



Influence of Sulphur Sources on Productivity, Profitability, Quality and use Efficiency of Soybean [*Glycine max* (L.) Merrill]

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10.18805/LR-5533

ABSTRACT

Background: Soybean is a miracle crop of the 21st century well known for its nutritional quality and oil content. Sulphur is an indispensable secondary macronutrient for plant growth. Sulphur deficiencies are widespread in Indian soils and it has been emerging as major limiting element for the productivity of pulses and oilseed crop. The Application of different elemental sulphur forms requires a longer time for oxidation, release and uptake by plants. Hence present investigation was carried out to study the effect of different sources of sulphur on soybean crop.

Methods: A field experiment was conducted at Agroforestry Unit, Zonal Agricultural Research Station, UAS, GKVK, Bengaluru during *kharif*-2022 and 2023, using randomized complete block design to assess the effect of eight treatments with different sources of sulphur. Growth, yield, quality parameters, nutrient use efficiency and economics were recorded with standard statistical procedures.

Result: Application of sulphur 90% dispersible granules @ 25 kg/ha along with recommended dose of fertilizer accounted for 14.9 and 15.16 per cent higher seed and haulm yield respectively, compared to application of zinc sulphate @ 12.5 kg/ha with RDF. This led to significantly higher productivity, profitability, quality and nutrient use efficiency of soybean crop.

Key words: Bentonite sulphur, Dispersible granular sulphur, Methionine, Nutrient use efficiency, Oil content, Soybean.

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) popularly known as “Wonder crop”, “Golden bean” and “Miracle crop” of the 21st century, is rich in protein (40-42%) and oil content (18-20%) (Patel *et al.*, 2019). In India, soybean has rapidly risen to prominence as the primary oilseed crop from a modest initial cultivation area of 0.03 m ha in 1970, its growth has been swift by 2024, soybean cultivation has expanded to cover 13.25 m ha, yielding a robust production of 13.06 m tonnes with an average yield of 985 kg ha⁻¹. Zooming on the state of Karnataka, soybean farming extends 0.38 m ha, with a production tally of 0.413 m tonnes. The average yield is slightly better than the national average, standing at 1062 kg ha⁻¹ (Anonymous, 2024).

Among various plant nutrients, Sulphur has emerged as an indispensable secondary macronutrient in plant growth, standing alongside of nitrogen, phosphorus and potassium as a primary nutrient. It is a constituent of proteinaceous amino acids, *i.e.* cystine, cysteine and methionine. Sulphur is involved in the formation of S-glycosides, coenzyme A, vitamins like biotin and thiamine and iron-sulphur proteins termed ferredoxins. Additionally, sulphur is vital for protection against oxidative damage protein synthesis, chlorophyll formation and facilitating oil synthesis (Chahal *et al.*, 2020).

The advantages of sulphur fertilization are most pronounced for oilseeds, followed by pulses and least for cereals (Zenda *et al.*, 2021). However, in India, sulphur deficiencies are notably extensive and dispersed. During the early 1990s, nearly 130 Indian districts reported sulphur deficiencies in soils, but recent data indicates a surge,

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How to cite this article: Veda, T.V., Mudalagiriappa, Vasanthi, B.G., Sneha, M.A., Hardev, R. and Rajkumari, P. (2026). Influence of Sulphur Sources on Productivity, Profitability, Quality and use Efficiency of Soybean [*Glycine max* (L.) Merrill]. *Legume Research*. **49(10)**: 1763-1770. doi: 10.18805/LR-5533.

Submitted: 19-06-2025 **Accepted:** 08-12-2025 **Online:** 29-12-2025

with around 45% of the country's districts exhibiting significant sulphur shortages (Meena *et al.*, 2019). Conventionally, sulphur is applied as a form of elemental sulphur, ammonium sulphate, ammonium thiosulphate, ammonium bisulphate, sulphides or calcium sulphate (gypsum). The main drawback of elemental sulphur products is that their oxidation to plant available sulphate is slow often taking more time from the application. Therefore, the application of granular elemental sulphur containing fertilizers quickly disperses into finely divided particles and increases surface area for microbial oxidation process compared to conventional sulphur fertilizers (Lisowska *et al.*, 2022). In these circumstances application of sulphur from suitable sources is one of the key measures to optimize sulphur use for sustainable crop productivity.

There are few studies regarding the use of improved sulphur fertilizers for enhancing the productivity and quality of crop species. Some field experiments have been carried out using commercial-grade fertilizers like elemental S, bentonite S, gypsum, phospho-gypsum and pyrites. In this regard present study was aimed to evaluate granular sulphur efficacy in soybean.

MATERIALS AND METHODS

This field experiment was conducted for two years 2022 and 2023 during *kharif* season at Agroforestry Unit, Zonal Agricultural Research Station, University of Agricultural Sciences, GKVK Campus, Bengaluru located in the northern part of Bengaluru between Latitude/longitude of 13°05'21"N /77°34'02"E and at an altitude of 989 m above mean sea level which comes under Eastern Dry Zone (ACZ-V) of Karnataka. During the years in 2022 and 2023, received 864.2 and 941.4 mm rainfall in 75 and 52 rainy days, respectively and 27.3 and 27.5°C mean maximum temperature, 18.1 and 19.7°C mean minimum temperature, 86.7 and 81.75 % mean relative humidity and 6 and 7.9 hr day⁻¹ bright sunshine hours, respectively. The details of meteorological data of an experiment area are presented in Fig 1. The soil of the experimental site was red sandy clay loam having initial slightly acidic pH 6.2, EC 0.19 dS/m, organic carbon 0.49 %, low in available nitrogen, medium in available phosphorus, potassium and sulphur (258.26, 34.58, 230.52 and 20.15 kg/ha, respectively). The eight treatments were laid down in randomized block design with three replications. The treatment details are T₁: RDF + Sulphur 90% Dispersible Granules @ 12.5 kg ha⁻¹, T₂: RDF + Sulphur 90% Dispersible Granules @ 18.5 kg ha⁻¹, T₃: RDF + Sulphur 90% Dispersible Granules @ 25 kg ha⁻¹, T₄: RDF + Sulphur 90% Powder @ 18.75 kg ha⁻¹, T₅: RDF + Sulphur 90% Granular Bentonite Pastille @ 20 kg ha⁻¹, T₆: RDF + Sulphur 90% Granular Bentonite Pastille @ 30 kg ha⁻¹, T₇: University recommendation (RDF+ zinc sulphate @12.5 kg/ha) and T₈: Absolute control. During the experiment farm yard manure (FYM) @ 7.5 t ha⁻¹ was applied

two weeks prior to sowing, recommended dose of fertilizers (25:62.5:25 kg N: P₂O₅: K₂O/ha) and different sulphur products as per treatments were applied at the time of sowing. The soybean crop (Var. JS-335) was sown during the second week of July with spacing of 30 cm × 10 cm. The experimental data on growth attributes (plant height, leaf area, dry matter accumulation and nodules per plant), yield and yield attributing (number of pods per plant, test weight, seed yield per plant, seed and haulm yield) were recorded from five randomly selected and labelled plants at harvest stage of the crop. Protein content in seed was calculated by multiplying nitrogen percentage with factor 6.25 (Simson *et al.*, 1965), fifteen grams of dried seeds of soybean drawn from the net plot of each treatment were used for estimation of oil content by nuclear magnetic resonance (NMR) method. Sulphur containing amino acids like methionine and cysteine content were estimated by Ultra-High Performance Liquid Chromatography-Mass Spectrometry (UPLC-MS/MS) system. Nutrient use efficiency of nitrogen, phosphorus, potassium and sulphur were quantified using different indices like agronomic efficiency (AE) and partial factor productivity (PFP).

$$AE \text{ (kg kg}^{-1}\text{)} = \frac{\text{Grain yield of fertilized plot (kg)} - \text{Grain yield of control plot (kg)}}{\text{Quantity of nutrient applied (kg)}}$$

$$PFP \text{ (kg kg}^{-1}\text{)} = \frac{\text{Grain yield of fertilized plot (kg)}}{\text{Quantity of nutrient applied (kg)}}$$

The data were subjected to Fisher's method of "Analysis of Variance" (ANOVA) as outlined by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

Growth attributes of soybean

Application of granular sulphur sources significantly maximize the growth attribute (plant height, leaf area, dry matter accumulation and nodules per plant) in soybean compared to control (Table 1). Significantly highest plant

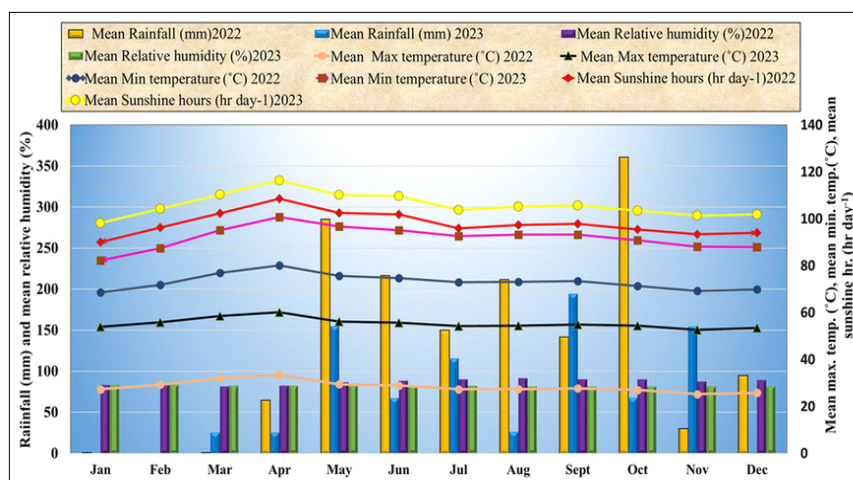


Fig 1: Mean monthly meteorological data of experiment site during 2022 and 2023.

Table 1: Influence of different sulphur sources on growth parameters of soybean (Pooled data of 2 years).

Treatments	Plant height (cm)				Leaf area (cm ²)				Dry matter accumulation (g plant ⁻¹)				Nodules plant ⁻¹		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	30 DAS	60 DAS
T ₁ : RDF + Sulphur 90% Dispersible Granules @ 12.5 kg ha ⁻¹	21.90	58.35	61.44	347.62	1484.04	3.88	23.33	43.12	12.90	22.92					
T ₂ : RDF + Sulphur 90% Dispersible Granules @ 18.5 kg ha ⁻¹	24.64	61.75	64.46	425.19	1728.86	4.36	25.25	46.36	14.39	26.34					
T ₃ : RDF + Sulphur 90% Dispersible Granules @ 25 kg ha ⁻¹	25.68	63.95	67.98	456.60	1793.86	4.49	27.57	48.05	14.61	27.73					
T ₄ : RDF + Sulphur 90% Powder @ 18.75 kg ha ⁻¹	22.88	58.47	61.32	354.09	1482.95	4.02	24.37	42.48	12.93	22.89					
T ₅ : RDF + Sulphur 90% Granular Bentonite Pastille @ 20 kg ha ⁻¹	23.20	58.59	60.93	363.94	1636.68	4.15	24.47	43.06	12.80	22.45					
T ₆ : RDF + Sulphur 90% Granular Bentonite Pastille @ 30 kg ha ⁻¹	24.34	59.58	64.76	429.83	1719.35	4.24	25.79	45.61	14.21	25.88					
T ₇ : University recommendation (RDF+ zinc sulphate @ 12.5 kg/ha)	21.81	57.82	61.26	332.73	1417.74	3.52	23.30	42.94	12.48	22.08					
T ₈ : Absolute Control	20.32	54.02	56.52	285.37	1384.41	3.42	21.84	37.52	11.79	21.46					
S.E.m. ±	0.85	1.53	1.79	10.57	50.73	0.22	1.10	1.58	0.62	0.67					
CD at 5 %	2.58	4.65	5.44	32.07	153.89	0.68	3.05	4.80	NS	2.03					

height of 25.68, 63.95 and 67.98 cm was recorded at 30, 60 DAS and at harvest, respectively with treatment receiving RDF + Sulphur 90% dispersible granules at 25 kg ha⁻¹ (T₃). However, it was found at par with treatments T₂ and T₆. There was increase in plant height of 26.3, 18.38 and 20.26 per cent over control at 30, 60 DAS and at harvest, respectively. The increase in plant height was attributed to the higher availability of sulphur in the soil that led to improved metabolic activity and biosynthesis of proteins which appears to have encouraged meristematic activity (Das *et al.*, 2022). Similarly, significantly higher leaf area of 456.60 and 1793.86 cm² plant⁻¹ was recorded in T₃ over control, which was at par with T₂ and T₆. The significant increase in leaf area was attributed to a higher number of trifoliate leaves per plant. Improved nutrient availability and sulphur absorption enhanced chlorophyll synthesis, as sulphur is a component of the succinyl Co-A enzyme

involved in this process. This activation at the cellular level promoted greater photosynthate production and meristematic activity. These findings are supported by Mir *et al.* (2013) and Bangar *et al.* (2014). Dry matter accumulation was significantly influenced by application of granular sulphur at all stages in soybean over control. Combination of RDF along with sulphur dispersible granules at 25 kg/ha recorded 4.49, 27.57 and 48.05 g/plant, respectively at 30, 60 DAS and at harvest. Application of RDF along with sulphur might have played a crucial role in chlorophyll synthesis and photosynthetic efficiency, thereby increasing the plant's ability to produce carbohydrates and accumulate dry matter. It also activates several enzymes involved in metabolic and growth processes, particularly in meristematic tissues where active cell division and expansion occurs. This observation aligns with findings of Devi *et al.* (2012). Similar trend was observed in case of number of nodules per plant. At 30 and

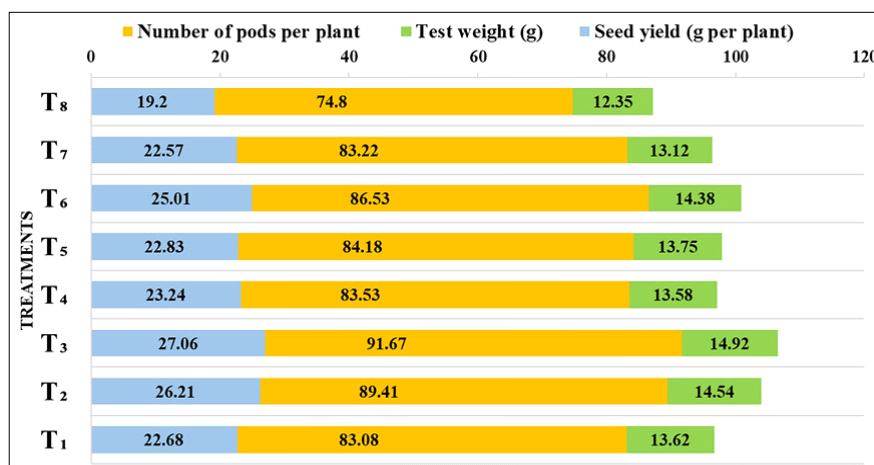


Fig 2: Yield parameters of soybean as influenced by different sources of sulphur application (Pooled data of 2 years).

Table 2: Productivity and economics of soybean as influenced by different sources of sulphur application (Pooled data of 2 years).

Treatments	Seed yield (kg ha ⁻¹)	Haulm yield (kg ha ⁻¹)	COC (₹ ha ⁻¹)	Gross returns (₹ ha ⁻¹)	Net returns (₹ ha ⁻¹)	B:C ratio
T ₁ : RDF + Sulphur 90% dispersible Granules @ 12.5 kg ha ⁻¹	2782	2934	40772	108631	67860	2.66
T ₂ : RDF + Sulphur 90% dispersible Granules @ 18.5 kg ha ⁻¹	3208	3351	41282	125255	83974	3.03
T ₃ : RDF + Sulphur 90% dispersible Granules @ 25 kg ha ⁻¹	3273	3448	41834	127803	85969	3.05
T ₄ : RDF + Sulphur 90% powder @ 18.75 kg ha ⁻¹	2944	3060	41374	114939	73565	2.78
T ₅ : RDF + Sulphur 90% Granular bentonite pastille @ 20 kg ha ⁻¹	2866	3049	41709	111938	70229	2.68
T ₆ : RDF + Sulphur 90% Granular bentonite pastille @ 30 kg ha ⁻¹	2980	3212	42709	116393	73684	2.73
T ₇ : University recommendation (RDF+ zinc sulphate @12.5 kg/ha)	2848	2994	40772	111218	70447	2.73
T ₈ : Absolute control	2219	2633	39709	86955	47246	2.19
S.Em. ±	97	79	-	-	-	-
CD at 5 %	293	241	-	-	-	-

60 DAS, T_3 has recorded higher number of root nodules plant⁻¹ of 14.61 and 27.73, respectively followed by T_2 over control. 23.9 and 29 per cent increase in root nodules were observed over control. Sulphur has several oxidising functions in plant nutrition and a constituent of Fe-S protein called ferredoxin, which plays a pivotal role in increasing root nodulation and atmospheric nitrogen fixation. The observed increases could be due to enhanced root growth facilitated by greater sulphur availability, which is consistent with the findings of Yadav *et al.* (2013).

Yield attributes and yield of soybean

Application of sulphur 90% at 25 kg ha⁻¹ through dispersible granules along with RDF in soybean crop recorded a significantly higher number of pods plant⁻¹ (91.67), test weight (14.92 g), seed yield/plant (27.06 g plant⁻¹), seed yield (3273 kg ha⁻¹) and haulm yield (3448 kg ha⁻¹) which was found at

par with T_2 and T_6 (Fig 2 and Table 2) compared to control (74.80, 12.35 g and 19.20 g plant⁻¹, 2219 kg ha⁻¹ and 2633 kg ha⁻¹, respectively). Sulphur played a crucial role in upsurge of growth characteristics, which in turn boosted chlorophyll content and the rate of photosynthesis. Consequently, the number of pods plant⁻¹ and test weight increased, contributing to a higher seed yield plant⁻¹ (Verma *et al.*, 2013 and Yadav *et al.*, 2013). Sulphur application increased the seed yield of soybean by 47.46 per cent over absolute control showing the indispensability of sulphur nutrition in oilseed crops. Sulphur fertilization played a pivotal role in enhancing yield by promoting vegetative growth for better photosynthesis, fortifying reproductive structures and producing assimilates for valuable sinks leading to a boost in seed yield. The results are in close conformity with the findings of Dheri *et al.* (2021) and Movalia and Savalia (2021). Better growth in terms of plant height, leaf area, dry matter accumulation, higher nutrient

Table 3: Quality parameters of soybean as influenced by different sources of sulphur application (Pooled of 2 years).

Treatments	Protein content (%)	Oil content (%)	Methionine (mg per g seed)	Cysteine (mg per g seed)
T_1 : RDF + Sulphur 90% Dispersible granules @ 12.5 kg ha ⁻¹	36.28	20.25	8.48	0.12
T_2 : RDF + Sulphur 90% Dispersible granules @ 18.5 kg ha ⁻¹	37.38	21.54	12.88	0.13
T_3 : RDF + Sulphur 90% Dispersible granules @ 25 kg ha ⁻¹	37.91	21.95	13.02	0.13
T_4 : RDF + Sulphur 90% powder @ 18.75 kg ha ⁻¹	36.84	20.33	10.02	0.11
T_5 : RDF + Sulphur 90% granular bentonite pastille @ 20 kg ha ⁻¹	36.79	20.05	9.45	0.11
T_6 : RDF + Sulphur 90% granular bentonite pastille @ 30 kg ha ⁻¹	37.27	21.18	12.77	0.12
T_7 : University recommendation (RDF+ zinc sulphate @12.5 kg/ha)	36.14	20.17	12.19	0.11
T_8 : Absolute control	35.69	19.45	6.14	0.08
S.Em. $\pm$	1.2	0.67	0.35	0.00
CD at 5 %	NS	NS	1.03	0.01

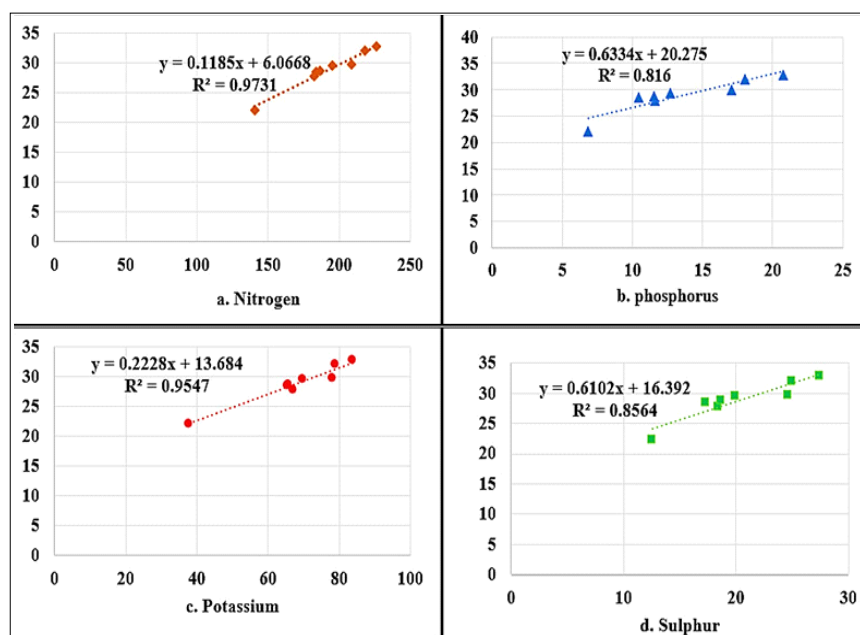


Fig 3: Simple linear regression between yield and nutrient uptake.

availability and uptake by soybean crop resulted in significantly higher haulm yield. These results were accordance with the findings of Patel *et al.* (2022) and Manoj *et al.* (2022).

Profitability of soybean

A perusal of data presented in Table 2 showed that RDF with sulphur 90% granular bentonite pastille at 30 kg ha⁻¹ application recorded a higher cost of cultivation (₹ 42709 ha⁻¹) due to higher cost of bentonite pastille. Lower cost of cultivation was observed in absolute control (₹ 39709 ha⁻¹) due to absence of cost on fertilizers. Gross returns, net returns and benefit-cost ratio were observed highest with the application of RDF + Sulphur 90% dispersible granules at 25 kg ha⁻¹ application (₹127803 ha⁻¹, ₹ 85969 ha⁻¹ and 3.05, respectively) followed by T₂. The higher returns were recorded due to higher returns obtained with higher seed yield. These results are in conformity with Prusty *et al.* (2020) in soybean and higher B:C ratio due to higher profit obtained per rupee invested (Agarwal and Singh, 2014) and Patel *et al.* (2022).

Quality parameters of soybean

A reference to data presented in Table 3, there was no significant difference in protein and oil content with application of granular sulphur. However, numerically higher protein (37.91%) and oil (21.95%) content was recorded in T₃ treatment, significantly higher methionine (13.02 mg per g seed) and cysteine content (0.13 mg per g seed) content was obtained under same treatment which was at par with T₂ and T₆ treatment. The higher protein content was due to sulphur application which plays a role in enhancing nitrogen assimilation where, nitrogen is a primary component of amino acid, protein and enzyme constituents which leads to higher protein content in seed. Similar results were reported by Nevase *et al.* (2016) and Mamatha *et al.* (2018). Significantly higher oil content might be due to direct involvement of sulphur in sulphhydryl (-SH) linkages in the lipid biosynthesis and these linkages are constituents of essential amino acids such as methionine and cysteine (Kumar *et al.*, 2017 and Manoj *et al.*, 2023).

Agronomic efficiency and partial factor productivity

Indices of nutrient use efficiency in terms of agronomic efficiency and partial factor productivity are presented in Table 4. Significantly higher AE_N (42.14 kg kg⁻¹), AE_P (16.86 kg kg⁻¹) and AE_K (42.14 kg kg⁻¹) was recorded with application of dispersible granules at 25 kg ha⁻¹ along with RDF, followed by T₂ (39.56, 15.82 and 39.56 kg kg⁻¹, respectively) and T₆ (30.42, 12.17 and 30.42, respectively). Significantly higher AE_S (58.68 kg kg⁻¹) was observed in T₂. Partial factor productivity of nitrogen (130.9 kg kg⁻¹), phosphorus (64.5 kg kg⁻¹) and potassium (130.9 kg kg⁻¹) was significantly maximum with T₃ treatment followed by T₂ (128.3, 64.5, 128.3 kg kg⁻¹, respectively) and T₆ (119.2, 59.5 and 119.2 kg kg⁻¹, respectively). T₁ treatment recorded significantly higher partial factor productivity of sulphur (244.88 kg kg⁻¹) followed by T₆ treatment (225.61 kg kg⁻¹). Significantly higher efficiency might be due to ability of plants to produce higher yield per unit nutrient applied. These results were in

Table 4: Nutrient use efficiency (kg kg⁻¹) in soybean as influenced by different sources of sulphur application (Pooled of 2 years).

Treatments	Agronomic efficiency (AE)			Partial factor productivity (PFP)		
	N	P	K	N	P	K
T ₁ : RDF + Sulphur 90% Dispersible granules @ 12.5 kg ha ⁻¹	22.50	9.00	22.50	111.3	44.5	111.3
T ₂ : RDF + Sulphur 90% Dispersible granules @ 18.5 kg ha ⁻¹	39.56	15.82	39.56	128.3	64.5	128.3
T ₃ : RDF + Sulphur 90% Dispersible granules @ 25 kg ha ⁻¹	42.14	16.86	42.14	130.9	64.5	130.9
T ₄ : RDF + Sulphur 90% Powder @ 18.75 kg ha ⁻¹	29.01	11.60	29.01	117.8	58.6	117.8
T ₅ : RDF + Sulphur 90% granular bentonite pastille @ 20 kg ha ⁻¹	25.86	10.34	25.86	114.6	57.2	114.6
T ₆ : RDF + Sulphur 90% granular bentonite pastille @ 30 kg ha ⁻¹	30.42	12.17	30.42	119.2	59.5	119.2
T ₇ : University recommendation (RDF+ zinc sulphate @ 12.5 kg/ha)	25.16	10.06	25.16	113.9	57.4	113.9
T ₈ : Absolute control	-	-	-	-	-	-
S.E.m. ±	4.02	1.61	4.02	4.02	5.28	4.02
CD at 5 %	12.38	4.95	12.38	12.38	16.26	12.38

conformity with the findings of Perveen *et al.* (2021) and Islam *et al.* (2012).

Simple linear regression

Correlation reveals the relationship between different variables, however with diverse variables it does not show how strong the relationship exists. Henceforth, for quantifying the degree of influence of diverse variables over dependent factor, such as seed yield, linear regression among an illustrative variable and a described variable is used (Sanam *et al.*, 2021). Between the total NPK and S uptake and yield, linear regression is revealed in Fig 3. It unveils the greatest impact of nutrient uptake and seed yield of soybean under different sulphur sources. The uptake of total nitrogen documented 97% of the seed yield. Likewise, total phosphorus, potassium and sulphur of 81%, 95% and 85%, respectively.

CONCLUSION

The effect of granular sulphur sources along with RDF has proven to be a promising approach for enhancing soybean growth, yield, quality and economic viability. Application of granular elemental sulphur particles *viz.*, dispersible granules which contains higher nutrient content and disperse quickly into finely divided particles which results in higher sulphur content in soil and improves the overall performance of soybean crop. Further, it can be concluded that the application of sulphur 90% dispersible granules at 25 kg ha⁻¹ along with RDF could be recommended for better yield and net returns to the farming community which recorded the highest benefit-cost ratio.

ACKNOWLEDGEMENT

Authors are grateful to University of Agricultural Sciences, Bangalore (Karnataka) and AICRP for Dryland Agriculture, UAS, GKVK, Bengaluru for providing facilities in smooth conduct of the experiment.

Disclaimers

The authors have made every effort to ensure the accuracy and integrity of the data and information presented in this research paper. However, they do not accept any liability for any direct, indirect, or consequential loss or damage arising from the use of the information contained herein.

Conflict of interest

The authors state that there is no conflict of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish or preparation of the manuscript.

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