Yield, nutrient content and their uptake by groundnut (*Arachishypogeae* L.) as affected by sulphur and planting methods in course textured soil of south-west Haryana, India

Abstract

The groundnut, scientifically known as *Arachis hypogea* L., is a summer legume plant with rising importance in food, industry, and medicine. Sulphur is the master nutrient for oilseed crop production because ithelps in the synthesis of cysteine,methionine, vitamins (B, biotin, and thiamine), metabolism of carbohydrates, oil content, protein content and also associated with growth and metabolism. The experiment was laid out in randomized complete block design in triplications on groundnut cultivar GNH 804in Bawal utilizingthree sulphur levels (0, 25, and 50 kg/ha) and three planting methods (flatbed, flatbed with earthing up, and ridge-furrow). The treatment with 50 kg/ha sulphur in the ridge-furrow method yielded the highest pod yield (2652 kg/ha) and superior nutrient content, including nitrogen, phosphorus, potassium, and sulphur, in both seeds and stover. This treatment also showed superior quality parameters such as oil and protein content and shelling percentage for groundnut. The treatment with 25 kg/ha of sulphur and the flatbed with earthing up method followed closely in performance.

Keywords: Yield nutrient, Groundnut,nutrientuptake,feed crop

INTRODUCTION

Groundnut (*Arachishypogaea*L.) is an important oil, food, and feed crop of the world and belongs to the Leguminosae (Fabaceae) family (Variath and Janila, 2017) [1]. It is also known as 'King of oilseeds' (Priya*et al*., 2013) [2], peanuts, earthnuts, manila nuts, jack nuts, and monkey nuts. In India groundnut was introduced in the middle of the nineteenth century on east coast of the South Arcot district in Tamil Nadu. Groundnut seed contain 43-55 % oil content (Din *et al*., 2009) [3], 24-26 % protein, 45-48 % fat, 3% fiber, and 15-18 % carbohydrate (Shokunbi*et al*., 2012) [4]. It is also used as fodder, seeds, straw, and hay (Smith, 2002) [5,42,43,44]. It is also known as wonder nut and poor men's cashew nut. Besides, the kernels are also rich in vitamins E, K, and all B vitamins except B12 (Naiknaware*et al*., 2015) [6]. It is the richest plant source of thiamine and is also rich in niacin, which is low in cereals. It can be used as food (cooking oil, raw, roasted), feed (green material, straw, seed pressings), and in the industry for raw material (Onyeike and Oguike, 2003) [7].

India is the second largest producer of groundnut in the world after China, followed by the USA and Nigeria. About 80 % of the total area and 84 % of the total production in the country is confined to the states of Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, and Maharashtra but also grown in the states of Rajasthan, Haryana, and Punjab. In India, during 2020-2021, the area under groundnut was 8528 thousand hectares with a production of 10244 thousand tonnes with productivity of 1703 kg ha^{-1} (Anonymous 2020-21) [8]. Whereas in Haryana, the area under groundnut was 9.25 thousand hectares and the production was 9.44 thousand tonnes with an average productivity of 1020 kg ha^{-1} during 2020-21 (Anonymous 2020-21) [8]. Balanced use of fertilizer is a key component of any oilseed production technology. Groundnut is an energy-rich crop therefore it requires the right quantity and source of nutrients. Nutrients most often recommended for successful oilseed farming are nitrogen (N), phosphorus (P), potassium (K), sulphur (S), zinc (Zn), and boron (B).

Sulphur is a secondary macronutrient recognized as the fourth most important nutrient for plant growth and root development after nitrogen, phosphorus, and potassium (Tandon and Messick, 2002 [9]; Jamal *et al.*, 2010 [10]). It plays an important role in the catalytic and electrochemical functions of biomolecules in the plant cells. The overall requirement of sulphur for oil seed crops is as high as phosphorus, so considered as master nutrient for oilseed production and enhances yield as well as crop quality because ithelps in the synthesis of cysteine, methionine, vitamins (B, biotin, and thiamine), metabolism of carbohydrates, oil andprotein content, and also associated with growth and metabolism, especially by its effect on the proteolytic enzymes (Najar*et al.*, 2011) [11].The application of sulphur to the soil improves nitrogenase activity, nitrogen fixation, plant dry matter, and the quality of crops in sulphur-deficient soils (Kandpal and Chandel, 1993) [12]. It helps in the formation of plant proteins and is essential for chlorophyll formation, nodulation, microbial activity, improves root growth, and increases the availability of other nutrients (Singh, 2007) [13].

Groundnuts can be planted using a number of methods which include planting on flat ground (FG), earthing up after planting on flat ground (EFG), planting on raised bed (RB) and planting on ridge (R) (Olayinka*et al.*, 2015) [14]. The performance of crop management techniques like nutrient application, irrigation and weed control, among others, is highly dependent on the design of the land. Due to the groundnut's peculiar mechanism, geotropism, a loose and well-aerated soil surface has an advantageous effect on peg penetration and pod development. Earthing up is the raising of the soil around the plant in order to cover the pegs, depending on the cultivar (Mhungu and Chiteka, 2010) [15]. Jadhav*et al*. (2022) [16]found higher growth, yield, and yield attribute parameters in ridge and furrow system over flat sowing planting method.

MATERIALS AND METHODS

The field experiment was conducted at the Regional Research Station, CCS HAU Bawal during *kharif* 2022 in district Rewari at 28.10° N latitude and 76.50° E longitude with 266 m above mean sea level in south-western area of Haryana, India. The climate of Bawal is semi-arid with average rainfall of 577 mm. The soil of experimental field had loamy sand texture with a pH of 8.17, electrical conductivity (EC) 0.18 dS/m, organic carbon (OC) 0.17 %, available nitrogen (113.10 kg/ha), available phosphorus (11.90 kg/ha) and available potassium (162.10 kg/ ha), respectively as micronutrients in 0-15 cm depth. The experiment was laid out in randomized complete block design in triplications on groundnut cultivar GNH 804. Nine treatments were assigned consisting of three sulphur application levels [0 (S_0), 25 (S_{25}), 50 (S_{50}) kg S/ha] in plot and three planting methods(flatbed, flatbed with earthing up, and ridge-furrow). The recommended dose of fertilizer (RDF) was 15:50:25 kg for N, $P_2O_5$and K_2O /ha, respectively as par package and practices. The fertilizers (RDF, K_2O and $ZnSO_4$) were applied at the time of sowing through soil application. The soil samples were collected at random from the experiment area up to the depth of 0-15 cm from selected plots before overlaying the treatments and after harvesting the crop and analyzed for its various chemical properties. Soil pH and EC were determined in (1:2) soil:water suspension using digital pH meter and direct read type conductivity meter (Jackson 1973) [17], respectively. Soil OC was determined by the Walkley and Black (1934) [18] method. Available nitrogen was determined by alkaline permanganate method (Subbiah and Asija 1956) [19], available P by spectrophotometer at 420 nm (Olsen et al. 1954) [20], available K by ammonium acetate method using a flame photometer (Jackson 1973) [17]. Available sulphur was extracted using a calcium chloride solution at 420 nm (Chesnin and Yien,1951) [21].

Collection and Analysis of plant samples

Samples of seed and stover were collected at the time of harvesting and dried (65±2 °C for 48 hr). The dried samples thus obtained were ground to a fine powder and processed further for estimation of various macronutrients (N, P, K and S). Total nitrogen content in the digested plant material was determined by colorimetric method using Nessler's reagent as described by Lindner (1944). Total phosphorus in plant sample was determined by Vanadomolybdophosphoric acid yellow colour method as proposed by Koenig and Johnson (1942) [23]. Potassium in the acid digest of plant samples was determined by using flame photometer. The data on concentration of NPKS, pod yield and stover yield was used to determine the uptake of nitrogen (N), phosphorus (P), potassium (K), and sulphur (S) using the following formula:

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Nutrient concentration in pod/stover (\%)} \times \text{pod/stover yield (kg ha}^{-1})}{100}$$

Statistical analysis

The data recorded during the experiment was subjected to statistical analysis by proper methods using online statistical package OPSTAT developed by Sheoran*et al.* (1998)**.**

RESULTS AND DISCUSSION

Effect of sulphur

Pod and stover yield

The pod yield was significantly increased due to the application of sulphur up to S_{50}treatment. The highest pod yield (2652kg ha^{-1}) was recorded with S_{50} treatment, followed by (2372kg ha^{-1}) with S_{25} treatment. Both treatments were statistically differentfrom each other and significantly superior over the control (S_0). The increase in pod yield of groundnut was 6.84% and 19.45% due to the application of S_{25} and S_{50} treatment, respectively, over the control S_0 (Table 1).

Applying varying levels of sulphur resulted in an increase in the groundnut stover yield, as illustrated in Table 1. Stover yield ranged from 2937 to 3483 kg ha^{-1}. Notably, the stover yield saw a significant increase with the application of sulphur, particularly up to the S_{50} treatment. The highest stover yield was observed with the S_{50} treatment at 3483 kg ha^{-1}, followed closely by the S_{25} treatment at 3189 kg ha^{-1}. These two treatments showed statistically similar results. In contrast, the control (S_0) yielded the lowest stover at 2937 kg ha^{-1}. Comparatively, the S_{50} and S_{25} treatments resulted in 18.59% and 8.58% higher stover yield, respectively, compared to the control.

Moreover, this isthe role of S in various metabolic and enzymatic processes including photosynthesis, respiration, legume-Rhizobium symbiotic N-fixation, protein synthesis, and more over higher nutrient uptake resulted in higher plant height and number of branches per plant and ultimately helped in realization of higher crop yield. These results can also be ascribed to the effect of sulphur application on cell division, enlargement, and elongation resulting in an overall improvement in plant organs associated with faster and uniform vegetative growth of the crop. The above results are in conformity with the results of Banu*et al.* (2017) [24], Patel *et al.* (2018) [25] and Noman *et al.* (2021) [26] in their work.

Nutrient content and uptake by seed and stover

Sulphur application caused a significant increase in the nutrient content (N, P, K and S) of the groundnut seed. However, the content of nutrients increased with the highest level i.e.,50 kg S ha^{-1}and it significantly differed with 25 kg and 0 kg S ha^{-1}. Results showed that total nitrogen, phosphorous, potassium, and sulphur uptake and content in seed were significantly influenced by different sulphur levels. Both S_{25} and S_{50} treatments recorded significantly higher N (3.43 and 3.56 %), P (0.31 and 0.32 %), K (1.09 and 1.18 %), and S (0.18 and 0.21 %) content and uptake of N (81.87 and 94.54 kg ha^{-1}), P (7.40 and 8.61 kg ha^{-1}), K (26.16 and 31.41 kg ha^{-1}), and S (4.26 and 5.45 kg ha^{-1}) in seed as compared to control.

In case of stover, S_{25} and S_{50} treatments recorded significantly higher N (1.22 and 1.41 %), P (0.17 and 0.20 %), K (0.88 and 0.92 %), and S (0.23 and 0.25 %) content and uptake of N (39.29 and 49.34 kg ha^{-1}), P (5.59 and 7.16 kg ha^{-1}), K (28.26 and 33.89 kg ha^{-1}) and S (7.28 and 9.04 kg ha^{-1}) in stover over the control.

Sulphur might have shown a synergistic effect in increasing the P and K uptake in the crop.The probable reason for higher uptake of S under higher application of sulphur might have increased their concentration in soil solution, which increased the availability and uptake of sulphur by plant.Sulphur availability may influence photosynthetic rate since ferredoxin and acetyl-CoA contain S and play a significant role in the reduction of CO_2 and the production of organic compounds. Also, sulphur is necessary for enzymatic reactions, chlorophyll formation, synthesis of certain amino acids and vitamins, hence, it helps to have a good vegetative growth leading to have a high yield. The results found are in confirmation with the results of Patel and Zinzala (2016) [27], Longkumer*et al.* (2017) [28], Yadav *et al.* (2020) [29], Prusty*et al.* (2020) [30] and Mehmood*et al.* (2021) [31] in their work.

Effect of planting methods

Pod and stover yield

The application of different planting methods also significantly affected the pod yield of groundnut. Significantly, the highest pod yield (2775kg ha^{-1}) was recorded with **Ridge and Furrow**treatment followed by **Flat with earthing up** (2450kg ha^{-1}), both treatments were statistically different. The lowest pod yield (2019kg ha^{-1}) was recorded with control (**Flatbed**). The **Ridge and Furrow**and **Flat with earthing up** treatment produced 37.44 and

21.34 % higher pod yield over control. The interacting effect between sulphur and planting methods was found significant(Table 1).

Similarly, in the case of stover yield, the higherstover yield was recorded with **Ridge and Furrow**treatment(3655kg ha^{-1}), followed by **Flat with earthing up** treatment(3247kg ha^{-1}). However, treatments **Ridge and Furrow**and **Flat with earthing up** were statistically at par with each other. The lowest stover yield (2707kg ha^{-1}) was recorded with control (flat bed). The increased in stover yield was 35.02% and 19.94% due to application of **Ridge and Furrow**and **Flat with earthing up** treatments, respectively over control.

The increase in pod and stover yield might be due to ridges provide loose friable soil with and less mechanical compaction that permitted roots to grow profusely with more length compared to flat bed. This treatment offered more opportunity for peg proximity to the soil surface. For instance, it was observed that pegs produced at the upper parts of the branches had a shorter distance to travel and therefore ended up forming pods as a result of the uniform distance that was maintained between the pegs and the soil surface as the branches extend outward from the main stem. It is also because excess rainfall is properly directed through furrows. It also increases water-use efficiency both under rainfed and irrigated scenarios because water moves laterally from furrows into beds thereby reducing evaporation losses. Similar results were found by Mathukia*et al*. (2014) [32], Olayinka*et al.* (2015) [14], Mvumi*et al.* (2018) [33], Olayinka*et al*. (2021) [34], and Chowdary*et al.* (2022) [35].

Nutrient content and uptake by seed and stover

Results showed that nutrient content was found to be influenced significantly by the planting methodsand their uptakes were also influenced significantly. The application of the**Ridge and Furrow method**showed significantly higher values of uptake of nitrogen (98.01 kg ha^{-1} and 50.43 kg ha^{-1}) by seed and stover in Table 2 and Table 3.Ridge-furrow plays a vital role in enhancing growth, which may be attributed to more conducive soil conditions like proper aeration and adequate availability of moisture essential for emergence that resulted in more crop productivity. Better nutrient uptake in raised bed planting might be due to the fact that ridge-furrow planting resulted in better utilization of available resources like water, nutrients, and sunlight due to favourable microclimate. Similar findings were also illustrated by Singh et. al. (2021)[36], andDodwadiya and Sharma (2012)[37] in their work.

From the findings, it can be concluded that both the seed and stover yield of groundnut significantly increased over the control with the application of S @ 50 kg ha^{-1} andridge-furrow method. Also, the application of sulphur @ 50 kg ha^{-1} and ridge-furrow planting method significantly increases the nutrient content and uptake in seed and stover of groundnut in coarse-textured medium S status soil.

Quality Parameters

Effect of sulphur

The quality parameters such as protein content, oil content and shelling percentage are presented in Table 3. Application of sulphur significantly increased the protein, oil content and shelling %. Significantly, higher protein, oil content and shelling (22.26 ,47.80 and 67.85 %) was recorded with S_{50} treatment, followed by (21.42, 45.65 and 66.08 %) with S_{25} treatment respectively over control. These both the treatments were statistically differ with each other and significantly superior over control. The lowest protein, oil content and shelling (19.51, 43.36 and 64.70%) were recorded with control (S_0), respectively. This might be due to the fact that sulphur application improved over all nutritional environment of the Rhizosphere as well as plant system which could be more advantageous for profused vegetative and root growth which activated higher absorption of nutrients from the soil and improved metabolic activities inside the plant. These results may be attributed to the sulphur plays an important role in synthesis of essential amino acids like cysteine, methionine and certain vitamin like biotin, thymine as well as the formation of ferrodoxin (iron-containing plant protein) that act as an electron carrier in the photosynthetic process and chlorophyll which required for the production of oil. Sulphur besides being a structural component of protein is also directly involved in protein bio-synthesis This might be due to the synergistic effect of sulphur on nitrogen uptake which facilitates protein synthesis and activates different enzymes. The results are found to be similar with the results from Rao *et al.* (2013)[38], Kannan *et al.* (2017)[39], Patel *et al.* (2018)[40] and Prusty*et al.* (2020) [41].

Effect of planting methods

The quality parameters such as protein content, oil content and shelling percentage are presented in Table 3. Significant differences were observed among the different planting methods evaluated. The findings revealed that the application of ridge-furrow method significantly influences the protein, oil content and shelling of groundnut. Protein, oil content and shelling varied from 22.06, 46.25 and 67.85 percent under the treatment ridge-furrow followed by the treatment flat bed with earthing up (20.99, 45.75 and 66.27%) while, the minimum value of protein, oil content and shelling (20.14, 44.82 and 64.51%) were observed under control (flatbed) respectively. The results are in agreement with the findings of Olayinka*et al.* (2015)[14].

CONCLUSION

The research findings indicate that varying levels of sulphur and different planting techniques have a significant impact on growth parameters. Among these, employing the ridge-furrow planting method along with a higher application of 50kg sulphur per hectare proves to be the most effective approach for enhancing both the quality and yield parameters of groundnut. This method surpasses the flat bed and flat bed with earthing up planting methods, as well as lower sulphur application rates. However, it's worth noting that the flat bed with earthing up technique, particularly when combined with 50kg sulphur, also yields favourable results compared to the control method. The highest yields of groundnut seed and stover are achieved through ridge-furrow planting with 50 kg sulphur, outperforming all other treatments.

Table 1. Effect of S levels and planting method on yields and quality parameters of groundnut

Treatment	Pod yield (q/ha)	Stover yield (q/ha)	Oil (%)	Protein (%)	Shelling (%)
S levels (kg/ha)					
0	22.20	29.37	45.36	19.51	64.70
25	23.72	31.89	45.65	21.42	66.08
50	26.52	34.83	47.80	22.26	67.85
CD (p=0.05)	1.25	3.27	1.51	0.63	1.55
Planting Methods					
Flat Bed	20.19	27.07	44.82	20.14	64.51
Flat bed with earthing up	24.50	32.47	45.75	20.99	66.27
Ridge and Furrow	27.75	36.55	46.25	22.06	67.85
CD (p=0.05)	1.25	3.27	NS	0.63	1.55
Interaction	2.16	NS	NS	NS	NS

Table 2. Effect of S levels and planting method on nutrient content and their uptake in groundnut

Treatment	Content in seed (%)				Uptake (kg/ha)			
	N	P	K	S	N	P	K	S
S levels (kg/ha)								
0	3.12	0.29	0.99	0.16	69.75	6.57	22.21	3.64
25	3.43	0.31	1.09	0.18	81.87	7.40	26.16	4.26
50	3.56	0.32	1.18	0.21	94.54	8.61	31.41	5.45
CD (p=0.05)	0.11	0.01	0.07	0.01	4.36	0.46	2.39	0.41
Planting Methods								

Flat Bed	3.20	0.29	0.96	0.17	65.56	5.94	19.52	3.52
Flat bed with earthing up	3.33	0.31	1.10	0.18	82.59	7.64	27.15	4.53
Ridge and Furrow	3.53	0.32	1.19	0.19	98.01	9.01	33.10	5.30
CD (p=0.05)	0.10	0.02	0.07	NS	4.35	0.46	2.39	0.41
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Table 3. Effect of S levels and planting methods on nutrient content and their uptake in groundnut

Treatment	Content in stover (%)				Uptake (kg/ ha)			
	N	**P**	**K**	**S**	**N**	**P**	**K**	**S**
S levels (kg/ha)								
0	1.12	0.16	0.85	0.20	33.65	4.75	25.09	5.97
25	1.22	0.17	0.88	0.23	39.29	5.59	28.26	7.28
50	1.41	0.20	0.92	0.25	49.34	7.16	33.89	9.04
CD (p=0.05)	0.18	0.02	NS	0.01	7.50	0.60	4.83	0.82
Planting Methods								
Flat Bed	1.11	0.17	0.79	0.19	30.17	4.49	21.46	5.18
Flat bed with earthing up	1.27	0.18	0.88	0.22	41.67	5.77	29.69	7.28
Ridge and Furrow	1.37	0.20	0.98	0.27	50.43	7.25	36.09	9.82
CD (p=0.05)	0.18	0.02	0.08	0.01	7.50	0.60	4.83	0.82
Interaction	NS	NS	NS	0.02	NS	NS	NS	1.23

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