



Impact of Sulphur Sources and Organic Manures on Soil Health in Sesame (*Sesamum indicum* L.) Cultivation

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Authors' contributions

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

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ABSTRACT

Sulphur (S) is the fourth major plant nutrient after nitrogen, phosphorus, and potassium and is essential for sustainable crop production. The study aims to evaluate the impact of different sulphur sources and organic manures on soil health in sesame (*Sesamum indicum* L.) Cultivation. The field experiment was conducted at Jobner, Rajasthan, India, during *kharif* 2022. The experiment was

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arranged as a factorial in a randomised complete block design with three replications, comprising a total of twenty treatment combinations. One factor consisted of four sulphur sources (control, gypsum, elemental sulphur, and bentonite) while the other factor comprised five organic manure treatments (control, FYM at 5 t/ha, FYM at 10 t/ha, vermicompost at 2.5 t/ha, and vermicompost at 5 t/ha). Results revealed that gypsum improved available sulphur and calcium content and alkaline phosphatase and arylsulphatase enzyme activity in soil, while higher organic manure rates significantly increased soil organic carbon, macronutrient and micronutrient availability, soil microbial biomass and dehydrogenase, alkaline phosphatase and arylsulphatase enzyme activity. Vermicompost at 5 t/ha and FYM at 10 t/ha were particularly effective in enhancing soil fertility and enzyme activity. The study concluded that integrating inorganic sulphur sources (gypsum) with organic manures (vermicompost/FYM) improves soil health, nutrient availability, and enzyme activity in sesame cultivation, promoting sustainable agriculture practices.

Keywords: Sesame; sulphur sources; organic manure; soil fertility; enzyme activity.

1. INTRODUCTION

Sesame (*Sesamum indicum* L.) is one of the oldest cultivated oilseed crops, widely known by regional names such as sesamum, til, gingelly, simsim, and gergelim. It belongs to the family Pedaliaceae (Yadav *et al.* 2022) and ranks next to groundnut in importance among oilseed crops in India. It is the most ancient and traditional crop domesticated in India more than 5000 years ago (Duhoon *et al.*, 2000; Khan *et al.*, 2021). Sesame is extensively cultivated in tropical and subtropical regions of India due to its adaptability to diverse environmental conditions. Sesame is a hardy crop requiring minimal agronomic inputs, and its extensive root system confers considerable drought tolerance, allowing it to utilise residual soil moisture following the withdrawal of the monsoon. It also exhibits substantial heat tolerance, making it well-suited for semi-arid and arid regions. Sesame seeds are highly valued for their nutritional and medicinal properties, providing quality food and edible oil, and contributing to biomedicine and healthcare. They are rich in oil (48–50%) and protein (18–20%) (Cui *et al.* 2021). Sesame as a valued oil seed appears to have numerous industrial applications (Mondal *et al.*, 2023). Sesame is cultivated on around 12.82 million hectares worldwide with a production of 6.55 million tonnes and a productivity of 545.85 kg/ha. It is grown on 16.27 lakh hectares in the country with a total yield of 7.8 lakh tonnes, with the average productivity of 485 kg/ha (Anonymous, 2021-22a). The total area under the sesame crop in Rajasthan in 2021-22 was 290.16 thousand ha with an average productivity of 265.00 kg/ha and a total production of 77.02 thousand tonnes (Anonymous, 2021-22b).

Sulphur (S) is the fourth major plant nutrient after nitrogen, phosphorus, and potassium and is

essential for sustainable crop production (Patel *et al.* 2019). Among the widely used sulphur sources, gypsum contains approximately 18% sulphur and is abundantly available in Rajasthan. Elemental sulphur (ES), with about 80% sulphur content, is another effective but relatively costlier source, while bentonite sulphur contains approximately 90% sulphur (Parmar *et al.* 2018). In the current agricultural context, many soils are characterised by low fertility and limited organic matter content, typically ranging from 0.34 to 0.56%. The application of organic manures such as farmyard manure (FYM) and vermicompost (VC) can be effective in improving soil fertility by supplying both macronutrients and micronutrients, as well as beneficial organic matter and enzyme activity. Integrating inorganic sulphur fertilisers with organic manures represents a sustainable nutrient management strategy that can reduce cultivation costs while maintaining or enhancing soil health. Therefore, this study was undertaken to evaluate the effects of different sulphur sources and organic manures on soil health, nutrient availability, and enzyme activity in sesame cultivation under the semi-arid conditions of Rajasthan.

2. MATERIALS AND METHODS

The field experiment was conducted during the *kharif* season of 2022 at the Agronomy Farm, Sri Karan Narendra College of Agriculture, Jobner (Rajasthan), India (26°05'N, 75°28'E, 427 m above mean sea level). The region belongs to agro-climatic zone IIIA (Semi-arid Eastern Plain Zone), characterised by hot summers (30–46 °C), cold winters (as low as –3 °C), and average annual rainfall of 400–500 mm, most of which occurs between July and September. The experiment was arranged as a factorial in a randomised complete block design with three replications, comprising a total of twenty

treatment combinations. One factor consisted of four sulphur sources (control, gypsum, elemental sulphur, and bentonite) while the other factor comprised five organic manure treatments (control, FYM at 5 t/ha, FYM at 10 t/ha, vermicompost at 2.5 t/ha, and vermicompost at 5 t/ha). All sulphur sources and organic manures were applied as basal dressings. Gypsum contains 16% sulphur and 29% calcium. Elemental sulphur has 80% sulphur. Bentonite sulphur contains 90% sulphur and 10% bentonite clay. FYM contains 0.5% N, 0.2% P, and 0.5% K, while vermicompost has 1.5% N, 0.8% P, and 1.0% K. Initial soil properties of the experimental field are given in Table 1.

Table 1. Initial soil properties of the experimental field

Physical properties	
Bulk density (Mg/m ³)	1.50
Particle density (Mg/m ³)	2.56
Chemical properties	
pH (1:2 Soil: Water)	8.10
EC (dS/m) (1: 2 Soil: Water)	0.390
Organic carbon (%)	0.185
Available N (kg/ha)	127.80
Available P (kg/ha)	18.90
Available K (kg/ha)	224.32
Available sulphur (mg/kg)	9.861
Available Ca (cmol(p ⁺)/100 g)	3.376
Available Mg (cmol(p ⁺)/100 g)	1.207
Available Fe (ppm)	4.241
Available Zn (ppm)	0.442
Available Mn (ppm)	6.218
Available Cu (ppm)	1.318
Biological properties	
Microbial biomass carbon (µg/g soil)	125.21
Dehydrogenase (µg TPF/g soil/24 h)	17.28
Alkaline phosphatase enzyme (µg pNP produced/ g soil/h)	8.79
Arylsulphatase (µg pNP produced/g soil/h)	18.86

Soil samples were collected randomly from the experimental plot at a depth of 0 to 15 cm before sowing and after harvesting of the crop. These were bulked together to form a composite sample from which a sub-sample was taken to the Soil Science laboratory for analysis for physical, chemical and biological properties of the soil. The observation data were analysed statistically through analysis of variance (ANOVA) with the Factorial concept, and significance was tested at the probability level of 0.05. The standard error of the mean and the Critical Difference value were mentioned in the tables to compare the difference.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

An appraisal of data presented in Table 2 indicates that the application of different sources of sulphur and different organic manures did not bring any significant change in pH, EC, bulk density and particle density of the soil after harvest of sesame. The data indicate that the organic carbon content in soil increased significantly due to the application of organic manure as compared to the control. Among the organic manures, the application of 10 t/ha FYM recorded the highest organic carbon content (0.205%) in the soil after harvest. The application of 10 t/ha FYM increased the organic carbon content in soil by 14.53, 6.77, 10.81 and 6.22 % after harvest over control, 5 t/ha FYM, 2.5 t/ha vermicompost and 5 t/ha vermicompost, respectively. Both FYM and vermicompost contain partially decomposed plant and animal residues. When added to soil, they increase the pool of organic carbon through humification. The increase of soil organic carbon in soil might be due to the mineralisation of applied organic manure. These results are supported by Sheikh and Dwivedi (2017), Singh *et al.* (2024) and Raj *et al.* (2024).

An appraisal of data presented in Tables 3,4 and 5 indicates that the effect of different sources of sulphur on available N, P, K, Mg, Fe, Zn, Mn and Cu content in soil after harvest of sesame was found non-significant. The significantly higher available S and Ca content (11.55 mg/kg and 3.880 cmol(p⁺)/kg) in soil was recorded with the application of gypsum. Due to being readily released into the soil solution and onto cation exchange sites, making S and Ca immediately available for plant uptake and detectable in soil tests. These results are supported by Murmu *et al.* (2015), Jat *et al.* (2017), Singh *et al.* (2024) and Mathew *et al.* (2013).

The data presented in Tables 3,4, and 5 reveal that application of organic manures exerted a significant effect on available N, P, K, S, Ca, Mg, Fe, Zn, Mn and Cu content in soil after harvest of sesame. The significant higher available N, P, K, S, Ca, Mg, Fe, Zn, Mn and Cu content (133.67, 19.82, 229.40 kg/ha, 11.49 mg/kg, 3.775, 1.398 cmol(p⁺)/kg, 4.327, 0.457, 6.438, 1.373 ppm) in soil was recorded with the application of 5 t/ha vermicompost, which was found statistically at par with 10 t/ha FYM after harvest. Organic manures such as farmyard manure (FYM) and vermicompost play a crucial role in improving soil fertility and nutrient availability in sesamum

cultivation. Their application increases the content of available macronutrients and micronutrients by enhancing mineralisation of organic matter and improving soil microbial activity. The slow and sustained release of nutrients from organic sources helps maintain soil fertility over time while reducing nutrient losses. These results are supported by Elayaraja and Sathiyamurthi, (2020), Choudhary *et al.* (2017), Gaddi *et al.* (2020), Singh *et al.* (2024) and Rodrigues *et al.* (2016).

An appraisal of data presented in Table 6 indicates that the application of different sources of sulphur did not bring any significant change in microbial biomass carbon and dehydrogenase enzyme activity in soil after harvest of sesame.

But it bring significant change in alkaline phosphatase and arylsulphatase enzyme activity in soil after harvest of sesame. The maximum alkaline phosphatase and arylsulphatase enzyme activity (11.04 µg pNP produced/ g soil/h, 21.34 µg pNP produced/g soil/h) in soil was observed with the application of gypsum compared to elemental sulphur and bentonite. Due to its supply of calcium and sulphate, which improve soil structure and support beneficial microbial activity. Calcium enhances enzyme stability, while sulphate stimulates sulphur-cycling microbes. Better root growth and microbial activity lead to greater enzyme production. These results are supported by Malik *et al.* (2021), Khalili *et al.* (2024) and Tang *et al.* (2016).

Table 2. Effect of sulphur sources and organic manures on soil pH, EC, OC, bulk density and particle density

Treatment	pH	EC (dS/m)	OC (%)	Bulk density (Mg/M ³)	Particle density (Mg/M ³)
Sulphur source					
Control	8.09	0.390	0.188	1.495	2.557
Gypsum	8.02	0.403	0.194	1.474	2.536
Element sulphur	7.97	0.393	0.192	1.479	2.549
Bentonite	7.94	0.392	0.190	1.476	2.547
SEm±	0.07	0.004	0.002	0.012	0.022
CD (P=0.05)	NS	NS	NS	NS	NS
Organic manures					
Control	8.10	0.389	0.179	1.500	2.555
FYM @ 5 t/ha	8.06	0.390	0.192	1.476	2.547
FYM @ 10 t/ha	7.95	0.399	0.205	1.464	2.541
Vermicompost @ 2.5 t/ha	8.00	0.391	0.185	1.486	2.551
Vermicompost @ 5 t/ha	7.91	0.403	0.193	1.475	2.546
SEm±	0.08	0.004	0.002	0.014	0.025
CD (P=0.05)	NS	NS	0.005	NS	NS

Table 3. Effect of sulphur sources and organic manures on available nitrogen, phosphorus and potassium in soil

Treatment	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Sulphur source			
Control	123.97	18.54	222.31
Gypsum	128.09	19.08	225.27
Element sulphur	127.11	18.94	224.65
Bentonite	126.58	18.80	224.14
SEm±	1.09	0.16	1.23
CD (P=0.05)	NS	NS	NS
Organic manures			
Control	116.57	17.57	216.01
FYM @ 5 t/ha	125.62	18.56	223.26
FYM @ 10 t/ha	130.30	19.54	228.10
Vermicompost @ 2.5 t/ha	126.02	18.70	223.69
Vermicompost @ 5 t/ha	133.67	19.82	229.40
SEm±	1.22	0.18	1.38
CD (P=0.05)	3.49	0.52	3.95

Table 4. Effect of sulphur sources and organic manures on available sulphur, calcium and magnesium in soil

Treatment	Available S (mg/kg)	Available Ca (cmol(p ⁺)/kg)	Available Mg (cmol(p ⁺)/kg)
Sulphur source			
Control	9.52	3.330	1.200
Gypsum	11.55	3.880	1.215
Element sulphur	11.02	3.410	1.205
Bentonite	10.97	3.380	1.210
SEm±	0.09	0.031	0.011
CD (P=0.05)	0.27	0.087	NS
Organic manures			
Control	9.39	3.175	0.998
FYM @ 5 t/ha	10.74	3.425	1.148
FYM @ 10 t/ha	11.39	3.675	1.298
Vermicompost @ 2.5 t/ha	10.79	3.475	1.198
Vermicompost @ 5 t/ha	11.49	3.775	1.398
SEm±	0.10	0.034	0.012
CD (P=0.05)	0.30	0.098	0.034

Table 5. Effect of sulphur sources and organic manures on available Fe, Zn, Mn and Cu in soil

Treatment	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
Sulphur source				
Control	4.171	0.432	6.220	1.310
Gypsum	4.251	0.437	6.246	1.339
Element sulphur	4.231	0.436	6.234	1.329
Bentonite	4.217	0.435	6.229	1.324
SEm±	0.036	0.004	0.053	0.013
CD (P=0.05)	NS	NS	NS	NS
Organic manures				
Control	4.043	0.409	5.975	1.272
FYM @ 5 t/ha	4.203	0.429	6.175	1.314
FYM @ 10 t/ha	4.323	0.447	6.375	1.356
Vermicompost @ 2.5 t/ha	4.218	0.434	6.198	1.314
Vermicompost @ 5 t/ha	4.327	0.457	6.438	1.373
SEm±	0.040	0.004	0.060	0.014
CD (P=0.05)	0.115	0.012	0.170	0.040

It is evident from the data presented in Table 6 that the microbial biomass carbon and dehydrogenase, alkaline phosphatase and arylsulphatase enzyme activity in soil were noted to be significantly enhanced due to the application of different organic manures as compared to the control after harvest of sesame. The maximum microbial biomass carbon and dehydrogenase, alkaline phosphatase and arylsulphatase enzyme activity (132.75 µg/g soil, 18.71 µg TPF/g soil/24h, 11.30 µg pNP produced/g soil/h, 21.68 µg pNP produced/g soil/h, respectively) in soil was recorded with the application of 10 t/ha FYM at

harvest. The increase in the soil phosphatase activity with the addition of organics could have been due to the soil substrate enrichment caused by the addition of mineral fertilisers. The phosphates added through organics and fertiliser improved the phosphatase activity, which may be ascribed to the stabilised extra cellular fraction of the enzyme. The increased dehydrogenase activity might be due to the incorporation of organics, owing to an increase in microbial activity of the soil. Similar results were reported by Malik *et al.* (2020), Dotaniya *et al.* (2025), Parham *et al.* (2002) and Borase *et al.* (2020).

Table 6. Effect of sulphur sources and organic manures on soil microbial biomass carbon and enzymatic activity of dehydrogenase, alkaline phosphatase and arylsulfatase in soil

Treatment	Microbial biomass carbon ($\mu\text{g/g soil}$)	Dehydrogenase ($\mu\text{g TPF/g soil/24h}$)	Alkaline phosphatase ($\mu\text{g pNP produced/g soil/h}$)	Arylsulphatase ($\mu\text{g pNP produced/g soil/h}$)
Sulphur source				
Control	125.40	17.16	8.74	18.81
Gypsum	127.03	17.66	11.04	21.34
Element sulphur	126.62	17.41	10.39	20.81
Bentonite	126.07	17.26	10.34	20.71
SEm \pm	1.08	0.15	0.09	0.18
CD (P=0.05)	NS	NS	0.27	0.51
Organic manures				
Control	120.25	16.21	8.85	18.89
FYM @ 5 t/ha	127.29	17.51	10.40	20.80
FYM @ 10 t/ha	132.75	18.71	11.30	21.68
Vermicompost @ 2.5 t/ha	123.75	16.84	9.63	19.88
Vermicompost @ 5 t/ha	127.35	17.56	10.45	20.83
SEm \pm	1.20	0.17	0.10	0.20
CD (P=0.05)	3.45	0.48	0.30	0.57

4. CONCLUSION

Integrating sulphur sources and organic manures significantly improved soil health in sesame cultivation. Gypsum effectively increased available sulphur and calcium, and alkaline phosphatase and arylsulphatase enzyme activity, while higher rates of FYM and vermicompost enhanced organic carbon, macronutrient and micronutrient availability, and soil enzyme activity. This integrated nutrient management approach offers a sustainable strategy for improving soil fertility and soil enzyme activity under semi-arid conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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