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EFFECT OF SULPHUR APPLICATION ON YIELD, YIELD ATTRIBUTES, NUTRIENT UPTAKE AND QUALITY OF CHICKPEA (*CICER ARIENTINUM* L.)

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ABSTRACT

Chickpea is a sulphur-sensitive crop with lower targeted fertilization regimens in India. Continuous use of sulphur-free fertilizers, growing of high-yielding varieties and reduced tillage intensity along with multiple cropping causes worldwide sulphur deficiency in soil and decreases the yield, plant nutrient content and uptake along with quality of produce. To examine this, a field experiment was conducted to evaluate the effect of sulphur application on chickpea during the *rabi* season 2018–19 in black cotton soil. The research trial comprised nine treatments including absolute control, soil application of S (sulphur) @ 10, 20, 30 kg ha^{-1} through Bentonite sulphur and Gypsum, in addition to RDF at the time of sowing. Findings indicate that based on an analysis of all growth yield and quality parameters, Bentonite sulphur was found to be superior to Gypsum. Results revealed that application of S @ 30 kg ha^{-1} through Bentonite sulphur along with RDF resulted in the highest seed yield (25.58 q ha^{-1}) and straw yield (31.98 q ha^{-1}) followed by S @ 30 kg ha^{-1} through Gypsum + RDF. Similarly, the highest number of pods per plant (42.60), test weight (25.67 g), protein content (21.09 %) and total chlorophyll (1.012 mg g^{-1}) was also noticed with the application of Bentonite sulphur @ 30 kg ha^{-1}. Furthermore, application of Bentonite sulphur and Gypsum resulted in higher content and uptake of N, P, K, sulphur, and micronutrients. Hence, application of S @ 30 kg ha^{-1} through Bentonite sulphur combined with RDF (25:50:30 kg ha^{-1} of N, P_2O_5, K_2O) at the time of sowing resulted in increased production, nutrient uptake, protein and chlorophyll content of chickpea in sulphur deficient soil of semi-arid zone of Maharashtra.

Key words : Sulphur, Bentonite sulphur, Gypsum, Productivity, Nutrient uptake, Protein content, Chlorophyll content.

Introduction

India is leading across the world in the production of pulses. The total area under pulse in India increased from 19 million hectares in 1950–51 to 28.8 million hectares in 2021–22. In India, the cultivated area for chickpeas was 10.0 million hectares, generating 11.9 million tonnes of production with an average productivity of 1192 kg ha^{-1} in 2020–21 (Anonymous, 2022). Following Madhya Pradesh, Maharashtra is the second-largest chickpea-producing state. The area under Chickpea cultivation in Maharashtra was 2.23 million hectares yielding production of 2.40 million tones with an average productivity of 1074 kg ha^{-1} (Anonymous, 2022). Thus, Maharashtra contributes 22.32% of the country's acreage and 20.12% of India's chickpea production. Global crop productivity needs to double by 2050 (Ray *et al*., 2013) to meet the growing population's increasing demand for food and energy (Vollset *et al*., 2020). Udayana *et al*. (2021) pointed out that managing water and nutrients is essential to achieving expected production demands. Now Sulphur must be considered along with nitrogen, phosphorus and potassium for managing nutrient strategies due to the decline in sulphur accumulation over the past 20 years.

Sulphur is the 4^{th} major essential plant nutrient after N, P and K because of its role in the synthesis of proteins, formation of chlorophyll, vitamins, flavoured compounds and activation of enzymes in plants. Generally, plant sulphur requirement is equal to phosphorus and also 9-15% amount of nitrogen (Udayana *et al*., 2021), however leguminous and cruciferous crops require sulphur more than phosphorus (Verma *et al*., 2020). An essential component of amino acids, protein, methionine (21% S), cysteine (27% S) and cysteine (Tandon *et al*., 1984; Jamal *et al*., 2005 and 2006), sulphur plays a crucial role in the metabolic activities of the entire plant (Droux, 2004). Being a growth-limiting element, sulphur also affects the uptake of nutrients like N, P, K, molybdenum, zinc, iron, selenium and boron (Abdin *et al*., 2003; Bona and Monterio; El-Eyuoon and Amin, 2018). Sulphur helps towards conversion of nitrogen into protein and influences the protein content in pulse crops. Sulphur also improves the S-containing amino acid and ultimately enhances the protein content (Das *et al*., 1975).

Chickpea is sensitive to sulphur deficiency. The deficiency of sulphur is emerging fast in areas where continuously sulphur-free fertilizers like DAP, urea etc are being used. Use of high analysis S-free fertilizers, less use of organic manures, decreased use of S-containing fungicides and insecticides (Scherer, 2001; Eriksen, 2004), heavy sulphur removal due to intensification of agriculture by growing of high-yielding varieties of oilseed crops, and in some cases reduced tillage intensity (Sutradhar *et al*., 2017) along with multiple cropping contributed to widespread sulphur deficiencies in Indian soils. Worldwide Sulphur deficiencies have been reported in 72 countries (Morris, 1988). In Indian soils, sulphur deficiency has been noticed at 32.9% (Shukla *et al*., 2016), while in Maharashtra sulphur deficiency was recorded to the extent of 37.48%, while in Vidarbha it was noticed at 25.76% (Katkar *et al*., 2017). Sulphur deficiency decreases the concentration of nitrogen in the shoots and seeds of many legumes (Claro-Cortes *et al*., 2002), which reduces nutrient uptake and ultimately declines the yield and quality of crop produce (Mahi *et al*., 2007; Schonhof *et al*., 2007; *et al*., 2010). Several researchers reported the impact of sulphur deficiency on yield reduction. Saalbach (1973) reported 10-30% yield reduction whereas Zhao *et al*. (2000) reported 50% yield loss in cereals and Singh et al. 2014 mentioned 35% yield loss in corn crop respectively. Singh *et al*. (1995) observed 15-29% yield losses in groundnut due to sulphur deficiency in medium black calcareous soil. Chandra and Pandey (2016) also noticed 60, 50, 36 and 59% reductions in cysteine level, storage protein, pod count and seed weight per plant under sulphur-deficient conditions. Thus, it is crucial to assess the impact of sulphur application on chickpea yield, quality and nutrient uptake in black cotton soil. The area of black cotton soil under the semi-arid region of Maharashtra is proven to be the best soil for chickpea production. The proposed research was carried out to examine the impact of soil applications of sulphur on the production, nutritional uptake and quality of chickpea.

Materials and Methods

Location, climate and soil of experimental site

The field experiment was conducted at Pulses Research Unit, Washim Road Farm, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, during the *rabi* season 2018–19. The experimental field is situated at the latitude 20^o 40' 35" North and longitude of 76^0 59' 10" East with an altitude of 307.4 m above mean sea level (MSL). The climate of the Akola region is semi-arid and characterized by three distinct seasons *viz*., hot and dry summer from March to May, warm and rainy monsoon from June to October and mild cold winter from November to February. The average annual precipitation in the Akola region is 711.1 mm. The details of mean monthly weather parameters *viz*., maximum and minimum temperatures, rainfall (mm), relative humidity (%), wind speed (km h^{-1}), sunshine (h) and USWB open pan evaporation (mm) recorded during cropping seasons (2018–19) from Agro-meteorology Observatory, Dr. PDKV, Akola is depicted in Fig. 1. The soil (0–30 cm depth) of the experimental site was slightly alkaline in reaction (pH–8.96), having normal electrical conductivity (EC– 0.24 dS m^{-1}), medium in organic carbon (5.28 g kg^{-1}), calcareous in nature ($CaCO_3$ 6.87 %), low in available nitrogen (N–188.2 kg ha^{-1})) and phosphorus (P–13.65 kg ha^{-1}), very high in available potassium (K–581.2 kg ha^{-1}), deficient in available Sulphur (S–9.82 mg kg^{-1}) and sufficient in DTPA-Zn (11.64), Fe (9.37), Cu (1.60) and Mn (1.22) mg kg^{-1}.

Details of experiment, treatment and crop management

The certified seed of the most popular variety of chickpea (JAKI–9218) was sown in rabi season on 12th November 2018 by drilling at the rate of 75 kg ha^{-1} at spacing 30 × 10 cm. The experiment was laid out in Randomized Block Design and replicated thrice with nine treatments as shown in (Fig. 2). Initially, the experimental site was ploughed after the harvest of the kharif crop, harrowed, made free of grasses before the preparation of the layout. An initial composite surface soil sample was collected from 0–30 cm depth to analyse the physicochemical properties of the soil. The details of treatments include T_1 – Absolute control, T_2 – S free RDF (NPK through Urea, DAP, MOP), T_3 – RDF (NPK

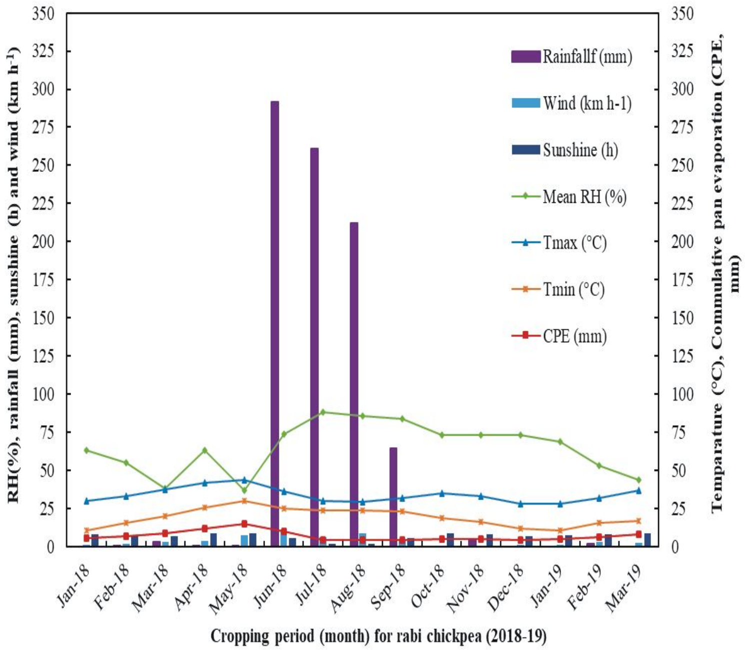

Fig. 1 : Monthly mean of weather conditions prevailed during chickpea cropping seasons (2018–19).

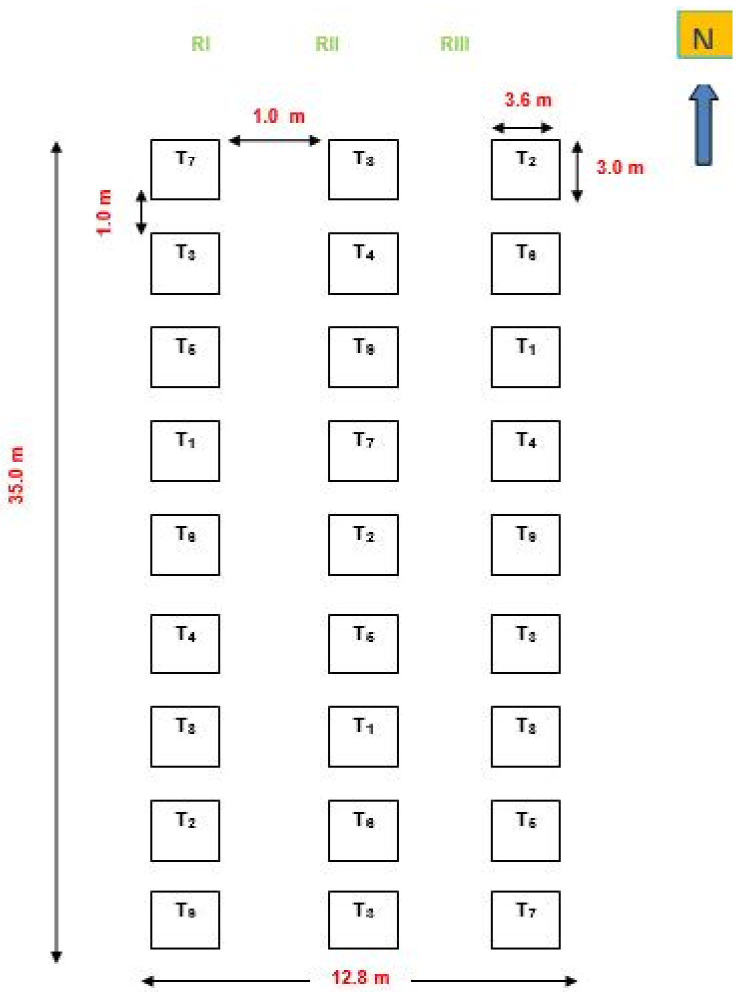

Fig. 2 : Layout of experiment.

through Urea, SSP, MOP), T_4 – S @ 10 kg ha^{-1} through Bentonite Sulphur + RDF, T_5 – S @ 20 kg ha^{-1} through Bentonite Sulphur + RDF, T_6 – S @ 30 kg ha^{-1} through Bentonite Sulphur + RDF, T_7 – S @ 10 kg ha^{-1} through Gypsum + RDF, T_8 – S @ 20 kg ha^{-1} through Gypsum + RDF, T_9 – S @ 30 kg ha^{-1} through Gypsum + RDF.

All the fertilizers (Urea, DAP, SSP, MOP, Bentonite sulphur and Gypsum) were applied as basal doses at the time of sowing. From treatments T_4 to T_9, sulphur-free RDF (25:50:30 kg N, P_2O_5, K_2O kg ha^{-1}) was applied through Urea, DAP and MOP and the effect of graded doses of sulphur was evaluated. Sulphur was given through Bentonite sulphur to the treatments T_4, T_5 and T_6 and through Gypsum to the treatments T_7, T_8 and T_9. Irrigation was given two times by using a sprinkler irrigation system after sowing and before the flowering stage of the crop. Cultural operations *viz.*, gap filling and thinning were done and plant population was maintained. The periodical operations such as weeding and hoeing were carried out to maintain the experimental plot free from weeds as per recommended practices. As a plant protection measure spraying of Flubendiamide 20% WG was undertaken to control chickpea pod borer.

Yield, yield attributes, quality parameters and plant sample analyses

Chlorophyll content in leaves was determined at the flowering stage, with the help of a Spectrophotometer by acetone extraction method (Arnon, 1949). Randomly five plants from each plot were selected at the maturity stage of the crop to record the yield attributes *viz.*, plant height, number of branches, number of pods and number of grains per plant and for subsequent lab analysis. The crop was harvested manually at fully matured stage and grain and straw yield was measured at the time of harvesting and expressed in quintal ha^{-1}. Treatment wise plant samples were air dried and then oven dried at 64°C for 24 hours. Using a grinding mill, the plant samples were ground into a powder and utilised to assess content and uptake of N, P, K, S and micronutrients. Plant samples (0.5 g) were digested and nitrogen was determined by micro kjeldahl's method using a digestion mixture (1:5:1) consisting of $CuSO_4$, K_2SO_4, Selenium powder and H_2SO_4 (Jackson, 1973). Di-acid extract (HNO_3:$HClO_4$ in 9:4 ratio) was used for P, K, S and micronutrient analysis. The phosphorus and Potassium content in the di-acid digested plant sample was determined by the Vanadomolybdate yellow colour method using spectrophotometer and Flame Photometer method as described by Jackson (1973). Sulphur was estimated turbidimetrically on Spectrophotometer (Chesnin and Yien, 1951). Micronutrients including Zn, Fe, Mn and Cu were estimated by Atomic Absorption Spectrophotometer (Issac and Kerber, 1971). The seed vigour index was analysed by taking the weight of 100 chickpea seeds from each plot and designated it as the seed index. The protein content was determined as the procedure described by AOAC (1975).

Statistical analysis

To investigate the impact of sulphur levels on the growth, yield, nutrient uptake and quality parameters of chickpea, data from the experiment were statistically analysed using a Randomized block design (Panse and Sukhatme, 1985.) For separating the means of different treatments, Duncan's multiple range tests were used to calculate the least significant differences (LSD) at p = 0.05.

Results

Effect on growth, yield and yield attributing characters of chickpea

The yield attributing characters such as plant height, number of branches plant^{-1}, pods plant^{-1}, seeds plant^{-1} of chickpea was influenced significantly with the application of increasing doses of sulphur (via Bentonite sulphur and Gypsum) along with RDF (Table 1). The significantly (p=0.05) highest plant height (46.37 cm), number of branches plant^{-1} (19.27), pods plant^{-1} (42.60), seeds plant^{-1} (44.75), of chickpea were observed with the application of S @ 30 kg ha^{-1} through Bentonite sulphur along with RDF (T_6) which was on par with the treatment (T_9), (T_5), (T_8) and (T_3). Findings showed that treatment T_6 recorded 29.5, 61.0, 103.8, and 111.3% enhancement in case of plant height, number of branches plant^{-1}, pods plant^{-1}, seeds plant^{-1} of chickpea as compared to treatment T_1 (absolute control). Similarly, the significantly (p=0.05) highest seed yield (25.58 q ha^{-1}) and straw yield (31.98 q ha^{-1}) were recorded with the application of S @ 30 kg ha^{-1} through Bentonite sulphur along with RDF (T_6) followed by treatment S @ 30 kg ha^{-1} through

Table 1 : Growth, yield and yield attributes of chickpea as influenced by sulphur application.

Treatments		Plant height (cm)	No. of branches plant^{-1}	No. of pods plant^{-1}	No. of seeds plant^{-1}	Yield (q ha^{-1})	
						Seed	Straw
T_1	Absolute control	35.81^c	11.97^e	20.90^d	21.18^d	13.80^c	17.25^c
T_2	S free RDF (NPK through Urea, DAP, MOP)	42.21^b	16.01^d	35.93^c	38.37^c	20.40^b	25.49^b
T_3	RDF (NPK through Urea, SSP, MOP)	44.01^{ab}	18.20^{abc}	41.47^a	42.05^{ab}	23.96^a	29.95^a
T_4	S @ 10 kg ha^{-1} through Bentonite Sulphur + RDF	43.37^b	17.71^{bc}	38.30^c	40.45^{bc}	23.56^a	29.38^a
T_5	S @ 20 kg ha $^{-1}$ through Bentonite Sulphur + RDF	44.57^{ab}	18.63^{abc}	40.57^{ab}	42.62^{ab}	24.86^a	31.09^a
T_6	S @ 30 kg ha^{-1} through Bentonite Sulphur + RDF	46.37^a	19.27^a	42.60^a	44.75^a	25.58^a	31.98^a
T_7	S @ 10 kg ha^{-1} through Gypsum + RDF	43.07^b	17.31^{cd}	37.97^{bc}	40.19^{bc}	23.35^a	29.19^a
T_8	S @ 20 kg ha^{-1} through Gypsum + RDF	44.39^{ab}	18.29^{abc}	40.23^{ab}	42.34^{ab}	24.45^a	30.58^a
T_9	S @ 30 kg ha^{-1} through Gypsum + RDF	46.23^a	19.10^{ab}	42.13^a	44.21^a	25.35^a	31.72^a
SE (m) ±		0.80	0.46	0.94	0.92	0.66	0.85
LSD (p=0.05)		2.41*	1.38*	2.83*	2.77*	1.98*	2.57*

At the p = 0.05 level * indicate the significant and ^{ns} non-significant differences in the mean of uptake of plant height (cm), No. of branches plant^{-1}, no. of pods plant^{-1}, No. of seeds plant^{-1}, seed yield (q ha^{-1}) and straw yield (q ha^{-1}) with successive doses of sulphur. DMRT test representing that values within the columns with different superscripts letters are significantly different.

Table 2 : Effect of sulphur application on quality parameters of chickpea.

Treatments		Chlorophyll content in leaves (mg g^{-1})			Test weight (g)	Protein content (%)	Protein yield (kg ha^{-1})
		Chlorophyll A (mg g^{-1})	Chlorophyll B (mg g^{-1})	Total chlorophyll (mg g^{-1})			
T_1	Absolute control	0.494^b	0.310^c	0.804^f	20.23^d	19.46^c	268.9^d
T_2	S free RDF (NPK through Urea, DAP, MOP)	0.530^b	0.316^c	0.846^e	22.92^c	19.77^{bc}	403.2^c
T_3	RDF (NPK through Urea, SSP, MOP)	0.635^a	0.317^c	0.952^c	24.18^{abc}	20.71^{ab}	496.1^{ab}
T_4	S @ 10 kg ha^{-1} through Bentonite Sulphur + RDF	0.607^a	0.309^c	0.916^d	23.69^{bc}	19.94^{bc}	470.0^b
T_5	S @ 20 kg ha^{-1} through Bentonite Sulphur + RDF	0.625^a	0.404^a	1.029^{ab}	24.47^{abc}	20.76^{ab}	515.8^a
T_6	S @ 30 kg ha^{-1} through Bentonite Sulphur + RDF	0.648^a	0.393^{ab}	1.041^a	25.67^a	21.09^a	539.5^a
T_7	S @ 10 kg ha^{-1} through Gypsum + RDF	0.609^a	0.306^c	0.915^d	23.47^{bc}	19.90^{bc}	464.2^b
T_8	S @ 20 kg ha^{-1} through Gypsum + RDF	0.604^a	0.351^{bc}	0.955^c	24.08^{abc}	20.55^{abc}	502.6^{ab}
T_9	S @ 30 kg ha^{-1} through Gypsum + RDF	0.638^a	0.373^{ab}	1.011^b	25.27^{ab}	20.87^{ab}	528.7^a
SE (m) ±		0.02	0.02	0.01	0.59	0.34	13.89
LSD (p=0.05)		0.05*	0.05*	0.03*	1.76*	1.01*	41.64*

At the p = 0.05 level * indicates the significant and ^{ns} non-significant differences in the mean of different sulphur application treatments. DMRT test representing that values within the columns with different superscripts letters are significantly different.

Gypsum + RDF (T_9) (Table 1). In comparison to the absolute control (T_1), the seed yields of treatments T_6 and T_9 improved by 85.3 and 83.7%, while as compared sulphur-free RDF (T_2) yield improvement registered by 25.4 and 23.4%, respectively. Sulphur was applied @ 37.5 kg ha^{-1} through Single Super Phosphate in the treatment T_3 (NPK through Urea, SSP and MOP) and recorded seed yield (23.96 q ha^{-1}) that was equally comparable to S at 30 kg ha^{-1} through Bentonite Sulphur (T_6) and Gypsum (T_9).

Quality parameters as influenced by sulphur application

The test weight (100 seed weight), protein content of chickpea seed, and chlorophyll content of leaves were also significantly influenced by the application of sulphur through Bentonite Sulphur and Gypsum (Table 2). Significantly (p=0.05) highest test weight of chickpea grain (25.67 g) was recorded in treatment T_6 – S @ 30 kg ha^{-1} through Bentonite sulphur + RDF and was found to be on par with treatment T_9 – S @ 30 kg ha^{-1} through Gypsum + RDF. The application of S @ 30 kg ha^{-1} through Bentonite sulphur (T_6) increased the test weight of chickpea by 12 per cent over S-free RDF (NPK through Urea, DAP, MOP – T_2) and 6.16 per cent over S containing RDF (NPK through Urea, SSP, MOP – T_3). The application of S @ 30 kg ha^{-1} through Bentonite sulphur along with RDF (T_6) enhanced the protein content of chickpea seed by 6.66% over S-free RDF (NPK through Urea, DAP, MOP – T_2). The significantly (p=0.05) higher protein content in chickpea seed (21.09%) was recorded in treatment T_6 and was found to be on par with treatments T_9, T_5, T_8 and T_3. The lowest protein content in chickpea seed (19.46%) was recorded in absolute control (T_1). In comparison to the absolute control (T_1), treatments T_6 and T_9 registered increased protein content by 8.93 and 7.28%, respectively.

A similar trend was recorded for protein yield, treatment T_6 recorded the maximum protein yield (539.5 kg ha^{-1}), while treatment T_1 displayed the lowest protein yield (268.9 kg ha^{-1}). Total chlorophyll, chlorophyll (a) and chlorophyll (b) content of chickpea leaves significantly increased with the soil application of graded doses of sulphur through Bentonite Sulphur and Gypsum. The

Table 3 : Effect of sulphur application on seed, stover and total uptake of nutrients (kg ha^{-1}) by chickpea.

	Treatments	Total uptake of nutrients (kg ha^{-1})											
		N			P			K			S		
		Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total
T_1	Absolute control	43.02^{d}	33.09^{d}	76.11^{e}	3.23^{c}	2.85^{e}	6.08^{e}	17.02^{f}	28.51^{f}	45.54^{g}	3.65^{e}	4.17^{e}	7.83^{f}
T_2	S free RDF (NPK through Urea, DAP, MOP)	64.51^{c}	50.80^{c}	115.30^{d}	5.70^{b}	4.61^{d}	10.31^{d}	25.82^{e}	43.67^{e}	69.48^{f}	5.85^{d}	6.70^{d}	12.54^{e}
T_3	RDF (NPK through Urea, SSP, MOP)	79.37^{ab}	63.88^{b}	143.25^{bc}	7.19^{ab}	6.04^{bc}	13.23^{abc}	35.15^{bcd}	60.24^{bc}	95.39^{bcd}	7.88^{bc}	9.20^{bc}	17.08^{bcd}
T_4	S @ 10 kg ha^{-1} through Bentonite Sulphur + RDF	75.20^{b}	64.16^{b}	139.35^{c}	6.84^{ab}	5.66^{c}	12.51^{bcd}	33.15^{d}	55.92^{cd}	88.88^{de}	7.25^{cd}	8.60^{c}	15.85^{cd}
T_5	S @ 20 kg ha $^{-1}$ through Bentonite Sulphur + RDF	82.53^{a}	70.66^{ab}	153.19^{abc}	7.79^{ab}	6.71^{ab}	14.50^{ab}	36.85^{abc}	62.94^{ab}	99.78^{abc}	8.58^{abc}	10.15^{abc}	18.73^{abc}
T_6	S @ 30 kg ha^{-1} through Bentonite Sulphur + RDF	86.32^{a}	76.51^{a}	162.83^{a}	8.25^{a}	7.25^{a}	15.50^{a}	39.18^{a}	67.83^{a}	107.00^{a}	9.63^{a}	11.28^{a}	20.91^{a}
T_7	S @ 10 kg ha^{-1} through Gypsum + RDF	74.27^{b}	61.32^{bc}	135.58^{c}	6.55^{ab}	5.37^{cd}	11.92^{cd}	32.38^{d}	53.39^{d}	85.76^{e}	7.06^{cd}	8.23^{cd}	15.29^{de}
T_8	S @ 20 kg ha^{-1} through Gypsum + RDF	80.42^{ab}	68.63^{ab}	149.05^{abc}	7.26^{ab}	6.48^{ab}	13.73^{abc}	34.72^{cd}	59.61^{bc}	94.32^{cd}	8.20^{abc}	9.71^{abc}	17.92^{abcd}
T_9	S @ 30 kg ha^{-1} through Gypsum + RDF	84.59^{a}	72.69^{ab}	157.29^{ab}	7.80^{ab}	7.06^{a}	14.87^{a}	38.09^{ab}	64.96^{ab}	103.05^{ab}	9.22^{ab}	10.89^{ab}	20.11^{ab}
SE (m)±		2.22	3.63	5.38	0.64	0.25	0.72	0.99	1.83	2.62	0.48	0.58	1.00
LSD (p=0.05)		6.66*	10.9*	16.1*	1.98*	0.76*	2.16*	2.96*	5.48*	7.88*	1.46*	1.75*	3.00*

At the p=0.05 level * indicate the significant and ^{ns} non-significant differences in the mean of seed, stover and total uptake (kg ha^{-1}) of nitrogen, phosphorus, potassium and sulphur with increasing doses of sulphur. DMRT test represents that values within the columns with different superscript letters are significantly different.

significantly (p=0.05) higher chlorophyll a (0.648 mg g^{-1}) was observed with the application of S @ 30 kg ha^{-1} through Bentonite sulphur along with RDF (T_6), while significantly higher chlorophyll b (404 mg g^{-1}) was observed with the application of S @ 20 kg ha^{-1} through Bentonite sulphur + RDF (T_5). In the case of total chlorophyll significantly highest value was registered in treatment T_6 (1.041 mg g^{-1}) followed by T_5 (1.291 mg g^{-1}) and T_9 (1.011 mg g^{-1}) (Table 2). Treatments T_6 and T_9 showed an increase in total chlorophyll content by 24.49 and 25.80% as compared to absolute control (T_1).

Effect on nutrient uptake

The seed, stover and total uptake of nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) improved significantly (p=0.05) with the application of increasing doses of sulphur (Table 3). Significantly (p=0.05) highest total uptakes (seed + straw) of nitrogen (162.83 kg ha^{-1}), phosphorus (15.50 kg ha^{-1}), potassium (107.00 kg ha^{-1}) and sulphur (20.91 kg ha^{-1}) were observed with application of S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) and found to be at par with application of S @ 30 kg ha^{-1} through Gypsum + RDF (T_9). Treatment T_1 (absolute control) reported a remarkable reduction in total uptake of nitrogen, phosphorus, potassium and sulphur compared to T_6 by 53.3, 60.8, 57.4 and 62.6%, respectively. Treatment T_6 increased the total uptake of N, P, K, and S by 41.22%, 50.30%, 54.0% and 66.67%, respectively over S-free treatment (T_2 – NPK through Urea, DAP, MOP).

Discussion

Growth and yield

The data regarding yield shows that relative to gypsum, there was a greater increase in the case of bentonite sulphur (Table 1). This might be due to the result of the availability of pelletized Bentonite sulphur, which delivers sulphur in sulphate form, which the plant can readily absorb. Due to its pellet structure, Bentonite sulphur releases sulphur slowly and is accessible throughout the chickpea growth season. The increase in seed and straw yield was brought about by increased sulphur availability in soil (Wright, 1962) and uptake, as well as its active participation in the synthesis of amino acids, regulation of various metabolic and enzymatic processes (Droux, 2004), enhanced nitrogen fixation (Lange *et al.*, 1994; Scherer *et al.*, 2006) and biomass accumulation, all of which ultimately contributed to growth and yield. Increased plant sulphur content, which is a key constituent of sulphur-containing amino acids (Jamal *et al.*, 2006) plays a significant role in plant metabolism, and photosynthesis and also aids in crop growth and development, may be the reason for the improvement in chickpea growth and yield characteristics (Droux, 2004). These findings are in accordance with the results reported by Jadeja *et al.* (2016), Sindagi (2014) and Das *et al.* (2016). Srinivasulu *et al.* (2015) showed the advantage of applying sulphur in increasing the grain and straw production of chickpea, whereas Das *et al.* (2016) observed a rise in growth, crop yield, and yield-attributing characteristics of chickpea with increasing sulphur doses. Jadeja *et al.* (2016) also reported enhanced seed and straw yield of chickpea with the sulphur application as compared to the control.

Quality parameters

Sulphur is a constituent of protein and hence the application of sulphur showed a positive effect on an increase in protein content and protein yield in seeds of chickpea (Table 2). Srinivasulu *et al.* (2015) mentioned that the application of 20 and 40 kg S ha^{-1} increased the protein content by 7.5 and 8.0% respectively, over the control. Das *et al.* (2016) also reported that regardless of FYM, applying 20 kg ha^{-1} of sulphur greatly increased the protein content by 3%. These result's relation to protein content is in complete agreement with Mir *et al.* (2013) and Patel *et al.* (2014). An increase in protein content with the application of higher doses of sulphur might be due to increased root activity and translocation of higher nitrogen and sulphur resulting in the synthesis of more sulphur-containing amino acids such as methionine, cysteine and cystine. The synergistic action of nitrogen and sulphur with each other increased their availability in the soil might be attributed to increased N, S and protein content in chickpea grain (Ramkala and Gupta, 1999). The increased seed weight may be attributed to the role of sulphur in enhancing the protein content of seeds ultimately enhancing seed weight. The findings concerning the test weight conform with the results reported by Jadeja *et al.* (2016) and Kala *et al.* (2017). Chlorophyll concentration in chickpea leaves might have increased due sulphur plays a direct role in the production of chlorophyll in leaves. Jamal *et al.* (2006) stated that the unavailability of sulphur directly affects photosynthesis and causes a significant drop in chlorophyll a/b binding protein and rubisco. The application of sulphur accelerated photosynthesis because it boosted protein synthesis and maintained a high chlorophyll concentration (Ahmad and Abedin, 2000). These findings are in accordance with the results reported by Bera and Ghosh (2015).

Nutrients uptake

Following sulphur treatment, the oxidation of sulphur in the soil causes it to become acidic and lowers the soil pH (Fontain *et al*., 2021; Yang *et al*., 2007). This reduced pH helps in the availability of macro and micronutrients which leads to an increase in their uptake. Bahadur and Tiwari (2014) reported that an increase in sulphur application up to 30 kg ha^{-1} significantly increased the content and uptake of nitrogen, phosphorus and sulphur both in seed and stover of chickpea as compared to 15 kg ha^{-1} and control. According to Chiaiese *et al*. (2004) and Kumar *et al*. (2003) applying sulphur to chickpea increased the amount of sulphur present in both grain and stover. Das (2017), also mentioned that sulphur and nitrogen worked together to enhance the uptake of other nutrients. Sulphur application increased the number of root nodules along with nitrogen fixation (Lange *et al*., 1994; Scherer *et al*., 2006), which may have encouraged the production of more above-ground dry matter, increased nutrient uptake, which in turn raised nutrient content in grain and stover along with better seed and stover production (Table 3). These findings regarding the total uptake of nutrients are also evaluated by the researchers (Sindagi, 2014; Singh *et al*., 2013; Islam and Ali, 2009; Kala *et al*., 2017).

Conclusion

Being a constituent of sulphur-containing amino acid (Cysteine, Methionine), a controversial chemical element (Ostowska, 2008), indispensable for the growth and metabolism (Vidyalakshmi *et al*., 2009), having 0.24-0.32% concentration in pulses (Singh, 2001), responsible for the transfer of electrons during the light reactions of photosynthesis (Randall, 1988), engaged in the formation of chlorophyll (Mehta *et al*., 1979) and root nodule (Daramola *et al*., 1982; Scherer *et al*., 2008), involved in the formation of nitrogenase enzyme to increase nitrogen fixation in legumes (Scherer *et al*., 2006) and concerned with superior, nutritional and market quality of crop produce (Sexton *et al*., 1998), sulphur is directly related to the growth, yield quality and nutrient uptake of pulse crop with improved crop production. It is concluded that the application of sulphur @ 30 kg h^{-1} through Bentonite sulphur along with RDF (25:50:30 kg N, P_2O_5, K_2O) at the time of sowing proved to be the best combination which recorded the highest growth, yield, nutrient uptake, protein content, protein yield, test weight (100 seed weight) and chlorophyll content of chickpea in sulphur deficient soil of semi-arid zone of Maharashtra.

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Disclosure statement

No potential conflict of interest was reported by the author (s).

References

Abdin, M.Z., Ahmad A., Khan N., Khan I., Jamal A. and Iqbal M. (2003). Sulfur interaction with other nutrients, in: Sulphur in Plants, *Springer, Dordrecht*. pp. 359–374.

Ahmad, A. and Abdin M.Z. (2000). Photosynthesis and its related physiological variables in the leaves of Brassica. genotypes as influenced by sulphur fertilization. *Physiol. Plantarum*, **110**, 144–149.

Anonymous (2022). *Agricultural Statistics at a Glance, 2022*. Economics & Statistics Division, Department of Agriculture & Farmers Welfare. www.agricoop.nic.in & http://desagri.gov.in.

AOAC (1975). *Official Methods of Analysis*. 12th Edition, Association of Official Analytical Chemists, Washington DC.

Arnon, D.I. (1949). Copper enzymes in isolated chloroplasts. Polyphenoxidase in *Beta vulgaris*. *Plant Physiol*., **24**, 1–15.

Bahadur, L. and Tiwari D.D. (2014). Nutrient management in mungbean (*Vigna radiata* L.) through sulphur and biofertilizers. *Legume Res*., **37(2)**, 180–187.

Bera, M. and Ghosh G.K. (2015). Efficacy of sulphur sources on green gram (*Vigna radiata* L.) in red and lateritic soil of West Bengal. *Int. J. Plant, Anim. Environ. Sci*., **5(2)**, 2231–4490.

Bona, F.D. De and Monteiro F.A. (2010). Nitrogen and sulfur fertilization and dynamics in a Brazilian Entisol under pasture. *Soil Sci. Soc. Am. J*., **74(4)**, 1248–1258.

Chandra, N. and Pandey N. (2016). Role of sulfur nutrition in plant and seed metabolism of *Glycine max* L. *J. Plant Nutr*., **39(8)**, 1103–1111.

Chesnin, L. and Yien C.H. (1951). Turbidimetric determination of available sulphur. *Soil Sci. Soc. Am. Proc*., **15**, 149–151.

Chiaiese, P., Ohkama-Ohtsu N., Molvig L., Godfree R., Dove H., Hocart C., Fujiwara T., Higgins T.J.V. and Tabe L. (2004). Sulphur and nitrogen nutrition influence the response of chickpea seeds to an added, transgenic sink for organic sulphur. *J. Exp. Bot*., **55(404)**, 1889–1901.

Claro-Cortes, P., Nunez-Escobar R. and Etchevers-Barra J.D. (2002). Greenhouse grown maize response to sulphur in two soils of Puebla state Mexico. *Agrociencia*, **36**, 633–636.

Daramola, D.S., Adebayo A. and Odeyemi O. (1982). Effect of herbicide application on legume *Rhizobium symbiosis* with and without starter nitrogen. *Turrialba*, **32**, 315–320.

Das, S.K. (2017). Effect of phosphorus and sulphur on yield attributes, yield, nodulation and nutrient uptake of green gram [*Vigna radiata* (L.) Wilczek]. *Legume Res*., **40(1)**, 138–143.

Das, S.K., Biswas B. and Jana K. (2016). Effect of farm yard manure, phosphorus and sulphur on yield parameters, yield, nodulation, nutrient uptake and quality of chickpea (*Cicer arietinum* L.). *J. Appl. Nat. Sci*., **8(2)**, 545–549.

Das, S.K., Chopra P., Chatterjee S.R., Abrol Y.P. and Deb D.L. (1975). Influence of sulphur fertilization on yield of maize and protein quality of cereals. *Fert. News*, **20(3)**, 30–32.

Droux, M. (2004). Sulfur assimilation and the role of sulfur in plant metabolism: A survey. *Photosynth. Res*., **79(3)**, 331–348.

El-Eyuoon, A. and Amin A.Z. (2018). Improvement in phosphorus use efficiency of corn crop by amending the soil with sulfur and farmyard manure. *Soil Environ*., **37(1)**, 62–67.

Eriksen, J., Thorup-Kristensen K. and Askegaard M. (2004). Plant availability of catch crop sulfur following spring incorporation. *J. Plant Nutr. Soil Sci*., **167(5)**, 609–615.

Fontaine, D., Eriksen J., Sorensen P., McLaughlin M.J. and Degryse F. (2021). The application method influences the oxidation rate of biologically and chemically produced elemental sulfur fertilizers. *Soil Sci. Soc. Am. J*., **85(3)**, 746–759.

Islam, M. and Ali S. (2009). Effect of integrated application of sulphur and phosphorus on nitrogen fixation and nutrient uptake by chickpea (*Cicer arietinum* L.). *Agrociencia*, **43(8)**, 815–826.

Issac, R.A. and Kerber J.D. (1971). Atomic absorption and flame photometry: Technique and uses in soil, plant and water analysis. In Walsh, L.M. (ed). Instrumental Method of Soils and Plant Tissue. *Soil. Sci. Soc. Am. Madison*, Wisconsin: 18–37.

Jackson, M.L. (1973). *Soil Chemical Analysis*. Prentice Hall of India Pvt., Ltd., New Delhi.

Jadeja, A.S., Rajani A.V., Foram, Chapdiya, Kaneriya S.C. and Kavar N.R. (2016). Soil application of potassium and sulphur and effect on growth and yield components of chickpea (*Cicer arietinum* L.) under south Saurashtra region of Gujarat. *Int. J. Sci., Environ. Tech*., **5(5)**, 3172–3176.

Jamal, A., Fazli I.S., Ahmad S. and Abdin M.Z. (2006). Interactive effect of nitrogen and sulfur on yield and quality of groundnut (*Arachis hypogea* L.). *Korean J. Crop Sci*., **51(6)**, 519–522.

Jamal, A., Fazli I.S., Ahmad S., Abdin M.Z. and Yun S.J. (2005). Effect of sulfur and nitrogen application on growth characteristics, seed and oil yields of soybean cultivars. *Korean J. Crop Sci*., **50(5)**, 340–345.

Jamal, A., Moon Y.S. and Abdin M.Z. (2010). Enzyme activity assessment of peanut (*Arachis hypogea* L.) under slow-release sulfur fertilization. *Aust. J. Crop Sci*., **4(3)**, 169–174.

Kala, D.C., Dixit R.N., Meena S.S., Nanda G. and Kumar R. (2017). Effect of graded doses of sulphur and boron on yield attributes and nutrient uptake by chickpea. *Int. J. Curr. Microbiol. Appl. Sci*., **6(6)**, 55–60.

Katkar, R.N., Kharche V.K, Lakhe S.R., Deshmukh P.R., Shukla A.K., Tiwari Pankaj, Aage A.B. and Kadlag A.D. (2017). *Geographical Information based Micro and Secondary nutrients in soils of Maharashtra*. Dr. P.D.K.V., Akola. Bulletin No. 491: 10.

Kumar, N., Khangarot S.S. and Meena R.P. (2003). Effect of sulphur and plant growth-regulators on yield and quality parameters of chickpea (*Cicer arietinum* L.). *Ann. Agric. Res*., **24(2)**, 434–436.

Lange, A., Scherer H.W. and Werner W. (1994). Influence of sulfur supply on biological nitrogen fixation in legumes. [German] *Vortrage zum Generalthema des*, **106**, 19–24.

Malhi, S.S., Gan Y. and Raney J.P. (2007). Yield, seed quality, and sulfur uptake of Brassica oilseed crops in response to sulfur fertilization. *Agron. J*., **99(2)**, 570–577.

Mehta, U.R. and Singh H.G. (1979). Response of green gram to sulphur in calcareous soils. *Indian J. Agricult. Sci*., **49**, 703–706.

Millan, T. (2010). A consensus genetic map of chickpea (*Cicer arietinum* L.) based on 10 mapping populations. **175**, 175–189.

Mir, A.H., Lal S.B., Salmani M., Abid M. and Khan I. (2013). Growth, yield and nutrient content of black gram (*Vigna mungo*) as influenced by levels of phosphorus, sulphur and phosphorus solubilizing bacteria. *SAARC J. Agric*., **11(1)**, 1–6.

Morris, R.J. (1988). Sulphur in World Agriculture. *Proceedings of TSI-FAI Symposium* (Sulphur in Indian Agriculture) KS **(1)**, 1–14.

Ostowska, D., Pietkiewicz S., Ciesinski M., Kucinska K. and Gozdowaski D. (2008). Biomass accumulation and absorption of Photosynthetic active radiation by rapeseed plant depending on sulphur fertilization. *World J. Agricult. Sci*., **4(2)**, 133–136.

Panse, V.G. and Sukatme P.V. (1985). *Statistical Methods for Agricultural Workers*. ICAR, New Delhi.

Patel, H.K., Patel P.M., Suthar J.V. and Patel M.R. (2014). Yield, quality and post-harvest nutrient status of chickpea as influenced by application of sulphur and phosphorus fertilizer management. *Int. J. Scientific Res. Publi*., **4(7)**, 2250–3153.

Piper, C.S. (1966). *Soil and Plant Analysis*. Asian Reprint, Hans Publication Bombay, India.

Ramkala and Gupta S.P. (1999). Effect of source and level of sulphur on yield and quality of chickpea (*Cicer arietinum* L.). *Indian J. Agron*., **37 (1)**, 112–114.

Randall, P.J. (1988). Evaluation of the sulphur status of soils and plants. Techniques and interpretation. *Proc. of TSI-FAI symp. Sulphur in Indian agriculture*. New Delhi, pp: Sl/3 (1–15).

Ray, D.K., Mueller N.D., West P.C. and Foley J.A. (2013). Yield trends are insufficient to double global crop production by 2050. *PLoS One*, **8(6)**, e66428.

Saalbach, E. (1973). The effect of S, Mg, and Na on yield and quality of agriculture crops. *Pontif. Acad. Sci. Scr.* Varia **38**, 451–538.

Scherer, H.W. (2001). Sulfur in crop production. *Eur. J. Agron*., **14(2)**, 81–111.

Scherer, H.W., Pacyna S., Spoth K. and Schulz M. (2008). Low levels of ferredoxin, ATP and leghemoglobin contribute to limited N fixation of peas (*Pisum sativum* L.) and alfalfa (*Medicago sativa* L.) under S deficiency conditions. *Biol. Fertil. Soils*, **44**, 909–916.

Scherer, H.W., Pacyna S., Manthey N. and Schulz M. (2006). Sulphur supply to peas (*Pisum Sativum* L.) influences symbiotic N_2 fixation. *Plant Soil Environ*., **52(2)**, 72–77.

Schonhof, I., Blankenburg D., Müller S. and Krumbein A. (2007). Sulfur and nitrogen supply influence growth, product appearance and glucosinolate concentration of broccoli. *J. Plant Nutr. Soil Sci*., **170(1)**, 65–72.

Sexton, P.J., Paek N.C. and Shibles R. (1998). Soybean sulphur and nitrogen balance under varying levels of available sulphur. *Crop Sci.*, **37**, 1801–1806.

Shukla, A.K., Tiwari P., Siddiqqui S., Patra A.K. and Chaudhary S.K. (2016). Micro and Secondary nutrients in Indian soils, condition of deficiency, prevention and recommendations. *IISS*, Bhopal, **3**, 25.

Sindagi, A.S. (2014). Studies on levels of phosphorus and sulphur on yield, quality and uptake of nutrients by chickpea in a Vertisol under irrigation. *M.Sc. Thesis*. University of Agricultural Sciences, Dharwad.

Singh, A.K., Meena M.K., Bharati R.C. and Gade R.M. (2013). Effect of sulphur and zinc management on yield, nutrient uptake, changes in soil fertility and economics in rice (*Oryza sativa*)-lentil (*Lens culinaris*) cropping system. *Indian J. Agri., Sci*., **83(3)**, 344–348.

Singh *et al*. (1995). Source and mode of sulphur application on groundnut productivity. *J. Plant Nutr.*, **18**, 2739-2759.

Singh, M.V. (2001). Importance of sulphur balanced fertilizer use in India. *Fertilizer News*, **46**, 13–18.

Srinivasulu, D.V., Solanki R.M., Kumari C.R. and Babu M.V. (2015). Nutrient uptake, yield and protein content of chickpea (*Cicer arietinum* L.) as influenced by irrigation and sulphur levels in medium black soils. *Int. J. Agri. Sci*., **11**, 54–58.

Sutradhar, A.K., Kaiser D.E. and Fernandez F.G. (2017). Does total nitrogen/sulfur ratio predict nitrogen or sulfur requirement for corn? *Soil Sci. Soc. Am. J.*, **81(3)**, 564–577.

Tandon, H.L.S. (1984). *Research and Agriculture Production in India*. Fertilizer Develop. and Consultation Organization, New Delhi, India, pp. 13–23.

Udayana, S.K., Singh P., Jaison M. and Roy A. (2021) *Sulfur: A Boon in Agriculture*.

Verma, J., Kushwaha S., Singh S.P. and Pandey P.R. (2020). Effect of Sulphur on Oilseed Crops. *Environment, Agriculture and Health*, p. 32.

Vidyalakshmi, R., Paranthaman R. and Bhakyaraj R. (2009). Sulphur Oxidizing Bacteria and Pulse Nutrition-A review. *World J. Agricult. Sci*., **5(3)**, 270–278.

Vollset, S.E., Goren E., Yuan C.W., Cao J., Smith A.E., Hsiao T., Bisignano C., Azhar G.S., Castro E., Chalek J., Dolgert A.J. and Murray C.J. (2020). Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: A forecasting analysis for the Global Burden of Disease Study. *Lancet*, **396 (10258)**, 1285–1306.

Wright, D.E. (1962). Amino acid uptake by plant roots, Arch. Biochem. *Biophys*, **97(1)**, 174–180.

Yang, Z., Haneklaus S., Singh B.R. and Schnug E. (2007). Effect of repeated applications of elemental sulfur on microbial population, sulfate concentration and pH in soils. *Commun. Soil Sci. Plant Anal*., **39(1–2)**, 124–140.

Zhao, F.J., McGrath S.P. and Hawkesford M.J. (2000). Sulphur Nutrition and the Sulphur Cycle, Institute of Arable Crops Research Report, pp. 36–39.