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# VARIETAL RESPONSE TO SULPHUR LEVELS AND SOIL SULPHUR FRACTIONS UNDER DIFFERENT RICE ESTABLISHMENT METHODS

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## ABSTRACT
A field experiment was conducted during Kharif and Rabi seasons of 2025 at Indian Institute of Rice Research, Hyderabad, to evaluate the effect of graded levels of elemental sulphur on soil sulphur fractions in different rice establishment methods and varieties. The experiment was laid out with two crop establishment methods [direct-seeded rice (DSR) and transplanted rice (TPR)], two rice varieties (Kamala and Samba Mahsuri) and four sulphur levels (0, 20, 40 and 60 kg S ha$^{-1}$) in a split-split plot design with three replications. The soil samples were collected from 0–15 cm depth of the experimental plots at the end of each season and analysed for water-soluble sulphur, sulphate sulphur, inorganic sulphur, organic sulphur, residual sulphur and total sulphur. The results showed that sulphur application significantly influenced all sulphur fractions. DSR recorded higher water-soluble, sulphate and inorganic sulphur contents, whereas TPR showed higher organic and residual sulphur. The application of 40 kg S ha$^{-1}$ produced the maximum content of water-soluble sulphur (9.12 and 10.16 mg kg$^{-1}$), sulphate sulphur (16.47 and 17.00 mg kg$^{-1}$), inorganic sulphur (23.07 and 24.94 mg kg$^{-1}$), organic sulphur (229.82 and 224.05 mg kg$^{-1}$) and total sulphur (308.57 and 305.84 mg kg$^{-1}$) during Kharif and Rabi, respectively. Residual sulphur decreased up to 40 kg S ha$^{-1}$ which indicated its transformation into more available sulphur in both the seasons. Kamala recorded higher available sulphur fractions than that of Samba Mahsuri. The study concluded that elemental sulphur at 40 kg ha$^{-1}$ was the optimum level for improving sulphur availability and its accumulation in soil under different rice establishment methods.

## INTRODUCTION
Sulphur is an essential secondary macronutrient playing a vital role in several physiological and biochemical processes in plants like protein synthesis, chlorophyll formation, enzyme activation and oil biosynthesis. Sulphur exists in the form of various chemical pools including water soluble, sulphate, organic, inorganic, residual and total sulphur in soils. All these sulphur pools interact and co-exist in a highly dynamic and stable state to determine the sulphur available for plant uptake. Early studies were primarily concerned with quantifying sulphur pool and its relative contribution. However, Bettany et al. (1980) demonstrated that long years of cultivation drastically depleted the total sulphur with a shift in the contribution of organic and inorganic sulphur fractions. The sulphur content decreased from 0.049% in pasture soil to 0.031% in cultivated soil after 65 years of cultivation with inorganic sulphate sulphur decreasing from 4.6 to 3.2 µg g$^{-1}$. Singh et al. (1993) recorded a considerably higher contribution of organic sulphur (77%) in the soils of Jharkhand. Similarly, Bhogal et al. (1996) reported that organic sulphur contributed 89% total sulphur in the Calciorthents of North Bihar. Cumulatively, the studies have shown that organic sulphur contributes predominantly to the total sulphur in the soil and sustains the sulphur supplying capacity of the soils.

With the growing recognition of the importance of organic matter in the cycling of nutrients in the soil, the interaction of sulphur pools with nutrients and organic matter became the focus of later studies. Ghosh et al. (2017) showed that FYM application along with sulphur fertilizers increased the sulphur availability due to gradual mineralization of the sulphur bound with organic matter. Nguyen and Goh (2006) established statistically significant positive relationships between total sulphur, organic sulphur with soil organic carbon and total nitrogen, which suggests the possible role of sulphur in the quality and quantity of soil organic matter. In line with this, Rajkonwar et al. (2012) reported that the sulphur fractions followed the order Total S > Organic S > Heat-soluble S > Sulphate S > Water-soluble S > Adsorbed S. The major sulphur fractions positively correlated with soil organic carbon and clay content suggesting that organic matter accumulation and mineral matter in the form of clay also influence sulphur transformation and retention. Collectively, the findings suggest the close inter-relationship between sulphur fractions in the soil through a network of mineralization-immobilization, desorption-adsorption, oxidation-reduction reactions. The variations in sulphur fractions could be attributed to differences in soil properties and management practices.

In recent years, conservation agriculture and crop residue management have gained attention for their potential to conserve and recycle sulphur in the intensively cultivated soils. Kumar et al. (2022) and Somasundaram et al. (2020) reported that residue burning caused 4-60% sulphur loss while conservation agriculture helped conserve sulphur in the soil-plant system. Similar results were reported by Alhammad et al. (2023) and Meena et al. (2022) who recorded higher sulphur availability in conservation agriculture due to increased organic C and microbial sulphur mineralization. Meena et al. (2022) estimated the relative contribution of various sulphur fractions and recorded that water-soluble sulphur, adsorbed sulphur, available sulphur, heat-soluble sulphur and organic sulphur accounted for 3.57, 3.67, 3.99, 11.4 and 64.1% of the total sulphur respectively. Kumar et al. (2022) recorded a significant increase in total sulphur (584–668 mg kg$^{-1}$), organic sulphur (50–153 mg kg$^{-1}$), available sulphur (7.9–21.6 mg kg$^{-1}$) and water-soluble sulphur (6.0–17.0 mg kg$^{-1}$) under conservation agriculture with strip planting along with higher residue retention reporting the highest values.

Results from long-term experiments also provide evidence of the potential of conservation-based management practices to enhance sulphur nutrition. Karadihalli et al. (2024) reported that nine years of zero tillage and residue retention greatly increased the available sulphur, water-soluble sulphur, heat-soluble sulphur, inorganic sulphur, organic sulphur, sodium bicarbonate extractable sulphur and total sulphur pools as compared to conventional tillage. Overall, the findings indicate a shift in the understanding of sulphur in the soils from characterization of individual sulphur fractions to realization of the fact that sulphur is highly dependent on organic matter, microbes, residue management and tillage. The dominance of organic sulphur and its susceptibility to changes in soil organic carbon highlight the importance of conservation of organic matter and reduction in residue loss for sulphur availability for better fertility maintenance under intensive cropping.

## MATERIALS AND METHODS

### Experimental site

A field experiment was conducted at the ICAR–Indian Institute of Rice Research farm during Kharif and Rabi seasons of 2025 on a deep black clayey vertisol (Typic Pellustert) at the IIRR Rice Research farm, Hyderabad (17°19′ N latitude, 78°23′ E longitude, 542 m altitude, mean annual precipitation of 750 mm). The plots selected for the study were B-6 and B-7. Detailed plot characteristics are given in the table. Initial and post-harvest soil samples were collected before the commencement of the study and are presented in the table. All agronomic parameters under the different rice establishment methods were recorded. The experimental site had medium land and altitude, with soils predominantly vertisols having a pH of 8.2 to 8.5. The site had an assured irrigation facility, uniform topography and good drainage. Hyderabad's climate is tropical, characterized by dry, hot summers and mild winters, with summer temperatures exceeding 40°C; May is the warmest month and January the coolest. Long-term weather data indicate a mean maximum temperature of 30.57°C, a mean minimum temperature of 21.22°C and average rainfall of 595 mm, over three-fourths of which is received through the south-west monsoon (July-September).

The experiment comprised four sulphur levels $S_0$ (control, 0 kg S ha$^{-1}$), $S_1$ (20 kg S ha$^{-1}$), $S_2$ (40 kg S ha$^{-1}$) and $S_3$ (60 kg S ha$^{-1}$) applied through elemental sulphur, tested on two rice varieties (Kamala and Samba Mahsuri) under two crop establishment methods, direct-seeded rice (DSR) and transplanted rice (TPR). A recommended fertilizer dose of 120:80:40 kg ha$^{-1}$ (N:$P_2O_5$: $K_2O$) was applied uniformly to all plots, independent of the sulphur treatments. Urea (46% N), DAP (18% N, 46% $P_2O_5$) and MOP (60% $K_2O$) were the sources used. Half of the N and the full doses of P and K were applied basally at transplanting/sowing; the remaining half of N was top-dressed in two equal splits at tillering and panicle initiation. Elemental S was applied basally as per treatment at the time of transplanting/sowing in plots B-6 and B-7. Soil samples were collected from a depth of 0–15 cm before the start of the experiment and after harvest of each season for fractionation of soil sulphur. The experiment was laid out in a split-split-plot design with three replications, with crop establishment method assigned to the main plot, variety to the sub-plot and sulphur level to the sub-sub-plot.

### Fractionation of Soil Sulphur

The sequential fractionation procedure was followed as described by Evans and Rost (1945), with modifications.

### Water-Soluble Sulphur (WS-S)

Five grams of processed soil were washed with 25 ml distilled water, shaken on a rotary shaker for 10 minutes and centrifuged at 3000 rpm for 15 minutes. The clear supernatant was filtered and water-soluble sulphur was determined turbidimetrically (Evans and Rost, 1945) and modified by Williams and Steinbergs (1959).

**Sodium Chloride Extractable Sulphur (Sulphate-S)**

The residue from WS-S extraction was treated with 25 ml of 1% NaCl, shaken for 30 minutes and centrifuged under the same conditions. The supernatant was filtered, treated with a pinch of $BaCl_2$ and 1 ml of 0.25% gum acacia and absorbance was measured at 420 nm using the turbidimetric method.

**Hydrochloric Acid Extractable Sulphur (Inorganically Bound-S)**

The residue after NaCl extraction was treated with 25 ml of 1% HCl, shaken for 10 minutes, centrifuged and filtered. HCl-extractable sulphur was determined turbidimetrically.

**Organically Bound Sulphur (OM-S)**

After HCl extraction, the soil was digested with hydrogen peroxide and extracted with 1% NaCl. The organic sulphur fraction was determined as described by Evans and Rost (1945) and modified by Williams and Steinbergs (1959).

**Total Sulphur (TS)**

Total sulphur was determined following Chowdhury and Cornfield (1978). Finely sieved soil (<0.5 mm) was digested with a mixture of nitric acid and potassium nitrate, heated on a steam bath for 1 hour, then in a muffle furnace at 550°C for 3 hours. Further digestion with 25% (v/v) acid was carried out for 1 hour and the extract was diluted to 100 ml for determination of total sulphur using the turbidimetric method (Chesnin and Yien, 1951).

**Residual Sulphur (Residual-S)**

Residual sulphur was calculated by difference, subtracting the sum of water-soluble, sulphate, HCl-extractable (inorganically bound) and organically bound sulphur fractions from the total sulphur content of the soil.

## RESULTS AND DISCUSSION

**Water-soluble Sulphur**

At the 0-15 cm soil depth, water-soluble sulphur content ranged from 3.58 to 10.54 mg $kg^{-1}$ during Kharif and from 3.96 to 11.74 mg $kg^{-1}$ during Rabi (Table 1). Crop establishment method significantly affected water-soluble sulphur. Direct-seeded rice (DSR) recorded significantly higher water-soluble sulphur contents of 7.28 and 8.05 mg $kg^{-1}$ during Kharif and Rabi, respectively, compared with 5.31 and 5.87 mg $kg^{-1}$ under transplanted rice (TPR). Among the varieties, Kamala recorded significantly higher water-soluble sulphur (6.73 and 7.44 mg $kg^{-1}$) than Samba Mahsuri (5.86 and 6.48 mg $kg^{-1}$) during Kharif and Rabi, respectively.

Application of elemental sulphur significantly increased water-soluble sulphur in the soil. The highest values were recorded with S40 (9.12 and 10.16 mg $kg^{-1}$), which were significantly higher than those recorded with S60 (6.65 and 7.19 mg $kg^{-1}$), S20 (5.16 and 5.81 mg $kg^{-1}$) and S0 (4.25 and 4.68 mg $kg^{-1}$) during Kharif and Rabi, respectively. The lowest water-soluble sulphur content was recorded under S0.

The interaction effects of crop establishment method × elemental sulphur level (A × C) and variety × elemental sulphur level (B × C) were significant during both seasons (Tables 7 and 8). The highest water-soluble sulphur was recorded under DSR × S40, with values of 10.54 and 11.74 mg $kg^{-1}$ during Kharif and Rabi, respectively. Similarly, the Kamala × S40 treatment recorded 9.76 and 10.87 mg $kg^{-1}$ during Kharif and Rabi, respectively. The A × B interaction was non-significant during both seasons.

The increase in water-soluble sulphur with elemental sulphur application is in agreement with the findings of Islam et al. (2016) and Mishra et al. (2022), who reported an increase in the readily available sulphur fraction with increasing sulphur application. The higher water-soluble sulphur under DSR than TPR may be related to differences in soil moisture and aeration conditions associated with the two crop establishment methods. The relatively less puddled soil under DSR may favour the oxidation of elemental sulphur and subsequent formation of soluble sulphate forms. Similar differences in soil sulphur fractions under contrasting crop establishment practices have been reported by Padhan et al. (2023).

**Sulphate Sulphur**

Sulphate sulphur content ranged from 12.24 to 17.91 mg $kg^{-1}$ during Kharif and from 12.49 to 18.48 mg $kg^{-1}$ during Rabi (Table 2). DSR recorded significantly higher sulphate sulphur contents of 16.18 and 16.78 mg $kg^{-1}$ than TPR, which recorded 13.59 and 14.10 mg $kg^{-1}$ during Kharif and Rabi, respectively.

Among the varieties, Kamala recorded significantly higher sulphate sulphur (15.50 and 16.08 mg $kg^{-1}$) than Samba Mahsuri (14.26 and 14.79 mg $kg^{-1}$) during Kharif and Rabi, respectively. Elemental sulphur application significantly influenced sulphate sulphur. The highest values were recorded under S40 (16.47 and 17.00 mg $kg^{-1}$), followed by S60 (15.41 and 15.98 mg $kg^{-1}$), S20 (14.23 and 15.09 mg $kg^{-1}$) and S0 (13.41 and 13.68 mg $kg^{-1}$) during Kharif and Rabi, respectively. The lowest values were recorded under S0.

The interactions A × B, A × C and B × C were non-significant during both seasons (Tables 9 and 10), indicating that the effects of crop establishment method, variety and elemental sulphur application were independent with respect to sulphate sulphur content.

The present findings are in agreement with Mishra et al. (2022), who reported an increase in sulphate sulphur with sulphur application in rice. The increase in sulphate sulphur with elemental sulphur application may be attributed to the gradual oxidation of elemental sulphur in the soil and its conversion into sulphate, which constitutes an important plant-available form of sulphur

**Inorganic Sulphur**

Inorganic sulphur content ranged from 13.71 to 25.64 mg $kg^{-1}$ during Kharif and from 14.22 to 27.71 mg $kg^{-1}$ during Rabi (Table 3). DSR recorded significantly higher inorganic sulphur contents of 21.25 and 22.81 mg $kg^{-1}$ than TPR, which recorded 17.00 and 18.25 mg $kg^{-1}$ during Kharif and Rabi, respectively. Similarly, Kamala recorded significantly higher inorganic sulphur (20.13 and 21.61 mg $kg^{-1}$) than Samba Mahsuri (18.12 and 19.45 mg $kg^{-1}$).

Elemental sulphur application significantly influenced the inorganic sulphur fraction. The highest inorganic sulphur contents were recorded under S40 (23.07 and 24.94 mg $kg^{-1}$), followed by S60 (20.06 and 21.68 mg $kg^{-1}$), S20 (17.95 and 19.48 mg $kg^{-1}$) and S0 (15.43 and 16.00 mg $kg^{-1}$) during Kharif and Rabi, respectively. The lowest values were recorded under S0.

The A × C interaction was non-significant during Kharif but significant during Rabi (CD = 0.715). During Rabi, the highest inorganic sulphur content was recorded under DSR × S40 (27.71 mg $kg^{-1}$) (Table 11). The A × B and B × C interactions were non-significant during both seasons (Table 12).

The higher inorganic sulphur content under DSR may be associated with relatively favourable soil conditions for the oxidation of elemental sulphur. The increase in inorganic sulphur up to S40 indicates that elemental sulphur application enhanced the inorganic sulphur pool. The lower value under S60 compared with S40 may be due to the slower oxidation of the additional elemental sulphur or its retention in less readily available forms. Similar changes in soil sulphur fractions with sulphur application have been reported by Mishra et al. (2022), Kumar et al. (2014), Kale et al. (2021), Bharamappanavara et al. (2020) and Srilatha et al. (2019).

**Organic Sulphur**

Organic sulphur, which constituted the major fraction of soil sulphur, ranged from 133.44 to 236.39 mg $kg^{-1}$ during Kharif and from 131.16 to 230.45 mg $kg^{-1}$ during Rabi (Table 4). TPR recorded significantly higher organic sulphur (187.70 mg $kg^{-1}$) than DSR (177.27 mg $kg^{-1}$) during Kharif. During Rabi, the corresponding values were 183.21 and 173.03 mg $kg^{-1}$, although the difference was non-significant.

Among the varieties, Kamala recorded significantly higher organic sulphur contents of 185.96 and 181.51 mg $kg^{-1}$ than Samba Mahsuri, which recorded 179.01 and 174.73 mg $kg^{-1}$ during Kharif and Rabi, respectively.

Elemental sulphur application significantly increased organic sulphur. The highest values were recorded under S40 (229.82 and 224.05 mg $kg^{-1}$), followed by S60 (194.89 and 190.34 mg $kg^{-1}$), S20 (167.84 and 163.09 mg $kg^{-1}$) and S0 (137.37 and 135.02 mg $kg^{-1}$) during Kharif and Rabi, respectively. The lowest values were recorded under S0.

None of the interaction effects were significant during either season (Tables 13 and 14). The higher organic sulphur under TPR, particularly during Kharif, may be associated with the puddled and relatively reduced soil conditions under transplanted rice, which can slow the decomposition and mineralization of organic matter and consequently favour the retention of sulphur in organic forms. The predominance of organic sulphur in the total sulphur pool is in agreement with Padhan et al. (2023) and Meena et al. (2023), who reported organic sulphur as the major fraction of total soil sulphur.

**Residual Sulphur**

Residual sulphur content ranged from 40.20 to 61.02 mg $kg^{-1}$ during Kharif and from 38.88 to 60.02 mg $kg^{-1}$ during Rabi (Table 5). TPR recorded significantly higher residual sulphur contents of 51.67 and 50.38 mg $kg^{-1}$ than DSR, which recorded 46.75 and 45.58 mg $kg^{-1}$ during Kharif and Rabi, respectively.

Between the varieties, Samba Mahsuri recorded significantly higher residual sulphur (51.67 and 50.38 mg kg$^{-1}$) than Kamala (46.75 and 45.58 mg kg$^{-1}$) during Kharif and Rabi, respectively.

Elemental sulphur application showed a different response pattern compared with the other sulphur fractions. The highest residual sulphur was recorded under S0 (58.12 and 57.16 mg kg$^{-1}$), which decreased progressively with increasing elemental sulphur application up to S40, where the lowest values of 42.31 and 40.93 mg kg$^{-1}$ were recorded during Kharif and Rabi, respectively. Thereafter, residual sulphur increased under S60 to 46.21 and 45.09 mg kg$^{-1}$.

None of the interaction effects were significant during either season (Tables 15 and 16). The decline in residual sulphur with elemental sulphur application up to S40 may be associated with increased transformation and availability of sulphur in the soil. The corresponding increase in water-soluble, sulphate and inorganic sulphur under S40 suggests a shift of sulphur from the relatively less available residual pool towards more available forms. The increase in residual sulphur under S60 may be related to incomplete oxidation of the additional elemental sulphur or its retention in less available forms. Similar changes in the distribution of soil sulphur fractions with sulphur application have been reported by Mishra et al. (2022), Kale et al. (2020), Sahoo et al. (2022), Gorlapalli, et al. (2022) and Parmar et al. (2022).

**Total Sulphur**

Total sulphur content ranged from 216.06 to 314.93 mg kg$^{-1}$ during Kharif and from 214.46 to 312.14 mg kg$^{-1}$ during Rabi (Table 6). Crop establishment method did not significantly influence total sulphur during Kharif. However, during Rabi, DSR recorded significantly higher total sulphur (267.31 mg kg$^{-1}$) than TPR (256.51 mg kg$^{-1}$). The corresponding values during Rabi were 265.04 and 254.33 mg kg$^{-1}$, respectively.

The effect of variety on total sulphur was non-significant during both seasons. Kamala and Samba Mahsuri recorded statistically comparable total sulphur contents of 259.21 and 264.61 mg kg$^{-1}$ during Kharif and 257.00 and 262.36 mg kg$^{-1}$ during Rabi, respectively.

Elemental sulphur application significantly influenced total soil sulphur. The highest total sulphur was recorded under S40 (308.57 and 305.84 mg kg$^{-1}$), followed by S60 (272.52 and 270.33 mg kg$^{-1}$), S20 (245.93 and 243.59 mg kg$^{-1}$) and S0 (220.62 and 218.97 mg kg$^{-1}$) during Kharif and Rabi, respectively. The lowest total sulphur was recorded under S0.

None of the interaction effects were significant during either season (Tables 17 and 18). The increase in total soil sulphur with elemental sulphur application up to S40 indicates effective incorporation of applied sulphur into the soil sulphur pool. The lower total sulphur under S60 compared with S40 may be associated with differences in sulphur oxidation and transformation, resulting in a greater proportion of applied sulphur remaining in forms not readily detected within the measured sulphur fractions at the time of sampling. Similar increases in total and available soil sulphur with graded sulphur application have been reported by Islam et al. (2016), Mishra et al. (2022). Tuli et al. (2022), Brajendra et al. (2012), Caon et al. (2017) and Rathod et al. (2021).

Overall, elemental sulphur application markedly influenced the distribution of sulphur among the different soil sulphur fractions. DSR generally recorded higher water-soluble, sulphate and inorganic sulphur contents, whereas TPR showed greater accumulation of organic and residual sulphur. Among the elemental sulphur treatments, S40 consistently recorded the highest values for most of the measured sulphur fractions and total sulphur. The results indicate that application of elemental sulphur at 40 kg ha$^{-1}$ was more effective than the other levels in increasing the availability and accumulation of sulphur in the soil under the conditions of the present investigation.

**CONCLUSIONS**

The present investigation showed that sulphur application significantly altered the distribution and dynamics of soil sulphur fractions under different rice establishment methods and varieties. The direct seeding of paddy resulted in higher contents of water-soluble, sulphate and inorganic sulphur fractions, whereas the transplanting of rice favoured accumulation of organic and residual sulphur forms. The organic sulphur was the main contributor to the total soil sulphur content, which implies its importance in maintaining the soil's sulphur-supplying capacity. Of the sulphur levels applied, the treatment of elemental sulphur at the rate of 40 kg S ha$^{-1}$ registered significantly higher values of water-soluble, sulphate, inorganic, organic and total sulphur fractions during the both Kharif and Rabi seasons. An increase in sulphur levels beyond 40 kg ha$^{-1}$ did not yield any significant improvement and in many cases, the sulphur fractions were found to be lower as compared with S40. Thus, it can be concluded that the application of elemental sulphur at the rate of 40 kg ha$^{-1}$ is optimum to improve the sulphur availability and to maintain a balanced distribution of sulphur fractions in the rice production systems studied. The findings stress on the need for appropriate sulphur management to maintain the soil fertility and efficient nutrient cycling in rice-based ecosystems.

**Effect of Crop Establishment Method, Variety and Sulphur Levels on Soil Sulphur Fractions (0-15 cm depth)**

Split-split-plot design: Factor A – crop establishment method (DSR, TPR);
Factor B – variety (Kamala, Samba Mahsuri);
Factor C – sulphur level (S1–S4); r = 3 replications.

**Table 1. Effect of crop establishment method, variety and sulphur levels on Water-soluble sulphur (mg kg$^{-1}$) of soil during Kharif and Rabi seasons**

| Treatment | Kharif | Rabi |
|---|---|---|
| **Crop establishment method (A)** | | |
| DSR | 7.28 | 8.05 |
| TPR | 5.31 | 5.87 |
| SEm± | 0.017 | 0.061 |
| CD (P=0.05) | 0.105 | 0.369 |
| **Variety (B)** | | |
| Kamala | 6.73 | 7.44 |
| Samba Mahsuri | 5.86 | 6.48 |
| SEm± | 0.039 | 0.070 |
| CD (P=0.05) | 0.152 | 0.275 |
| **Sulphur level (C)** | | |
| S1 | 4.25 | 4.68 |
| S2 | 5.16 | 5.81 |
| S3 | 9.12 | 10.16 |
| S4 | 6.65 | 7.19 |
| SEm± | 0.066 | 0.073 |
| CD (P=0.05) | 0.193 | 0.213 |
| **Interaction, CD (P=0.05)** | | |
| A × B | NS | NS |
| A × C | 0.272 | 0.301 |
| B × C | 0.272 | 0.301 |

**Table 2. Effect of crop establishment method, variety and sulphur levels on Sulphate sulphur (mg kg$^{-1}$) of soil during Kharif and Rabi seasons**

| Treatment | Kharif | Rabi |
|---|---|---|
| **Crop establishment method (A)** | | |
| DSR | 16.18 | 16.78 |
| TPR | 13.59 | 14.10 |
| SEm± | 0.078 | 0.043 |
| CD (P=0.05) | 0.475 | 0.261 |
| **Variety (B)** | | |
| Kamala | 15.50 | 16.08 |
| Samba Mahsuri | 14.26 | 14.79 |
| SEm± | 0.142 | 0.042 |
| CD (P=0.05) | 0.557 | 0.165 |
| **Sulphur level (C)** | | |
| S1 | 13.41 | 13.68 |
| S2 | 14.23 | 15.09 |
| S3 | 16.47 | 17.00 |
| S4 | 15.41 | 15.98 |
| SEm± | 0.164 | 0.185 |
| CD (P=0.05) | 0.479 | 0.539 |
| **Interaction, CD (P=0.05)** | | |
| A × B | NS | NS |
| A × C | NS | NS |
| B × C | NS | NS |

**Table 3. Effect of crop establishment method, variety and sulphur levels on Inorganic sulphur (mg kg$^{-1}$) of soil during Kharif and Rabi seasons**

| Treatment | Kharif | Rabi |
|---|---|---|
| **Crop establishment method (A)** | | |
| DSR | 21.25 | 22.81 |
| TPR | 17.00 | 18.25 |
| SEm± | 0.094 | 0.167 |

| | | |
|---|---|---|
| CD (P=0.05) | 0.573 | 1.014 |
| **Variety (B)** | | |
| Kamala | 20.13 | 21.61 |
| Samba Mahsuri | 18.12 | 19.45 |
| SEm± | 0.238 | 0.217 |
| CD (P=0.05) | 0.934 | 0.850 |
| **Sulphur level (C)** | | |
| S1 | 15.43 | 16.00 |
| S2 | 17.95 | 19.48 |
| S3 | 23.07 | 24.94 |
| S4 | 20.06 | 21.68 |
| SEm± | 0.264 | 0.173 |
| CD (P=0.05) | 0.771 | 0.506 |
| **Interaction, CD (P=0.05)** | | |
| A × B | NS | NS |
| A × C | NS | 0.715 |
| B × C | NS | NS |

**Table 4. Effect of crop establishment method, variety and sulphur levels on Organic sulphur (mg $kg^{-1}$) of soil during Kharif and Rabi seasons**

| Treatment | Kharif | Rabi |
|---|---|---|
| **Crop establishment method (A)** | | |
| DSR | 177.27 | 173.03 |
| TPR | 187.70 | 183.21 |
| SEm± | 1.262 | 2.288 |
| CD (P=0.05) | 7.680 | NS |
| **Variety (B)** | | |
| Kamala | 185.96 | 181.51 |
| Samba Mahsuri | 179.01 | 174.73 |
| SEm± | 0.929 | 1.057 |
| CD (P=0.05) | 3.650 | 4.149 |
| **Sulphur level (C)** | | |
| S1 | 137.37 | 135.02 |
| S2 | 167.84 | 163.09 |
| S3 | 229.82 | 224.05 |
| S4 | 194.89 | 190.34 |
| SEm± | 1.884 | 1.890 |
| CD (P=0.05) | 5.499 | 5.516 |
| **Interaction, CD (P=0.05)** | | |
| A × B | NS | NS |
| A × C | NS | NS |
| B × C | NS | NS |

**Table 5. Effect of crop establishment method, variety and sulphur levels on Residual sulphur (mg $kg^{-1}$) of soil during Kharif and Rabi seasons**

| Treatment | Kharif | Rabi |
|---|---|---|
| **Crop establishment method (A)** | | |
| DSR | 46.75 | 45.58 |
| TPR | 51.67 | 50.38 |
| SEm± | 0.273 | 0.220 |
| CD (P=0.05) | 1.659 | 1.339 |
| **Variety (B)** | | |
| Kamala | 46.75 | 45.58 |
| Samba Mahsuri | 51.67 | 50.38 |
| SEm± | 0.086 | 0.336 |
| CD (P=0.05) | 0.337 | 1.319 |
| **Sulphur level (C)** | | |
| S1 | 58.12 | 57.16 |
| S2 | 50.21 | 48.75 |
| S3 | 42.31 | 40.93 |

| | | |
|---|---|---|
| S4 | 46.21 | 45.09 |
| SEm± | 0.513 | 0.542 |
| CD (P=0.05) | 1.496 | 1.582 |
| **Interaction, CD (P=0.05)** | | |
| A × B | NS | NS |
| A × C | NS | NS |
| B × C | NS | NS |

**Table 6. Effect of crop establishment method, variety and sulphur levels on Total sulphur (mg $kg^{-1}$) of soil during Kharif and Rabi seasons**

| **Treatment** | **Kharif** | **Rabi** |
|---|---|---|
| **Crop establishment method (A)** | | |
| DSR | 267.31 | 265.04 |
| TPR | 256.51 | 254.33 |
| SEm± | 2.025 | 0.930 |
| CD (P=0.05) | NS | 5.658 |
| **Variety (B)** | | |
| Kamala | 259.21 | 257.00 |
| Samba Mahsuri | 264.61 | 262.36 |
| SEm± | 2.550 | 3.563 |
| CD (P=0.05) | NS | NS |
| **Sulphur level (C)** | | |
| S1 | 220.62 | 218.97 |
| S2 | 245.93 | 243.59 |
| S3 | 308.57 | 305.84 |
| S4 | 272.52 | 270.33 |
| SEm± | 3.678 | 2.600 |
| CD (P=0.05) | 10.734 | 7.590 |
| **Interaction, CD (P=0.05)** | | |
| A × B | NS | NS |
| A × C | NS | NS |
| B × C | NS | NS |

**Table 7. Interaction effect of crop establishment method × sulphur level on Water-soluble sulphur (mg $kg^{-1}$) of soil**

| **Sulphur level** | **S1** | **S2** | **S3** | **S4** |
|---|---|---|---|---|
| **Kharif** | | | | |
| DSR | 4.91 | 5.96 | 10.54 | 7.68 |
| TPR | 3.58 | 4.36 | 7.70 | 5.61 |
| **Rabi** | | | | |
| DSR | 5.42 | 6.71 | 11.74 | 8.31 |
| TPR | 3.96 | 4.90 | 8.57 | 6.07 |
| CD (P=0.05): Kharif = 0.272; Rabi = 0.301 | | | | |

**Table 8. Interaction effect of variety × sulphur level on Water-soluble sulphur (mg $kg^{-1}$) of soil**

| **Sulphur level** | **S1** | **S2** | **S3** | **S4** |
|---|---|---|---|---|
| **Kharif** | | | | |
| Kamala | 4.54 | 5.52 | 9.76 | 7.11 |
| Samba Mahsuri | 3.96 | 4.80 | 8.48 | 6.18 |
| **Rabi** | | | | |
| Kamala | 5.01 | 6.21 | 10.87 | 7.69 |
| Samba Mahsuri | 4.36 | 5.41 | 9.46 | 6.68 |
| CD (P=0.05): Kharif = 0.272; Rabi = 0.301 | | | | |

**Table 9. Interaction effect of crop establishment method × sulphur level on Sulphate sulphur (mg $kg^{-1}$) of soil**

| **Sulphur level** | **S1** | **S2** | **S3** | **S4** |
|---|---|---|---|---|
| **Kharif** | | | | |
| DSR | 14.58 | 15.46 | 17.91 | 16.75 |
| TPR | 12.24 | 12.99 | 15.04 | 14.07 |

| | | | | |
|---|---|---|---|---|
| **Rabi** | | | | |
| DSR | 14.87 | 16.41 | 18.48 | 17.36 |
| TPR | 12.49 | 13.78 | 15.53 | 14.59 |
| CD (P=0.05): Kharif = NS; Rabi = NS | | | | |

**Table 10. Interaction effect of variety × sulphur level on Sulphate sulphur (mg $kg^{-1}$) of soil**

| **Sulphur level** | **S1** | **S2** | **S3** | **S4** |
|---|---|---|---|---|
| **Kharif** | | | | |
| Kamala | 13.97 | 14.82 | 17.16 | 16.05 |
| Samba Mahsuri | 12.85 | 13.63 | 15.79 | 14.77 |
| **Rabi** | | | | |
| Kamala | 14.25 | 15.72 | 17.71 | 16.64 |
| Samba Mahsuri | 13.11 | 14.46 | 16.30 | 15.31 |
| CD (P=0.05): Kharif = NS; Rabi = NS | | | | |

**Table 11. Interaction effect of crop establishment method × sulphur level on Inorganic sulphur (mg $kg^{-1}$) of soil**

| **Sulphur level** | **S1** | **S2** | **S3** | **S4** |
|---|---|---|---|---|
| **Kharif** | | | | |
| DSR | 17.14 | 19.94 | 25.64 | 22.29 |
| TPR | 13.71 | 15.95 | 20.51 | 17.83 |
| **Rabi** | | | | |
| DSR | 17.77 | 21.65 | 27.71 | 24.09 |
| TPR | 14.22 | 17.32 | 22.17 | 19.27 |
| CD (P=0.05): Kharif = NS; Rabi = 0.715 | | | | |

**Table 12. Interaction effect of variety × sulphur level on Inorganic sulphur (mg $kg^{-1}$) of soil**

| **Sulphur level** | **S1** | **S2** | **S3** | **S4** |
|---|---|---|---|---|
| **Kharif** | | | | |
| Kamala | 16.23 | 18.89 | 24.29 | 21.11 |
| Samba Mahsuri | 14.62 | 17.00 | 21.86 | 19.00 |
| **Rabi** | | | | |
| Kamala | 16.84 | 20.51 | 26.25 | 22.82 |
| Samba Mahsuri | 15.15 | 18.46 | 23.63 | 20.54 |
| CD (P=0.05): Kharif = NS; Rabi = NS | | | | |

**Table 13. Interaction effect of crop establishment method × sulphur level on Organic sulphur (mg $kg^{-1}$) of soil**

| **Sulphur level** | **S1** | **S2** | **S3** | **S4** |
|---|---|---|---|---|
| **Kharif** | | | | |
| DSR | 133.44 | 163.04 | 223.26 | 189.32 |
| TPR | 141.29 | 172.64 | 236.39 | 200.46 |
| **Rabi** | | | | |
| DSR | 131.16 | 158.43 | 217.65 | 184.90 |
| TPR | 138.88 | 167.75 | 230.45 | 195.78 |
| CD (P=0.05): Kharif = NS; Rabi = NS | | | | |

**Table 14. Interaction effect of variety × sulphur level on Organic sulphur (mg $kg^{-1}$) of soil**

| **Sulphur level** | **S1** | **S2** | **S3** | **S4** |
|---|---|---|---|---|
| **Kharif** | | | | |
| Kamala | 139.99 | 171.04 | 234.21 | 198.60 |
| Samba Mahsuri | 134.75 | 164.65 | 225.44 | 191.18 |
| **Rabi** | | | | |
| Kamala | 137.59 | 166.19 | 228.32 | 193.96 |
| Samba Mahsuri | 132.45 | 159.98 | 219.78 | 186.71 |
| CD (P=0.05): Kharif = NS; Rabi = NS | | | | |

**Table 15. Interaction effect of crop establishment method × sulphur level on Residual sulphur (mg $kg^{-1}$) of soil**

| **Sulphur level** | **S1** | **S2** | **S3** | **S4** |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| **Kharif** | | | | |
| DSR | 55.22 | 47.70 | 40.20 | 43.90 |
| TPR | 61.02 | 52.72 | 44.42 | 48.52 |
| **Rabi** | | | | |
| DSR | 54.30 | 46.31 | 38.88 | 42.84 |
| TPR | 60.02 | 51.19 | 42.98 | 47.34 |
| CD (P=0.05): Kharif = NS; Rabi = NS | | | | |

**Table 16. Interaction effect of variety × sulphur level on Residual sulphur (mg $kg^{-1}$) of soil**

| Sulphur level | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| **Kharif** | | | | |
| Kamala | 55.22 | 47.70 | 40.20 | 43.90 |
| Samba Mahsuri | 61.02 | 52.72 | 44.42 | 48.52 |
| **Rabi** | | | | |
| Kamala | 54.30 | 46.31 | 38.88 | 42.84 |
| Samba Mahsuri | 60.02 | 51.19 | 42.98 | 47.34 |
| CD (P=0.05): Kharif = NS; Rabi = NS | | | | |

**Table 17. Interaction effect of crop establishment method × sulphur level on Total sulphur (mg $kg^{-1}$) of soil**

| Sulphur level | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| **Kharif** | | | | |
| DSR | 225.16 | 251.00 | 314.93 | 278.14 |
| TPR | 216.06 | 240.85 | 302.20 | 266.90 |
| **Rabi** | | | | |
| DSR | 223.49 | 248.61 | 312.14 | 275.90 |
| TPR | 214.46 | 238.56 | 299.54 | 264.75 |
| CD (P=0.05): Kharif = NS; Rabi = NS | | | | |

**Table 18. Interaction effect of variety × sulphur level on Total sulphur (mg $kg^{-1}$) of soil**

| Sulphur level | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| **Kharif** | | | | |
| Kamala | 218.34 | 243.39 | 305.38 | 269.71 |
| Samba Mahsuri | 222.89 | 248.46 | 311.75 | 275.33 |
| **Rabi** | | | | |
| Kamala | 216.72 | 241.07 | 302.69 | 267.55 |
| Samba Mahsuri | 221.22 | 246.10 | 309.00 | 273.12 |
| CD (P=0.05): Kharif = NS; Rabi = NS | | | | |

*Significant at P=0.05; **Significant at P=0.01; NS = non-significant

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