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Effect of Phosphorus and Sulphur Levels on Growth, Nodulation and Yield of Soybean [*Glycine max* (L.) Merrill] in South-Eastern Part of Rajasthan

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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

An experiment was conducted at Instructional Farm, College of Agriculture, Ummedganj, Kota during *kharif,* 2021. The twelve treatment combinations comprised of four levels of phosphorus *viz.,* 0, 20, 40 and 60 kg ha^{-1} allocated in main plots and three levels of sulphur *viz.*, 15, 30 and 45 kg ha^{-1} in sub plots. Results showed that application of 60 kg P_2O_5 ha^{-1} had significant effect on plant height at 60 DAS and at harvest, number of total root nodules $plant^{-1}$, effective root nodules $plant^{-1}$ and dry weight of root nodules at 45 DAS, chlorophyll content at 45 DAS and leaf area index at 50 DAS of soybean over application of 20 kg P_2O_5 ha^{-1} and control but it was found at par with 40 kg P_2O_5 ha^{-1}. The maximum seed yield (1942 kg ha^{-1}) and straw (3305 kg ha^{-1}) yield of soybean were recorded under application of 60 kg P_2O_5 ha^{-1} over application of 20 kg P_2O_5 ha^{-1} and control but it was found at par with 40 kg P_2O_5 ha^{-1}. Significantly higher plant height at 60 DAS and at harvest, number of total root nodules $plant^{-1}$, effective root nodules $plant^{-1}$ and their dry weight at 45 DAS, chlorophyll content at 45 DAS, leaf area index at 50 DAS, seed yield (1870 kg ha^{-1}) and straw yield (3179 kg ha^{-1}) of soybean were recorded under application of 45 kg sulphur ha^{-1} which was found at par with 30 kg sulphur ha^{-1} and both these sulphur levels gave significant increase over application of 15 kg sulphur ha^{-1}.

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1. INTRODUCTION

In India oilseed crops constitute the second largest agricultural produce, next to food grain and these crops are the important sources of fats and oils. The oil and economic end product of oilseed crop is an integral part of human diet. Beside the dietary needs, the vegetable edible oil has numerous mechanical, industrial, medicinal and therapeutic uses too. Soybean has paramount importance in human and animal nutrition, because it is a major source of edible vegetable oil and high protein feed as well as food in the world. Soybean is considered as miracle crop because it contains 38-42 per cent good quality protein, 23 per cent carbohydrates, 18-20 per cent oil, rich in poly unsaturated fatty acids, good amount of minerals and vitamins especially B-complex and tocopherols. It provides high amounts of phyto-chemicals and good quality dietary fibre which enables to protect human body against cancers and diabetes [1].

India ranks fifth in the world in area and production after USA, Brazil, Argentina and China. Soybean has emerged as an important oilseed crop in India. On the national basis, soybean occupied an area of 12.09 million ha with production and productivity of 11.22 metric tonnes and 928 kg ha^{-1}, respectively [2]. Soybean is grown as a major oilseed crop mainly in south-eastern parts of Rajasthan during *kharif* season. It covers 1.12 million ha with an annual production and productivity of 0.52 metric tonnes and 469 kg ha^{-1} respectively in the state [2]. Soybean crop has an area of 7.26 lac ha with annual production 3.43 lakh tones and average productivity is 636 kg ha^{-1} in the six districts viz Kota, Bundi, Baran, Jhalawar, Sawai madhopur and Karauli of state come under the jurisdiction area of Agriculture University, Kota. DOA, 2019-20 [3] which is quite less than its potential yield is owing to various stresses during growing season.

Plants require phosphorus for growth throughout their life cycle, especially during the early stages of growth and development. In soybean, the demand for phosphorus is the greatest during root, pod and seed development stage where more than 60 per cent of phosphorus tends up in the pods and seeds [4]. Its uptake and utilization by soybean are essential for ensuring proper nodule formation and improving yield and quality of the crop. Sulphur plays a pivotal role in various plant growth and development processes being a constituent of sulphur containing amino acids, cystine and methionine, and other metabolites *viz.,* lutathione and phyto chelators. Sulphur is used as soil amendment for amelioration, as plant nutrient for increasing yield and quality of crop produce, as chemical agent to acidulate other nutrient and pesticides [5]. A higher susceptibility of crops to certain diseases was observed in sulphur deficient soils [6]. Hence the present investigation was conducted to find out the effect of phosphorus and sulphure on growth yield and of soyabean. The sulphur is required in higher amount by the oilseeds and hence has been identified as key nutrient responsible for higher production and oil content. Still the studies on effect of phosphorus and sulphur in soybean are very meagre.

2. MATERIALS AND METHODS

A field experiment was conducted at Instructional Farm, College of Agriculture, Ummedganj, Kota during *kharif* -2021. Geographically, is situated at 25.11^0 North latitude and 75.50^0 East longitude at an altitude of 258 meters above mean sea level (MSL). In Rajasthan, this region falls under the Agro-Climatic Zone-V (Humid South Eastern Plain Zone). The soil of experimental field was clay loam in texture with adequate drainage facility, having moderately alkaline reaction. The soil was medium in available nitrogen, phosphorus & sulphur and high in available potassium.

The experiment laid out in factorial randomized block design with three replications. The treatments comprised combinations of four levels of phosphorus *viz.,* 0, 20, 40 and 60 kg ha^{-1} allocated in main plots and three levels of sulphur *viz.*, 15, 30 and 45 kg ha^{-1} in sub plots, thereby making twelve treatment combinations.

For recording pre and post-harvest observations, five plants were randomly selected for each plot and tagged with labels for various observations on growth parameters and yield as followed:

The total number of plants row length metre^{-1}at three spots selected randomly in each plot were counted at 30 DAS and at harvest and the average was worked out. Plant height (cm) was measured in order to estimate the effect and extent of plant growth due to various treatments. Height of the five randomly selected plants in each plot was measured in centimetres with the help of meter scale at 30, 60 DAS and at harvest in each plot separately. Plant height was measured from the base of plant at soil surface to the main stem (apical bud) to last foliate of soybean crop plant and mean value was computed.

The number of root nodules of five randomly selected plants was recorded in each plot at 45 DAS. Plants were uprooted carefully and after washing root nodules were separated from the roots of the plants, counted and total root nodules number was recorded. The number of effective root nodules of five randomly selected plants was recorded in each plot at 45 DAS. Plants were uprooted carefully and after washing root nodules were separated from the roots of the plants, counted and total root nodules number was recorded. The cut cross-sections of all nodules indicated clear differences in the color of nodular tissue between effective and ineffective. The ineffective nodules were white to light green colour inside while the effective nodules were characteristically pinkish brown colour inside and then separate both nodule types. The dry weight of total root nodules of five randomly selected plants was recorded in each plot at 45 DAS. The root nodules were dried in the sun then transferred to thermostatic controlled drying oven regulated at 80°C ± 2°C for 45 hours and dried up to a constant weight and finally their weight was recorded in (mg plant^{-1}) with the help of electronic balance.

Total chlorophyll content of leaves at 45 DAS was determined by the method advocated by Arnon (1949). Take 20 mg of leaf sample and crush and suspended in test tube containing 5 ml Dimethyl Sulphoxide (DMSO). Test tube were incubated at 60 ^{0}C for one hour in oven after that take reading on spectrophotometer at 645 and 663 nm.

Table 1. Physico-chemical properties of soil of experimental field

Properties	Values	Method used
A. Mechanical analysis		
Sand (%)	22.8	Hydrometer method (Bouyoucos,1962)
Silt (%)	37.2	
Clay (%)	40.0	
Textural class	Clay loam	Texture Triangular diagram (Brady and Weil, 1983)
B. Physical properties		
Bulk density (Mg m^{-3})	1.43	Core sampler method (Piper,1950)
Particle density (Mg m^{-3})	2.65	Pycnometer or RD bottle method (Black,1965)
C. Chemical properties		
Available N (kg ha^{-1})	264.5	Alkaline $KMnO_4$ method (Subbiah and Asija,1956)
Available P_2O_5 (kg ha^{-1})	21.7	Olsen's method (Olsen et al. 1954)
Available K_2O (kg ha^{-1})	388.6	Neutral ammonium acetate extraction and flame photometry (Hanway and Heidal, 1952)
Available S (kg ha^{-1})	15.8	Williams and Steinberg (1969)
Organic carbon (%)	0.52	Walkley and Black (1934)
ECs at 25 ^{0}C (dS m^{-1})	0.39	Using sol bridge soil tester (Jackson,1967)
Soil reaction (pH)	7.61	Potentiometric method using pH meter (Jackson, 1967)

Table 2. Treatment details with their symbols

A.	**Main Plot (Phosphorus kg ha^{-1})**		**Symbols**
i.	0	:	P_1
ii.	20	:	P_2
iii.	40	:	P_3
iv.	60	:	P_4
B.	**Sub Plot (Sulphur kg ha^{-1})**		
i.	15	:	S_1
ii.	30	:	S_2
iii.	45	:	S_3

Table 3. Treatment combinations

S. no.	Treatment combinations
1.	P1S1
2.	P1S2
3.	P1S3
4.	P2S1
5.	P2S2
6.	P2S3
7.	P3S1
8.	P3S2
9.	P3S3
10.	P4S1
11.	P4S2
12.	P4S3

$$Total\ chlorophyll\ content\ (mg\ .\ g^{1}) = \frac{(20.2\ x\ A645) + (8.03\ x\ A663)}{1000\ x\ weight\ of\ leaf\ sample\ taken\ (g)}$$

Leaves from five randomly selected tagged plants for each experimental unit were detached at 50 DAS and categorized as small, medium and large. Using leaf area meter, leaf area was measured. Leaf area index (LAI) was calculated with the help of following formulae (Reddy and Reddi,2001). It is a unit less figure.

$$LAI\ = \frac{Leaf\ area\ plant - 1\ (cm2)}{Ground\ area\ plant - 1\ (cm2)}$$

After threshing and winnowing, the clean seed obtained from the produce of individual net plot, were weighed and weight was recorded as seed yield. The seed yield recorded under each plot was converted in to kg ha^{-1}. Straw yield was obtained by subtracting the seed yield (kg ha^{-1}) from biological yield (kg ha^{-1}).

3. RESULTS AND DISCUSSION

3.1 Effect of Phosphorus on Growth Parameters

Data presented in Table 4 revealed that plant population of soybean at 30 DAS and at harvest was not significantly affected by any of the treatment combination. Thus, plant population was almost uniform in all the treated plots. Further, indicated that plant height at 30 DAS was remained significantly unaffected with the application of phosphorus. Results showed that the variation in plant height due to different levels of phosphorus fertilizer was significant at 60 DAS and at harvest. Application of 60 kg P_2O_5 ha^{-1} attained tallest plant height (47.23cm) at 60 DAS and (56.91 cm) at harvest over 20 kg P_2O_5 ha^{-1} and control, which remained statistically at par with 40 kg P_2O_5 ha^{-1} plant height (45.93 cm) at 60 DAS and (54.96 cm) at harvest. Significantly higher root nodules plant^{-1} (57.16) at 45 DAS was recorded with application of 60 kg P_2O_5 ha^{-1}, which was closely followed by 40 kg P_2O_5 ha^{-1} (54.93) over application of 20 kg P_2O_5 ha^{-1} and control in Table 5. The maximum number of effective root nodules plant^{-1}(40.16) at 45 DAS was recorded with application of 60 kg P_2O_5 ha^{-1} over 20 kg P_2O_5 ha^{-1} and control. The application of 40 kg P_2O_5 ha^{-1} found at par and equally effective in enhancing (38.38) effective root nodules plant^{-1} of soybean. Significantly higher dry weight of root nodules (52.48 mg plant^{-1}) at 45 DAS was recorded with the application of 60 kg P_2O_5 ha^{-1}which was closely followed by application of 40 kg P_2O_5 ha^{-1} dry weight of root nodules (50.69 mg plant^{-1}) over application of 20 kg P_2O_5 ha^{-1} and control (46.26 and 42.54 mg plant^{-1}) dry weight of root nodules, respectively. Significantly higher chlorophyll content (2.35 mg g^{-1}) at 45 DAS was recorded with the application of 60 kg P_2O_5 ha^{-1}in soybean as compared to application of 20 kg P_2O_5 ha^{-1} and control during the year of investigation. However, it was found at par with the application of 40 kg P_2O_5 ha^{-1} chlorophyll content (2.31 mg g^{-1}). Application of 60 kg P_2O_5 ha^{-1} produced higher leaf area index (5.29) at 50 DAS which remained statistically at par with 40 kg P_2O_5 ha^{-1}leaf area index (5.03) at 50 DAS over application of 20 kg P_2O_5 ha^{-1} and control.

Plant height may be increased due to uptake of nitrogen and phosphorus by the plants, which was made available phosphorus through nitrogen fixation and phosphorus solubilisation by the beneficial microorganisms [7]. Phosphorus promotes root growth, cell formation, leaf development, seed formation and accelerates early maturity of crop which may result to increment in branches, root nodules of plant [8]. This might be due to the fact that application of phosphorus results profuse growth of roots which ultimately resulted formation of a greater number of large size root nodules [9].

Each increment in phosphorus fertilizer levels recorded significantly variations in leaf area index and green leaves plant^{-1} at 45 DAS. Results reveals that the increasing phosphorus level enhanced the soil phosphorus availability and consequently it's mining by soybean crop plants which led to higher size of photosynthetic apparatus. This statement is endorsed by significantly higher chlorophyll content and leaf area index at different growth stages of the crop by many workers including Chavan et al. [10].

Table 4. Effect of phosphorus and sulphur on plant population, plant height, root nodules and root nodules dry weight of soybean

Treatments	Plant population (mrl^{-1})		Plant height (cm)			Root nodules (No. plant^{-1})	Effective root nodules (No. plant^{-1})	Dry weight of root nodules (mg plant^{-1})
	30 DAS	Harvest	30 DAS	60 DAS	Harvest			
A. Phosphorus (kg ha^{-1})								
0	10.94	10.58	14.9	39.1	44.2	45.39	30.20	42.54
20	11.02	10.62	15.2	42.7	50.5	51.71	34.02	46.26
40	11.07	10.73	15.6	45.9	54.9	54.93	38.38	50.69
60	11.18	10.73	16.1	47.2	56.9	57.16	40.16	52.48
SEm±	0.20	0.16	0.39	0.71	1.17	1.07	0.73	0.98
CD at 5%	NS	NS	NS	2.08	3.42	3.13	2.15	2.87
B. Sulphur (kg ha^{-1})								
15	10.98	10.63	15.0	40.6	47.2	47.98	33.44	44.48
30	11.06	10.65	15.2	44.5	52.4	53.28	35.93	48.83
45	11.12	10.72	16.0	46.1	55.2	55.63	37.69	50.66
SEm±	0.17	0.13	0.34	0.61	1.01	0.92	0.64	0.85
CD at 5%	NS	NS	NS	1.80	2.97	2.71	1.87	2.48

Table 5. Effect of phosphorus and sulphur on chlorophyll content, leaf area index and yield of soybean

Treatments	Chlorophyll content (mg/g)	Leaf area index	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})
A. Phosphorus (kg ha^{-1})				
0	1.98	3.78	1462	2502
20	2.19	4.43	1566	2674
40	2.31	5.03	1839	3137
60	2.35	5.29	1942	3305
SEm±	0.02	0.11	40	76
CD at 5%	0.05	0.33	117	224
B. Sulphur (kg ha^{-1})				
15	2.09	4.28	1464	2507
30	2.25	4.68	1773	3028
45	2.29	4.95	1870	3179
SEm±	0.01	0.10	35	66
CD at 5%	0.04	0.29	102	194

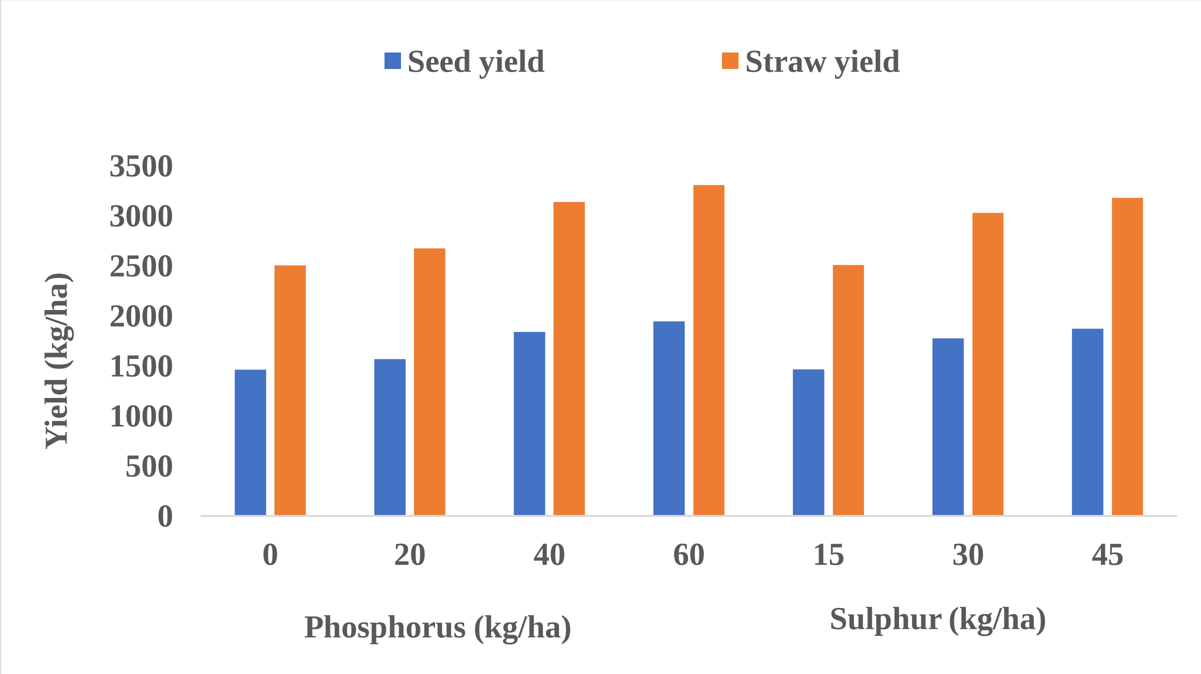

Fig. 1. Effect of phosphorus and sulphur on yield of soybean

3.2 Effect of Phosphorus on Yield

Data pertaining to yields were recorded during experimentation and data presented in Table 5 and depicted in Fig. 1. Aapplication of 60 kg P_2O_5 ha^{-1}produced the maximum seed yield (1942 kg ha^{-1}) which was statistically superior over application of 20 kg P_2O_5 ha^{-1} and control seed yield (1566 and 1462 kg ha^{-1}). The seed yield remained at par with the application of 40 kg P_2O_5 ha^{-1} with the seed yield (1839 kg ha^{-1}) of soybean. The maximum straw yield (3305 kg ha^{-1}) was observed under application of 60 kg P_2O_5 ha^{-1} , which was remained at par with 40 kg P_2O_5 ha^{-1} straw yield (3137 kg ha^{-1}) of soybean over application of 20 kg P_2O_5 ha^{-1} and control. Phosphorous application accelerated the production of photosynthates and their translocation from source to sink, which ultimately gave the higher values of yield contributing characters. Increase in yield contributing characters has also been reported by Meena et al. [11] and Kumar et al. [12]. This was mainly due to fact that the better availability of nitrogen and phosphorus caused well developed root system having higher nitrogen fixing capacity resulting better growth and development of plants and better diversion of photosynthates towards sink, even use of single or combination of fertilizers might be much advantageous for farmers [13].

3.3 Effect of Sulphur on Growth Parameters

Data presented in Table 4 revealed that plant population of soybean at 30 DAS and at harvest was not significantly affected by any of the treatment combination. Thus, plant population was almost uniform in all the treated plots. Further, indicated that plant height at 30 DAS was remained significantly unaffected with the application of sulphur. Significantly highest plant height (46.17 cm) at 60 DAS and (55.24 cm) at harvest was recorded with the application of 45 kg sulphur ha^{-1} in comparison the application of 15 kg sulphur ha^{-1} during the year of investigation. However, it was found at par with the application of 30 kg sulphur ha^{-1} at 60 DAS (44.51 cm) and at harvest (52.49 cm). Application of 45 kg sulphur ha^{-1}was recorded significantly higher total root nodules plant^{-1} (55.63) at 45 DAS which was higher over application of 15 kg sulphur ha^{-1}. However, it was found at par with application of 30 kg sulphur ha^{-1} (53.28) at 45 DAS total root nodules plant^{-1} in Table 5. Application of 45 kg sulphur ha^{-1}was recorded significantly higher effective root nodules plant^{-1} (37.69) at 45 DAS over 15 kg sulphurha^{-1} (33.44) effective root nodules plant^{-1}. However, it was found at par with the application of sulphur30kg ha^{-1} (35.93) effective root nodules plant^{-1}in Table 4. Application of 45 kg sulphur ha^{-1}was recorded significantly higher dry weight of root nodules (50.66 mg plant^{-1}) at 45 DAS over application of 15 kg sulphur ha^{-1}dry weight of root nodules (44.48 mg plant^{-1}). However, it was found with application of 30 kg sulphur ha^{-1} dry weight of root nodules (48.83 mg plant^{-1}). Application of 45 kg sulphur ha^{-1}was recorded significantly higher chlorophyll content mg g^{-1}(2.29 mg g^{-1}) at 45 DAS over application of 15 kg sulphur ha^{-1}. However, it was found at par with application of 30 kg sulphur ha^{-1}(2.25 mg g^{-1}) chlorophyll content in soybean. Significantly highest leaf area index (4.95) at 50 DAS was recorded with the application of 45 kg sulphur ha^{-1} which was higher over15 kg sulphur ha^{-1}. The leaf area index remained at par with application of 30 kg sulphur ha^{-1} at 50 DAS with the value of (4.68).

This may be due to better root development and profuse nodulation on account of increased *rhizobial* activity in the rhizosphere under sulphur and bio fertilizers availability. This finally resulted in the formation of bolder and more number of root nodules. The positive response of sulphur on nodulation was also observed by [14]. The plant height and branches improved by sulphur alone or combined with nitrogen whereas, nitrogen alone decreased number of pods plant^{-1} thus showing non-significant ($P \le 0.05$) variation in grain yield as compared to control. The results corroborate the findings of [15] sulphur application of 40 kg ha^{-1} enhanced the plant height and branches in soybean. he sulphur fertilizer levels recorded significantly variations in leaf area index (3.1) and green leaves plant^{-1} at 45 DAS. This reveals that increasing sulphur level enhanced availability of sulphur in soil and consequently it's mining by soybean crop plants which led to higher size of photosynthetic apparatus. This statement is endorsed by significantly higher chlorophyll content and leaf area index at different growth stages of the crop. The increase in green leaves plant^{-1} and leaf area index with sulphur levels has been ascribed to more dry matter accumulation, this might be due to high accumulation of net photosynthates. The results obtained are consistent with findings reported by [16].

3.4 Effect of Sulphur on Yield

Data pertaining to yields were recorded during experimentation and data presented in Table 5 and depicted in Fig. 1. Application of 45 kg sulphur ha^{-1} gave significantly higher seed yield (1870 kg ha^{-1}) which was higher over application of 15 kg sulphur ha^{-1}. The seed yield remained at par with application of 30 kg sulphur ha^{-1} with the value of seed yield (1773 kg ha^{-1}) of soybean. Application of 45 kg sulphur ha^{-1}attained the maximum straw yield (3179 kg ha^{-1}) and remained at par with 30 kg sulphur ha^{-1} straw yield (3028 kg ha^{-1}) of soybean over application of 15 kg sulphur ha^{-1}. The yield increased under sulphur fertilization might be ascribed to increased pods plant^{-1} and seeds pod^{-1} with heavier seeds. Thus, significant improvement in yield obtained under sulphur fertilization seems to have resulted owing to increased concentration of sulphur in various parts of plant that helped maintain the critical balance of other essential nutrients in the plant and resulted in enhanced metabolic processes [17]. Vyas et al. [18] also noticed increased yield of soybean with application of sulphur. Sulphur plays a vital role in improving vegetative structure for nutrient absorption, strong sink strength through development of reproductive structures and production of assimilates to fill economically important sink [19]. The seeds pod^{-1} and seed yield improved by sulphur as compared to control. The results corroborate the findings with application of 40 kg sulphur ha^{-1} enhanced the pod plant^{-1} and test weight (g) in black gram [20].

4. CONCLUSION

On the basis of present showing, it can be concluded that the application of 40 kg phosphorus ha^{-1} and 30 kg sulphur ha^{-1} were increased growth, number of root nodules, chlorophyll content and yield of soybean in the south eastern part of Rajasthan. Hence this dose of phosphorus and sulphur is proved as productive and remunerative in soybean.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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