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RESEARCH ARTICLE
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Photosynthetic Pigments, Symbiotic Traits, Yield Attributes and Nutrient Uptake of Soybean Crop as Influenced by Soil Amendments on Degraded Vertisol of Chambal Tablelands

I. Rashmi[1], Kuldeep Kumar[1], Ashok Kumar[1], S. Kala[1], Anita kumawat[1], Rama Pal[2], Yushma Sao[3]

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ABSTRACT

Background: Gypsum and organic amendments are potential ameliorants for reclamation of saline and/or sodic soil conditions to improve crop productivity and soil fertility. Application of gypsum at higher dose (>1 t ha^{-1}) with organic amendments such as FYM, crop residue on soybean crop is largely unknown for salt affected soils. Impact of these soil amendments on soybean chlorophyll pigments, symbiotic traits, nutrient uptake, nutrient harvest index, carbohydrate equivalent yield, crop productivity and economic returns is not being addressed properly. This is particularly true for oilseed crop grown under saline conditions.

Methods: A field experiment was conducted for two years (2017 and 2018) to assess the impact of amendments like gypsum, crop residue (CR), farm yard manure (FYM) with recommended dose of nitrogen-phosphorus-potassium (RNPK) fertilizer dose on soybean crop in degraded vertisol with eight treatments and three replications laid in randomized block design.

Result: Results revealed that among treatments, phenological traits such as total chlorophyll (1.561 and 1.593mg g^{-1}), carotenoid (0.156 and 0.154 mg g^{-1}) at 30DAS (days after sowing), nodulation traits (33.6 and 32.4 nodules $plant^{-1}$) and dry matter accumulation (26.2 and 23.9 g $plant^{-1}$ at harvest) improved significantly in RNPK+Gypsum+CR+FYM and RNPK+Gypsum+FYM treatments respectively. Combined application of fertilizers with organic and gypsum amendments increased soybean yield by the magnitude of 49-53% compared to only fertilizer applied treatments. Higher biological yield (4169-4339 kg ha^{-1}), carbohydrate equivalent yield (258.8-266.5 kg ha^{-1}) and nutrient uptake (118: 8:47:11 -140: 9: 57: 12 kg ha^{-1}N:P:K:S) were observed in RNPK+Gypsum+CR±FYM treatments. Economic analysis showed higher net returns and benefit-cost ratio in RNPK+Gypsum+CR (Rs 15247 and 1.48) and RNPK+Gypsum (Rs 14499 and 1.59) treatments.

Key words: Amendments, Chlorophyll, Nodulation, Nutrient uptake, Soybean, Yield attributes.

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is a major *kharif* oilseed crop of central and western India is commonly known as golden bean, containing about 40-42 per cent protein and 18-22 per cent oil occupying almost 11.6 million ha registering productivity of 10.45 q ha^{-1} in vertisol under rainfed ecosystem of Madhya Pradesh, Rajasthan, Maharashtra, Karnataka, Chhattisgarh and Telagana (Dupare *et al.,* 2020). When compared to other soybean cultivating countries, crop productivity is low in India. Major constraints in soybean productivity is mainly attributed to improper land treatment, imbalance nutrient supply, abiotic biotic stress erratic weather patterns and moisture stress (Ramesh *et al.,* 2017). Soybean-mustard and soybean-wheat is the common cropping system of the central and western India. With negligible application of sulfur and continuous cropping of oilseed crops, large scale sulfur deficiency is commonly observed in vertisol (Chahal *et al.,* 2020). Being oilseed legume crop, sulfur requirement of soybean is comparatively higher than cereal crops (Rashmi *et al*., 2018). In India, 41 percent (Singh 2001) and in Rajasthan, 34% of soils are deficient in S (Shukla *et al.,* 2021). Soil salinity, is another major challenge in sustaining oilseed crop production in semi-arid tropics (Ramesh *et al.,* 2017). In this regard, gypsum is known to sustain Ca/ Na and K/Na, in soil solution, reducing soil pH and providing sulfur nutrient to crops (Bello *et al.,* 2021). Maintenance of soil organic matter is pre-requisite for sustainable crop production, however, governed by other factors such as temperature, rainfall, cropping practices *etc*. Farm yard manure (FYM), crop residues (CR), green manure, root exudates significantly contribute to soil organic matter build

[1]ICAR-Indian Institute of Soil and Water Conservation, Research Center, Kota-324 002, Rajasthan, India.
[2]ICAR-Indian Institute of Soil and Water Conservation, Dehradun-248 195, Uttarakhand, India.
[3]Barrister Thakur Chhedilal College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya Bilaspur-495 006, Chhattisgarh, India.

Corresponding Author: I. Rashmi, ICAR-Indian Institute of Soil and Water Conservation, Research Center, Kota-324 002, Rajasthan, India. Email: rashmimenon109@gmail.com

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up in soils. Gypsum supply S, that enhances crops tolerance and resistance to biotic and biotic stress, by increasing chlorophyll components, amino acids and other metabolites thereby improving nutrient uptake (Cannon 2017). Crop residues (CR) application offers innumerable benefits including organic matter addition, moisture conservation, reducing soil erosion, soil fertility improvement and their recycling onto arable lands thus are inevitable strategy for improving soil health and sustainability of agroecosystem on long term basis (Turmel *et al.,* 2015). Crop residue Furthermore, conjoint use of gypsum with organic amendments have great potential in improving crop production and improving crop health. Previous studies on the use of gypsum and FYM as sole amendment has been performed with lower doses on soybean crop (Raza *et al.,* 2018; Bhairwa *et al.,* 2021). Moreover, earlier studies either evaluated saline soil reclamation with gypsum mostly on rice cropping system (Murtaza *et al.,* 2016; Sharma *et al.,* 2016). Imbalanced use of NPK fertilizers, no use of organic sources and sulphur fertilizer by the farmers in the region results in poor yield of soybean crop as well as deterioration of soil health. Limited information of high dose of gypsum and organic amendments application on soybean crop has been reported for saline soils. The study would provide new insights on the impact of soil amendments on crop phenological and yield attributes such as chlorophyll a/b, carotenoids, nodulation traits, carbohydrate equivalent yield and nutrient harvest index in soybean crop grown under saline-sodic soils. Keeping this in view, the present investigation was planned to assess the effect of soil amendments on chlorophyll pigments, symbiotic traits, crop growth and yield attributes, profitability, nutrient uptake and nutrient harvest index (NHI) of soybean crop in degraded vertisols of western India.

MATERIALS AND METHODS

The experiment was conducted for conducted for two consecutive years (2017-18 and 2018-19) at IISWC (Indian Institute of Soil and Water Conservation), Research farm, Kota (Latitude- 25°13′ 29″ to 25°14′ 18″ N; Longitude-75°52′18″ to 75°52′ 44″ E) which is a table land adjacent to Chambal ravine landform in semi arid region of south eastern Rajasthan state, India. Initial soil properties before experiment were recorded having soil pH 8.2, low soil organic carbon 3.5 g kg^{-1}, high exchangeable sodium percentage (ESP) value of 16.7%, low available sulfur (S) content of 4.4 mg kg^{-1}. Gypsum was broadcasted manually at the rate of 2.5 t ha^{-1} before crop sowing. During the experiment 10 t ha^{-1} of farm yard manure (FYM) applied one month before sowing and 3 t ha^{-1} of mustard crop residue (CR) were applied to cover soil suface after sowimg. Soybean as the test crop sown at 30 $\times$ 10 cm spacing during *kharif* season of two years (2017- 2018). Total rainfall received during soybean crop growth period of 2017 and 2018 was 495 and 798.0 mm, respectively. Crop was sown with the commencement of south west monsoon during last week of June to first week of July every year. The experiment was laid out in random block design (RBD) with three replications and eight treatments *viz*.; T1: Control (absolute control); T2: Recommended Dose of Fertilizer (RNPK) for Soybean (N:P:K- 20:40:40 kg ha^{-1}); T3: RNPK+Gypsum (2.5t ha^{-1}); T4: RNPK+FYM (10 t ha^{-1}); T5: RNPK+CR (mustard stover @ 3 t ha^{-1}); T6: RNPK+Gypsum+CR; T7: RNPK+Gypsum + FYM; T8: RNPK+Gypsum+CR+FYM. Nitrogen and phosphorus applied through diammonium phosphate DAP (18% N, 46% P), urea (46% N) and muriate of potash MoP (49.8% K) respectively. Almost 2/3rd of N and full dose of P and K was applied as basal dose during sowing and remaining 1/3rd N was applied after 35 DAS. Soybean biometric observations like nodules per plant and nodule dry weight per plant was recorded from randomly selected five plants at 45 DAS. Dried nodules were used for total N analysis by micro-kjeldahl method. Dry matter accumulation (DMA) at 30, 60 DAS and harvest stage were recorded from all the treatments. Other attributes like chlorophyll a, b, total chlorophyll and carotenoid content assessed during 45 and 60 DAS were calculated using equations based on the specific absorption coefficients (Henry and Grime, 1993). Yield attributing parameters like plant height, pods per plant, 100 seed weight, grain and stover yield was recorded during maturity and harvest. For plant analysis, seed and straw was digested with acid mixtures and was analysed for N by micro kjeldahl method, P by vanadomolybdate yellow color method and K content by flame photometer. Nutrient harvest index for N, P, K, S was calculated by dividing nutrient uptake in seed with total nutrient uptake by crop and multiplied by hundred. The economic yield of soybean crop converted into equivalent value of carbohydrate (kg ha^{-1}) (Gopalan *et al.,* 2004) and carbon output was calculated based on the biomass of the plant which contains on an average 44% carbon (Lal, 2004). Data was statistically analysed following standard procedure based on analysis of variance (ANOVA) using SPSS software (version 23). Means were compared with Turkeys' test at 5% level of significance.

RESULTS AND DISCUSSION

Impact of amendments on chlorophyll pigments, symbiotic traits and biomass of soybean

Chlorophyll a, b and carotenoid content in soybean leaf at 30 and 60 DAS significantly ($p<0.05$) increased in T6, T7 and T8 treatments against control and T2 (Table 1). Gypsum addition supplied sulfur, owing to its role in N metabolism and chlorophyll content in leaves and photosynthetic pigments. In addition, FYM amended treatments showed higher total chlorophyll content in T8 (1.561 mg g^{-1}) and T7 (1.593 mg g^{-1}) at 30 DAS because integration of organic amendments helps in maintenance of essential nutrients, improves nitrogen uptake and with increased N, chlorophyll ('a' and 'b') also increases (Cannon 2017). Moreover, sulfur applied through gypsum plays crucial for Rubisco and

Table 1: Effect of soil amendments on chlorophyll 'a', 'b', total chlorophyll and carotenoid content at 30 and 60 days after sowing of soybean crop.

Treatments	30 DAS (mg/g fresh weight)				60 DAS (mg/g fresh weight)			
	Chl a	Chl b	Total Chl	Carotenoids	Chl a	Chl b	Total Chl	Carotenoids
T1: Control	0.563c	0.094e	0.657d	0.104d	0.395c	0.101e	0.496e	0.066cd
T2: RNPK	0.589c	0.183d	0.772d	0.110c	0.645b	0.228d	0.872cd	0.099c
T3:RNPK+Gypsum	0.913b	0.272c	1.184c	0.138b	0.639b	0.427ab	1.066c	0.111c
T4: RNPK+FYM	0.936b	0.279c	1.215c	0.156a	0.730b	0.383bc	1.112c	0.127bc
T5: RNPK+ CR	0.870bc	0.167d	1.037d	0.150a	0.745ab	0.300c	1.046c	0.123bc
T6:RNPK+Gypsum+CR	1.125a	0.380b	1.504ab	0.156a	0.732ab	0.437a	1.169b	0.131a
T7:RNPK+Gypsum+ FYM	1.127a	0.467a	1.593a	0.154a	0.787a	0.466a	1.252a	0.129a
T8:RNPK+Gypsum+CR+FYM	1.128a	0.433a	1.561a	0.156a	0.801a	0.450a	1.250a	0.134a

Values represented by different lettersin same column differ significantly ($p \leq 0.05$) (RNPK- Recommended dose of fertilizer for soybean 20:40:40 N:P:K kg/ha; Gypsum-2.5 t/ha; CR-mustard crop residue @ 3 t/ha; FYM @ 10 t/ha).

chlorophyll, which are two crucial components for photosynthesis. Raza *et al.* (2018) reported that addition of sulfur improves Chl a and b content and the ratio between Rubisco and plant soluble protein thereby improving net photosynthetic rate of plants. Dry matter accumulation (DMA) recorded at 30, 60 DAS and at harvest illustrated that it increased gradually with advancement of crop age (Table 2). The combination of gypsum with FYM and CR showed higher values of DMA at all stages over control treatments. Our results are in line with those of Gupta *et al.* (2018) and Raghuwanshi *et al.* (2017) who reported similar growth response in soybean and other pulse crops with addition of sulfur and organic manures. Reduced photosynthesis under S deficient conditions of T1(control) and T2 cause decreases in CO_2 assimilation rate and reduce dry matter accumulation in plants. The number of nodules per plant and its dry weight was significantly influenced by different combinations of amendment (Table 2). The number of nodules per plant varied from 11.2 to 33.6 and maximum number of nodules per plant (31.6-33.6) was observed in T5, T6, T7 and T8 treatments which were statistically at par with each other and was two times higher than T2. Addition of gypsum with organic amendments improved the environment for better nodulation and N fixation in soybean. Similarly, maximum dry weight of nodules was also higher in sole and combined amendment treatments over control plots without any amendments (Table 2). Nodule N content followed the similar trend of nodulation and was highest for T8 (2.36%) followed by T7 (2.26%), T6 (2.05) and T5 (1.95%) which was significantly higher than control. Sulfur is an important component of ferredoxin, a Fe protein found in chloroplast. Gypsum added S which is acid producing amendment, regulating soil reaction by improving rhizobium activity showing positive impact on soybean yield. This protein plays metabolic role in N absorption by rhizobacteria in root nodules (Cannon, 2017; Raghuwanshi *et al.,* 2017) and sulfur being component of amino acids, its addition promotes root nodulation in legumes. Improvement in nodulation of soybean crop with addition of FYM with 100% NPK showed maximum and higher nodulation over only NPK (Bairwa *et al.,* 2021).

Impact of amendments on yield attributes, crop yield and profitability analysis

The data on soybean yield attributes such as plant height, branches per plant, 100 seed weight (Table 3) were significantly higher for T8> T7> T6> T5 treatments followed by T3>T5. Maximum number of soybean pods per plant and 100 seed weight was observed in T8 (36.9 pods plant^{-1} and 12.8) followed by T7 (36 pods plant^{-1} and 12.4) and T6 (35.8 pods plant^{-1} and 12.5) respectively. Application of gypsum, crop residue, FYM with chemical fertilizer (T8) in soybean produced highest mean grain yield (1304 kg ha^{-1}) followed by T7 (1264 kg ha^{-1}) > T6 (1251 kg ha^{-1}) and least yield (550 kg ha^{-1}) was observed in control plots. Soybean grain and biological yield varied significantly ($p<0.05$) across the treatments with amendment application. Compared to T2, soybean grain yield increased by 49-53% combined amendment (T6, T7, T8) and 18-38% (T4, T3, T5) in sole amendment treatments. Similarly, these treatments exhibited better performance in soybean biological yield (Table 3). Positive influence of amendments on root nodulation, total chlorophyll content and dry matter accumulation attributed to higher yield in these treatments. Further gypsum application enhanced available S content, bio resource cycling through FYM, CR enhanced soil organic matter, nutrient mobility and soil water storage capacity enhancing crop yield (Rashmi *et al.,* 2021; Gupta *et al.,* 2016). Yadav *et al.* (2019) reported addition of sulfur through gypsum or other sources attributes to improved vigour and development of legume crops as reflected in dry matter accumulation and crop yield. Further, carbohydrate equivalent (266 and 264 kg ha^{-1}) was recorded highest in combined application of organic amendments and gypsum. Similarly, carbon output (1712 kg CO_2 eq. ha^{-1}) was recorded highest in T8 followed by T6 (1696.9 kg CO_2 eq. ha^{-1}) and T7 (1609 kg CO_2 eq. ha^{-1}). This is because of the positive response of combination of soil amendments with RNPK which improved soil environment for optimum crop growth which resulted in

Table 2: Effect of soil amendments on plant height, dry matter accumulation (DMA) and symbiotic traits of soybean crop.

Treatments	Plant height (cm)	Branches	DMA (g/plant)			Nodulation at 45 DAS (Number/plant)	Nodule dry wt (mg/plant)	Nodule N (%)
			30	60	At harvest			
T1:Control	40.4c	2.4c	3.8c	10.7d	14.3e	11.2c	100.8d	1.08d
T2: RNPK	47.2ab	3.3b	4.5bc	12.8c	17.2de	13.5c	111.5d	1.55c
T3: RNPK+Gypsum	46.6ab	3.6a	4.6bc	13.1bc	19.3cd	29.1ab	160.0b	1.76bc
T4: RNPK+FYM	49.1a	4.0a	4.9ab	13.8ab	22.7bc	32.1a	181.0a	1.93ab
T5: RNPK+ CR	46.4ab	3.3b	4.6abc	13.6abc	19.7cd	28.2ab	155.0c	1.74bc
T6: RNPK+Gypsum+CR	48.4a	3.9a	5.4a	14.1a	24.5ab	31.6a	167.5ab	2.05ab
T7: RNPK+Gypsum+ FYM	50.6a	4.0a	5.4a	14.0ab	23.9ab	32.4a	178.8a	2.23a
T8:RNPK+Gypsum+CR+FYM	50.3a	4.0a	5.3ab	14.4a	26.2a	33.6a	178.3a	2.36a

Values represented by different lettersin same column differ significantly ($p \leq 0.05$) (RNPK- Recommended dose of fertilizer for soybean 20:40:40 N:P:K kg/ha; Gypsum-2.5 t/ha; CR-mustard crop residue @ 3 t/ha; FYM @ 10 t/ha).

Table 3: Effect of amendments on yield attributes, crop yield and economic analysis of soybean cropping system.

Treatments	Pods/ Plant	100 Seed weight	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Carbohydrate equivalent yield (kg ha^{-1})	Carbon output (kg CO_2 eq ha^{-1})	Net returns (Rs/ha)	Benefit-cost ratio
T1: Control	28.0c	8.9c	550d	1294d	107.1d	625.1e	129	1.01
T2: RNPK	30.5b	9.6c	921c	2117c	173.1c	986.9e	7531	1.33
T3: RNPK+Gypsum	32.0b	11.1c	1049bc	3317b	205.7c	1282.2d	14499	1.59
T4: RNPK+FYM	34.2ab	11.8ab	1135ab	3428b	238.8b	1347.9c	11033	1.35
T5: RNPK+ CR	32.1b	11.2c	1020bc	3474b	211.0bc	1308.4c	10845	1.39
T6: RNPK+Gypsum+CR	35.8a	12.5a	1251a	4284a	264.3a	1696.9a	15247	1.48
T7: RNPK+Gypsum+ FYM	36.0a	12.4a	1264a	4169a	258.8a	1609.1ab	11504	1.33
T8:RNPK+Gypsum+CR+FYM	36.9a	12.8a	1304a	4339a	266.5a	1712.2a	5410	1.13

Values represented by different lettersin same column differ significantly ($p \leq 0.05$) (RNPK-Recommended dose of fertilizer for soybean 20:40:40 N:P:K kg/ha; Gypsum-2.5 t/ha; CR-mustard crop residue @ 3 t/ha; FYM @ 10 t/ha).

higher yield and total harvested crop biomass. Upadhyay *et al.* (2022) reported higher carbohydrate equivalent yield and carbon output with maximum crop and stover yield in wheat and rice crops. Gypsum amendment addition fetched higher net return especially in T3 (₹ 14499/-) and T6 (₹ 15247/-) treatments as compared to other gypsum treatments (Table 3). Low net return in T7 and T8 treatments was because of high cost of FYM transportation and application in field. Our results are in line with Singh *et al.* (2016) who reported higher cost of FYM and higher energy required for handling, transport, mixing of FYM during agricultural operations. Likewise, highest profitability was observed in RNPK+Gypsum (1.59) and RNPK+Gypsum+CR (1.48) treatments. However, lower values were observed in T7 (1.33) and T8 (1.13) because of high cost incurred on FYM and proportionate return from these amendments were less compared to the cost incurred. Therefore, it is important to note that addition of gypsum with other organic amendments like CR, biofertilizers, green manures and other wastes can be cost effective strategy to reduce not onliy runoff, soil loss, but improve soil quality indices thereby improving crop yield in such degraded ecosystem (Ali *et al.*, 2021).

Impact of amendments on soybean nutrient uptake and nutrient harvest index

Uptake of nutrients by soybean crop (Table 4) increased significantly ($p<0.05$) with different amendment treatment over control. Among nutrients, highest uptake by soybean crop was observed in N followed by K, S and P uptake. Results showed N, P, K and S uptake increased by 90%, 83%, 93.5% and 118% respectively across T6, T7, T8 treatments over T2 plots. Higher nutrient uptake is because of application of gypsum and organic amendment which improved soil properties, enhanced nutrient cycling which might have increase bioavailability of nutrients (Rashmi *et al.*, 2021). Nutrient harvest index (NHI) signifies nutrients transport from soil and fertilizer into economic parts of the crop. Nitrogen, phosphorus, potassium and sulfur index varied from 55.3 to 60.7, 51.7 to 60, 17.3 to 21.8 and 41.2 to 49.4 per cent, respectively, under different soil amendment combinations (Table 4). Application of organic amendments and gypsum with recommended fertilizer dose, illustrated lower NHI, PHI, KHI, SHI values over the T1 and T2 treatment. Thus, NHI decreased with combined amendment application as compared to application of gypsum, organic

Table 4: Effect of soil amendments on nutrient uptake and nutrient harvest index (ratio of nutrient content in grain/ kernel to total nutrient uptake by crop) of soybean crop.

Treatments	Nutrient uptake (kg ha^{-1})				Nutrient harvest index (%)			
	N	P	K	S	NHI	PHI	KHI	SHI
T1: Control	45.5e	3.0d	19.3e	3.1d	56.9bc	51.7c	17.3ab	41.2b
T2: RNPK	70.1cd	4.8d	27.6d	5.5c	59.6a	58.9a	19.3a	48.4a
T3: RNPK+Gypsum	89.8c	6.4bc	34.1bc	8.2b	58.8ab	57.7ab	18.8ab	47.9a
T4: RNPK+FYM	104.0bc	7.0b	41.7b	7.9b	63.4a	62.0a	21.8a	49.4a
T5: RNPK+ CR	91.8c	6.5bc	39.3b	7.0bc	58.9aa	55.5b	21.7a	44.7b
T6: RNPK+Gypsum+CR	122.8ab	8.7a	49.9ab	12.1a	57.5bc	55.9b	20.9a	44.1b
T7: RNPK+Gypsum+ FYM	136.6a	8.8a	53.8a	11.8a	55.7c	55.9b	19.9a	44.2b
T8:RNPK+Gypsum+CR+FYM	139.9a	8.9a	56.5a	12.1a	56.2bc	55.9b	19.0a	43.8b

Values represented by different lettersin same column differ significantly ($p \leq 0.05$) (RNPK- Recommended dose of fertilizer for soybean 20:40:40 N:P:K kg/ha; Gypsum-2.5 t/ha; CR-mustard crop residue @ 3 t/ha; FYM @ 10 t/ha).

resources and fertilizers alone. This reduction in N, P, K and S indices would increase nutrient use efficiency and reducing nutrients removal from agricultural soil leading to sustainable land use (Sheoran *et al.,* 2017).

CONCLUSION

The present study evaluated use of soil amendments like gypsum (2.5 t ha^{-1}) with CR (3 t ha^{-1}) in conjunction with recommended fertilizer dose (T6) improved photosynthetic pigments and other yield attributes increasing soybean yield by 53% and produced maximum return of Rs 15247 kg ha^{-1} over RNPK alone in degraded vertisol. This study suggests a strong basis of incorporating amendments in soil management practices to improve crop productivity and nutrient uptake under similar conditions eleswhere.

Conflict of interest: None.

REFERENCES

Ali, S., Patel, A.M. and Sharma, S. (2021). Impact of cropping system and resource conservation techniques on productivity and profitability of systems. Indian Journal of Agricultural Research. 55(2): 175-180.

Bairwa, J., Dwivedi, B.S., Rawat, A., Thakur, R.K. and Mahawar, N. (2021). Long-term effect of nutrient management on soil microbial properties and nitrogen fixation in a vertisol under soybean-wheat cropping sequence. Journal of the Indian Society of Soil Science. 69(2): 171-178.

Bello, S.K., Alayafi, A.H., AL-Solaimani, S.G. and Abo-Elyousr, K.A.M. (2021). Mitigating soil salinity stress with gypsum and bio-organic amendments: A review. Agronomy. 11: 1735.

Cannon, K.A. (2017). Optimizing Soybean Yield with Nitrogen and Sulfur Applications. Master's Thesis, University of Tennessee, Konxville.

Chahal, H.S., Singh, A. and Malhi, G.S. (2020). Role of sulphur nutrition in oilseed crop production-A review. Journal of Oilseed Brassica. 11(2): 95-102.

Dupare, U., Sharma, P., Billore, S.D. and Verma, S.K. (2020). Impact of climate change on soybean cultivation in malwa and nimar region of Madhya Pradesh: Farmers' Perspective. Soybean Research. 18(1): 87-97.

Gopalan, C., Sastri, R. and Balasubramaniam. (2004). Nutritive Value of Indian foods (Rev. Ed.). Hyderabad, India: National Institute of Nutrition, ICMR. p. 47-57.

Gupta, M., Srivastava, P.K., Shikha, Niranjan, A. and Tewari, S.K. (2016). Use of a bioaugmented organic soil amendment in combination with gypsum for *Withania somnifera* growth on sodic soil. Pedosphere. 26(3): 299-309.

Gupta, S.C., Trivedia, B.K. and Singh, P. (2018). Effect of diverse nutrient application on symbiotic traits, yield attributes, nutrient uptake, microbial population, dehydrogenase activity and productivity of chickpea (*Cicer arietinum* L.) in black Soils. Legume Research. 1-6.

Henry, G.A.F. and Grime, J.P. (1993). Methods in Comparative Plant Ecology (A Laboratory Manual). London: Chapman and Hall.

Lal, R. (2004). Carbon emission from farm operations. Environment International. 30: 981-990. doi: 10.1016/j.envint.2004. 03.005.

Murtaza, B., Murtaza, G., Sabir, M., Owens, G., Abbas, G., Imran, M. and Shah, G.M. (2016). Amelioration of saline-sodic soil with gypsum can increase yield and nitrogen use efficiency in rice-wheat cropping system. Archives of Agronomy and Soil Science. 63(9): 1267-1280.

Raghuwanshi, O.P.S., Raghuwanshi, M.S., Raghuwanshi, S.R.S. and Ahirwar, R.F. (2017). Effect of organic sources in combination with fertilizers on nodulation, growth and yield of soybean (*Glycine max*) in soybean-wheat cropping system in Vidisha district of Madhya Pradesh. Soybean Research. 15(2): 9-14.

Ramesh, K., Patra, A.K. and Biswas, A.K. (2017). Biswas best management practices for soybean under soybean-wheat system to minimize the impact of climate change. Indian Journal of Fertilisers. 13(2): 42-55.

Rashmi, I., Ali, S., Mina, B.L., Kumar, K., Kumar, A. and Singh, R.K. (2021). Short-term effect of resource conservation practices on soil loss, productivity and energy budgeting of soybean-mustard system in table lands of chambal ravine. Agricultural Research. 10(2): 223-233.

Rashmi, I., Mina, B.L., Kumar, K., Ali, S., Kumar, A., Kala, S. and Singh, R.K. (2018). Gypsum-An inexpensive, effective sulphur source with multitude impact on oilseed production and soil quality- A review. Agricultural Reviews. 39(3): 218-225.

Raza, M.A., Feng, L.Y., Iqbal, N., Manaf, A., Bin Khalid, M.H., Rehman, S., Wasaya, A., Ansar, M., Billah, M., Yang, F. and Yang, W. (2018). Effect of sulfur application on photosynthesis andbiomass accumulation of sesame varietiesunder rainfed conditions. Agronomy. 8(149): 1-16.

Sharma, D.K., Singh, A., Sharma, P.C., Dagar, J.C., Chaudhari, S.K. (2016). Sustainable management of sodic soils for crop production: Opportunities and challenges. Journal of Soil Salinity and Water Quality. 8(2): 109-130.

Sheoran, S., Raj, D., Antil, R.S., Mor, V.S. and Dahiya D.S. (2017). Productivity, seed quality and nutrient use efficiency of wheat *(Triticum aestivum)* under organic, inorganic and integrated nutrient management practices after twenty years of fertilization. Cereal Research Communications. 45(2): 315-325.

Shukla, A.K., Behera, S.K., Prakash, C., Tripathi, A., *et al.* (2021). Deficiency of phytoavailable sulphur, zinc, boron, iron, copper and manganese in soils of India. Scientific Reports. 11: 19760.

Singh, M.V. (2001). Importance of sulphur in balanced fertilizer use in India. Fertilizer News. 46: 55- 58.

Singh, R.J., Ghosh, B.N., Sharma, N.K., Patra, S., Dadhwal, K.S. and Mishra, P.K. (2016). Energy budgeting and emergy synthesis of rainfed maize-wheat rotation system with different soil amendment applications. Ecological Indicators. 61(2): 753-765.

Turmel, M.S., Speratti, A., Baudron, F., Verhulst, N., Govaerts, B. (2015). Crop residue management and soil health: A systems analysis. Agricultural Systems. 134: 6-16.

Upadhyay, P.K., Sen, A., Singh Y., *et al*. (2022). Soil health, Energy budget and rice productivity as influenced by cow products application with fertilizers under south asian eastern indo-gangetic plains zone. Frontiers of Agronomy. 3: 758572.

Yadav, N., Yadav, S.S., Yadav, N., Yadav, M.R., Kumar, R., Yadav, L.R., Yadav, V.K. and Yadav, A. (2019). Sulphur management in groundnut for higher productivity and profitability under semi-arid condition of Rajasthan, India. Legume Research. 42(4): 512-517.