table 3: Vertical distribution different forms of sulphur (mg kg⁻¹) in soils of Bolpur and Illambazar block of Birbhum District, West Bengal

Sample	Ws-S			Org-S			Sulph-S			Ads-S			Hs-S			Tot-S		
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60
Bolpur																		
S1	1.89	1.24	0.32	128.34	95.17	32.51	7.55	3.11	2.05	10.12	13.25	14.12	39.31	28.02	19.17	223.17	135.33	73.34
S2	1.56	1.15	0.34	136.17	102.67	65.29	8.68	4.66	3.22	12.75	17.18	23.25	45.2	33.99	20.9	367.14	245.87	130.13
S3	2.32	1.52	0.57	115.38	98.34	28.79	7.95	5.0	3.87	14.8	16.3	21.37	53.87	41.83	25.06	247.92	194.48	80.37
S4	3.09	2.25	1.15	120.09	85.66	54.1	9.38	6.81	4.90	13.08	15.22	23.29	49.06	37.66	28.73	278.24	201.67	145.26
S5	2.15	1.08	0.56	103.47	76.16	33.37	6.95	3.37	1.34	14.79	16.74	20.81	33.43	19.99	10.06	250.07	186.33	83.85
S6	2.66	1.79	0.97	152.39	125.27	75.04	8.57	5.02	2.83	10.06	16.88	21.95	35.75	24.85	15.92	447.32	305.74	128.96
S7	1.57	1.07	0.35	98.11	62.17	22.08	6.42	4.75	1.56	18.25	21.05	23.12	36.2	20.22	11.29	216.6	107.56	75.22
S8	2.48	2.05	1.22	145.81	82.24	35.15	6.86	3.39	1.42	13.88	16.89	23.96	50.48	28.27	13.34	365.13	244.2	139.7
S9	2.01	1.58	0.73	152.95	124.52	72.34	8.69	5.80	1.92	15.51	17.85	24.52	56.45	34.54	21.11	432.43	316.74	185.24
S10	2.37	1.34	0.82	119.25	73.48	36.37	7.84	4.62	2.23	12.54	16.33	19.4	53.04	35.24	14.31	317.28	263.58	154.2
Range	1.56-	1.07-	0.32-	98.11-	62.17-	22.08-	6.42-	3.11-	1.34-	10.06-	13.25-	14.12-	33.43-	19.99-	10.06-	216.60-	107.56-	73.34-
	3.09	2.25	1.22	152.95	125.27	75.04	9.38	6.81	4.9	18.25	21.05	24.52	56.45	41.83	28.73	447.32	316.74	185.24
Mean	2.21	1.51	0.7	127.2	92.57	45.5	7.89	4.65	2.53	13.58	16.77	21.58	45.28	30.46	17.99	314.53	220.15	119.63
SD	0.48	0.41	0.33	19.4	20.94	19.42	0.95	1.15	1.17	2.47	1.97	3.05	8.49	7.38	6.08	84.8	68.15	39.01
Illambazar																		
S1	3.20	1.84	0.55	179.82	86.05	48.85	9.4	7.92	6.03	25.03	28.35	29.28	50.95	31.94	21.01	521.51	282.94	120.38
S2	2.65	1.33	0.56	128.01	71.55	42.63	8.12	5.11	3.1	18.77	21.83	23.41	49.84	24.75	14.90	221.05	147.48	102.17
S3	2.22	1.24	0.29	149.98	98.22	37.13	8.06	4.05	2.74	25.37	27.01	28.53	36.68	28.91	18.73	427.15	193.28	124.41
S4	3.10	1.83	0.42	142.37	64.54	39.44	6.99	4.35	2.77	20.65	23.53	25.45	45.51	30.58	19.57	298.23	202.09	104.3
S5	2.04	1.10	0.49	176.16	93.04	56.71	8.72	6.86	5.22	25.04	29.0	32.97	51.84	34.91	22.89	510.98	214.94	134.89
S6	2.48	1.22	0.21	136.68	81.15	42.38	8.72	4.54	2.78	21.43	23.95	26.11	46.70	25.77	14.76	308.83	204.19	106.0
S7	1.81	1.14	0.44	123.55	52.05	27.42	6.02	5.39	4.08	22.59	25.54	26.28	56.07	23.19	11.13	275.08	175.35	117.26
S8	2.95	1.48	0.69	145.25	66.4	36.49	7.83	5.93	4.29	26.96	28.63	30.12	41.12	28.14	17.18	363.19	286.81	170.35
S9	1.45	1.16	0.33	133.69	56.11	25.68	7.28	5.66	4.82	21.82	25.6	28.68	38.39	29.47	16.95	421.34	211.35	138.28
S10	3.11	1.79	0.72	181.39	92.36	53.71	9.61	6.03	3.1	22.11	24.26	26.56	52.09	36.17	23.15	545.04	190.17	129.24
Range	1.45-	1.10-	0.21-	123.55-	52.05-	25.68-	6.02-	4.05-	2.74-	18.77-	21.83-	23.41-	36.68-	23.19-	11.13-	221.05-	147.48-	102.17-
	3.2	1.84	0.72	181.39	98.22	56.71	9.61	7.92	6.03	26.96	29.0	32.97	56.07	36.17	23.15	545.04	286.81	170.35
Mean	2.5	1.41	0.47	149.69	76.15	41.05	8.08	5.58	3.89	22.98	25.77	27.74	46.92	29.38	18.03	389.24	210.86	124.72
SD	0.61	0.3	0.17	21.77	16.3	10.17	1.11	1.19	1.18	2.54	2.43	2.73	6.44	4.21	3.83	113.43	43.61	20.39

Table 4: Vertical distribution different forms of sulphur (mg kg^{-1}) in soils of Dubrajpur and Sainthia block of Birbhum District, West Bengal

Sample	Ws-S			Org-S			Sulph-S			Ads-S			Hs-S			Tot-S		
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60
Dubrajpur																		
S1	1.87	1.25	0.74	110.08	80.27	26.17	6.22	4.57	2.63	14.46	17.34	20.47	35.47	20.97	16.86	293.83	209.31	134.38
S2	3.02	1.63	1.06	154.18	101.77	78.95	9.35	8.21	4.9	14.8	15.86	21.6	53.91	36.94	25.75	442.09	284.85	172.17
S3	2.34	1.11	0.56	103.99	82.44	47.45	5.25	4.24	2.54	11.2	12.04	16.72	39.19	18.78	11.59	237.9	160.46	125.41
S4	1.52	0.95	0.38	120.15	85.76	41.76	6.06	4.41	2.57	11.02	13.52	15.64	48.63	31.61	22.42	385.79	210.65	143.3
S5	3.28	1.52	0.75	100.85	78.26	32.03	9.63	7.98	4.02	13.08	17.51	21.16	39.22	23.94	14.75	251.73	185.31	103.89
S6	2.46	1.34	0.63	137.86	98.37	53.7	8.86	5.6	2.5	13.39	15.46	22.3	44.35	35.8	23.61	352.58	241.72	158
S7	1.07	0.82	0.47	100.72	59.27	37.74	5.09	3.44	1.38	12.86	18.14	20.47	37.03	21.17	11.98	248.26	188.54	126.26
S8	1.22	1.15	0.51	101.54	63.62	33.81	7.51	6.72	2.09	16.47	14.05	16.31	41.61	28.22	13.03	205.98	178.18	107.35
S9	3.05	1.91	1.05	125.56	89.34	52	8.37	7.09	3.6	14.54	17.11	18.87	31.58	20.49	14.8	241.8	182.72	124.28
S10	2.09	1.65	0.89	123.42	83.58	40.03	9.54	5.86	2.51	17.25	19.77	23.75	45.35	28.19	15	254.94	155.56	95.24
Range	1.07-	0.82-	0.38-	100.72-	59.27-	26.17-	5.09-	3.44-	1.38-	11.02-	12.04-	15.64-	31.58-	18.78-	11.59-	205.98-	160.46-	103.89-
	3.28	1.91	1.06	154.18	101.77	78.95	9.63	8.21	4.9	17.25	19.77	23.75	53.91	36.94	25.75	442.09	284.85	172.17
Mean	2.19	1.33	0.7	117.84	82.27	44.36	7.59	5.81	2.87	13.91	16.08	19.73	41.64	26.61	16.98	291.49	199.73	129.02
SD	0.78	0.34	0.24	18	13.33	14.96	1.8	1.65	1.02	2.03	2.36	2.74	6.61	6.57	5.1	76.56	39.16	24.08
Sainthia																		
S1	3.39	1.06	0.52	170.1	32.08	12.08	7.86	5.67	2.06	22.4	24.29	28.12	38.6	22.2	14.54	482.9	210.52	125.62
S2	2.75	1.52	0.54	136.07	68.65	32.86	9.63	7.8	4.13	18.14	22.77	24.25	63.16	34.17	20.42	493.26	286.06	163.41
S3	2.05	1.54	0.62	137.46	47.36	24.36	7.22	5.3	3.77	19.74	23.95	25.37	39.33	25.01	12.26	230.79	151.67	104.65
S4	1.04	0.72	0.36	146.77	59.94	37.67	8.06	4.5	3.8	20.02	21.47	26.29	52.49	32.84	26.09	283.98	165.86	109.54
S5	2.11	0.87	0.37	156.25	33.67	16.94	9.09	5.07	4.25	13.41	15.94	17.81	39.35	25.17	13.42	456.8	196.52	115.13
S6	2.38	1.31	0.65	186.64	41.61	25.61	9.84	7.69	5.73	15.8	16.89	19.95	44.49	26.03	15.28	448.94	257.93	142.24
S7	2.02	1.29	0.49	189.91	73.91	48.65	8.35	6.54	4.61	16.96	19.48	24.12	58.72	35.4	17.65	396.73	199.75	147.5
S8	2.24	1.26	0.45	139.34	34.72	17.72	6.25	3.18	2.32	14.33	18.57	21.96	47.75	23.45	12.7	294.58	189.39	108.59
S9	1.75	0.85	0.23	141.48	38.86	20.91	8.51	4.08	2.83	21.19	23.54	28.52	43.77	32.42	22.48	312.83	213.93	138.52
S10	1.64	1.01	0.69	203.78	50.94	28.94	6.37	5.81	4.27	24.48	26.2	31.4	61.04	39.72	23.68	507.09	306.77	189.48
Range	1.04-	0.72-	0.23-	136.07-	32.08-	12.08-	6.25-	3.18-	2.06-	13.41-	15.94-	17.81-	38.60-	22.20-	12.26-	230.79-	151.67-	104.65-
	3.39	1.54	0.69	203.78	73.91	48.65	9.84	7.8	5.73	24.48	26.2	31.4	63.16	39.72	26.09	507.09	306.77	189.48
Mean	2.13	1.14	0.49	160.78	48.18	26.58	8.12	5.56	3.78	18.65	21.31	24.78	48.87	29.64	17.85	390.79	217.84	134.46
SD	0.64	0.28	0.14	25.07	14.94	10.93	1.24	1.48	1.11	3.57	3.43	4.11	9.41	5.98	5	101.45	50.45	27.37

444 **Table 5: Vertical distribution different forms of sulphur (mg kg⁻¹) in soils of Md.Bazar block of Birbhum District, West Bengal**

Sample	Ws-S			Org-S			Sulph-S			Ads-S			Hs-S			Tot-S		
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60
Md. Bazar																		
S1	1.32	0.95	0.37	178.21	83.28	32.78	4.32	3.61	2.1	25.49	28.01	29.3	52.35	33.26	18.13	320.22	252.05	165.61
S2	2.5	1.04	0.56	152.48	31.61	17.56	7.45	3.8	2.08	19.24	25.67	26.43	44.24	28.23	13.02	279.75	202.72	117.4
S3	2.02	1.45	0.44	144.44	60.11	25.06	3.72	2.86	1.72	22.83	24.49	28.55	50.47	36.07	18.86	436.39	235.52	139.64
S4	2.81	1.41	0.49	181.39	44.6	20.37	6.15	4.14	2.75	18.12	22.19	25.47	54.91	38.9	23.69	460.29	217.33	109.53
S5	2.04	1.85	0.58	151.91	90.42	46.64	5.72	4.7	2.19	22.51	24.66	27.99	66.24	36.23	14.02	418.07	245.41	140.12
S6	1.82	1.03	0.25	123.6	48.21	23.31	4.34	2.29	1.76	23.9	25.61	26.13	41.1	24.09	12.88	387.47	200.59	121.23
S7	3.01	1.51	0.42	186.05	52.11	27.35	6.19	3.67	2.06	20.05	23.2	26.3	68.08	32.46	16.25	511.32	191.18	102.49
S8	1.95	1.19	0.37	142.78	66.46	30.42	4.46	3.68	2.27	22.43	24.29	27.14	56.52	34.51	21.3	404.28	229.43	167.58
S9	2.32	1.73	0.58	133.92	63.16	28.31	4.61	3.78	2.79	19.29	22.26	25.7	38.79	27.79	16.08	330.58	218.18	113.51
S10	1.23	0.82	0.36	191.62	76.1	32.64	5.63	2.41	1.07	24.57	26.92	28.58	57.5	36.86	24.28	485.43	186.59	104.47
Range	1.23- 3.01	0.82- 1.85	0.25- 0.58	123.60- 191.62	31.61- 90.42	17.56- 46.64	3.72- 7.45	2.29- 4.7	1.07- 2.79	18.12- 25.49	22.19- 28.01	25.47- 29.3	38.79- 68.08	24.09- 38.9	12.88- 24.28	279.75- 511.32	186.59- 252.05	102.49- 167.58
Mean	2.1	1.3	0.44	158.64	61.6	28.45	5.26	3.49	2.08	21.84	24.73	27.16	53.02	32.84	17.85	403.38	217.9	128.15
SD	0.58	0.34	0.11	23.84	18.25	8.12	1.15	0.76	0.5	2.52	1.9	1.36	9.81	4.73	4.17	75.04	22.59	23.98

446

448

450

Table :6Relationship between forms of sulphur with soil physico-chemical properties at various soil depth

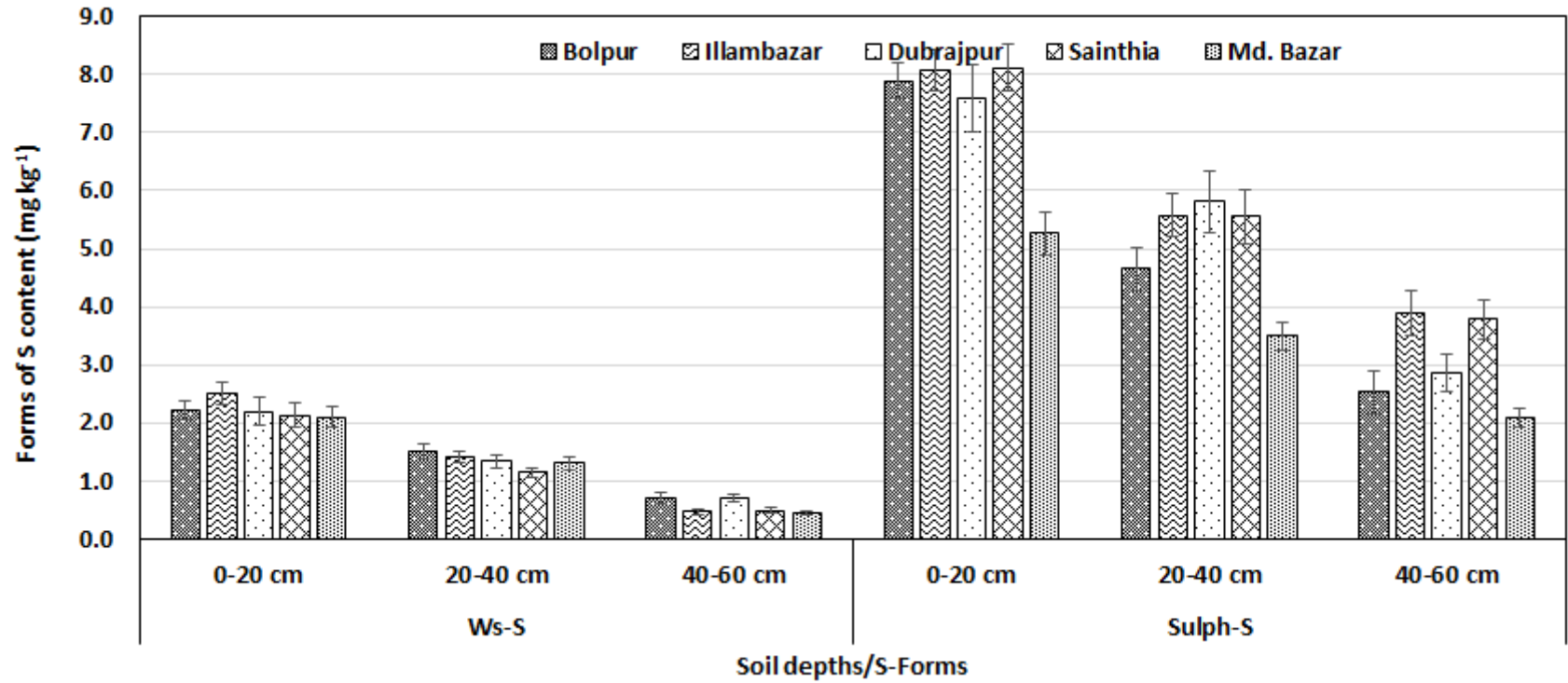
S Forms	Soil properties/Soil depth					
	0-20 cm soil depth					
	pH	OC	CEC	Sand	Silt	Clay
Ws-S	0.431**	0.295	0.09	-0.089	0.13	0.042
Org-S	-0.119	0.636**	0.03	-0.386**	0.327*	0.383**
Sulph-S	0.325*	0.305*	0.329*	-0.21	0.279*	0.121
Ads-S	-0.022	0.331*	0.026	-0.311*	0.196	0.368**
Hs-S	-0.207	0.599**	0.065	-0.133	0.026	0.207
Tot-S	-0.103	0.584**	0.059	-0.283*	0.248	0.274
	20-40 cm soil depth					
Ws-S	0.131	0.213	0.219	-0.011	0.038	0.011
Org-S	-0.063	0.114	0.349*	-0.034	0.09	0.126
Sulph-S	0.450**	0.165	0.354*	-0.288*	0.221	0.306*
Ads-S	-0.071	0.566**	-0.06	-0.282*	0.204	0.308*
Hs-S	-0.256	0.588**	0.232	-0.243	0.194	0.253
Tot-S	-0.068	0.407**	0.431**	-0.298*	0.141	0.383**
	40-60 cm soil depth					
Ws-S	0.074	0.119	0.387**	-0.236	0.241	0.199
Org-S	-0.071	0.274	0.364**	-0.125	0.300	0.223
Sulph-S	0.423**	0.115	0.349**	-0.263	0.228	0.251
Ads-S	-0.055	0.534**	0.092	-0.428**	0.241	0.506**
Hs-S	-0.141	0.504**	0.308*	-0.374**	0.239	0.422**
Tot-S	0.007	0.333*	0.461**	-0.401**	0.261	0.448**

*, ** Significant at 0.05 and 0.01 probability levels, respectively

Table : 7 Inter-relationship between forms of sulphur at various soil depths

Forms	Ws-S	Org-S	Sulph-S	Ads-S	Hs-S	Tot-S
0-20 cm soil depth						
Ws-S	1.000					
Org-S	0.442**	1.000				
Sulph-S	0.440**	0.097	1.000			
Ads-S	-0.047	0.489**	-0.233	1.000		
Hs-S	0.011	0.531**	-0.056	0.296*	1.000	
Tot-S	0.237	0.781**	0.24	0.398**	0.475**	1.000
20-40 cm soil depth						
Ws-S	1.000					
Org-S	0.440**	1.000				
Sulph-S	0.370**	0.206	1.000			
Ads-S	-0.116	0.283*	-0.099	1.000		
Hs-S	0.176	0.244	0.117	0.190	1.000	
Tot-S	0.220	0.344*	0.233	0.139	0.441**	1.000
40-60 cm soil depth						
Ws-S	1.000					
Org-S	0.153	1.000				
Sulph-S	0.188	0.217	1.000			
Ads-S	-0.199	-0.093	0.150	1.000		
Hs-S	0.064	0.361*	0.335*	0.259	1.000	
Tot-S	0.209	0.272	0.222	0.288*	0.345*	1.000
*, ** Significant at 0.05 and 0.01 probability levels, respectively						

Figures

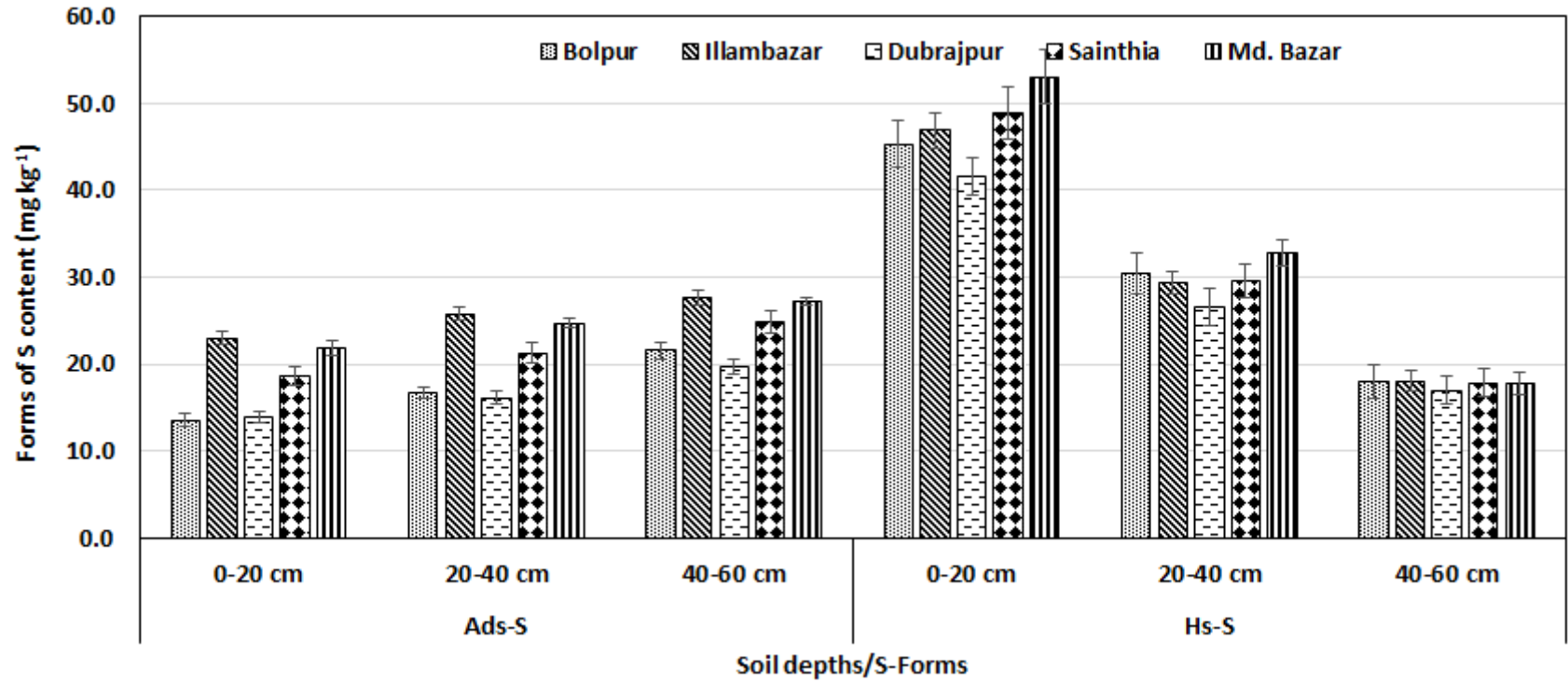


456

Fig. 1: Depth-wise distribution of water soluble sulphur (Ws-S) and sulphate sulphur (Sulph-S) forms of soil sulphur in the study area

458

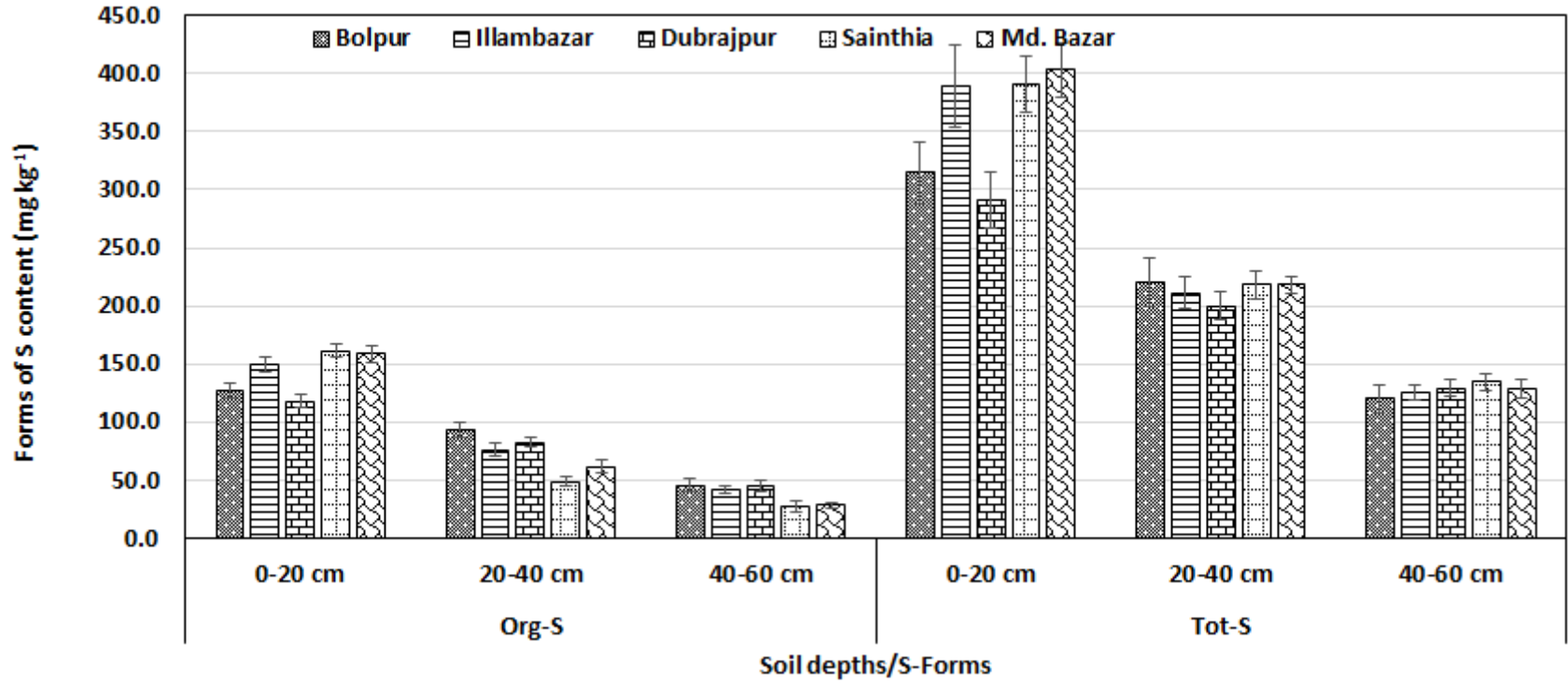
460



462

Fig. 2: Depth-wise distribution of adsorbed sulphur (Ads-S) and heat soluble sulphur (Hs-S) forms of soil sulphur in the study area

464



466

Fig. 3: Depth-wise distribution of organic sulphur (Org-S) and total sulphur (Tot-S) forms of soil sulphur in the study area

468