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RESEARCH ARTICLE

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Impact of Phosphorus and Sulphur Levels on Growth Parameters of Groundnut (*Arachis hypogaea* L.)

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ABSTRACT

Background: Groundnut, a well-recognized oilseed crop belonging to the Leguminosae family, faces several challenges in India that results in lesser productivity compared to the global average. The principal underlying cause of India's diminished groundnut production lies in the irregular and inadequate utilization of essential nutrients. Given its status as a leguminous oilseed crop, it exhibits a heightened demand for phosphorus, calcium and sulphur, which often remains unmet, further exacerbating the problem.

Methods: In a field experiment, split-plot design was employed to investigate the impact of four phosphorus levels (Control, 40, 50 and 60 kg P_2O_5 ha^{-1}) and four sulphur levels (Control, 25, 50 and 75 kg S ha^{-1}) on the growth parameters of groundnut.

Results: The findings demonstrate that the utilization of phosphorus and sulphur fertilizers yielded significant improvements in various aspects of groundnut growth parameters. These improvements encompassed increased plant height, root length, improved root-to-shoot ratio on a length and weight basis, greater numbers of root nodules per plant and dry weight of root nodules per plant.

Key words: Groundnut, Growth, Nodules, Phosphorus, Sulphur.

INTRODUCTION

The most crucial task that requires attention is to increase oil seed productivity in general and groundnut productivity in particular. Compared to the 11 kg/person/year recommendation made by the WHO, India's per capita use of oil climbed from 3 kg in 1949 to 18.5 kg in 2016. To keep up with current growth rates, our domestic oil output must increase more quickly to meet the future demand (Vaishnav *et al*., 2023). One of the most well-known oilseed crops is groundnut (*Arachis hypogaea* L.), which belong to the Leguminosae family and subfamily Papilionaceae. Its origin is traced back to South America (Hussainy *et al.,* 2023). Worldwide, groundnut cultivation spans an extensive area of 29.7 million hectares, resulting in a substantial production of 50.8 million tonnes, with an impressive productivity rate of 17.1 quintals per hectare (Anonymous 2020). China is the largest global producer of groundnuts followed by India. An estimated 28.30% of the total oilseeds farmed land in India is used to grow groundnuts, which make up 31.7% of the country's overall oilseed production (Ali *et al.,* 2021). Groundnut, classified as a leguminous oilseed crop, exhibits a pronounced demand for essential nutrients such as phosphorus, calcium and sulphur (Kamal *et al*., 2023a).

For a crop to produce well, phosphorus is thought to be an essential mineral fertilizer. (Hasan *et al.,* 2021). Phosphorus can be found in various forms within soil, encompassing both organic and inorganic states. The distribution of these forms varies significantly across different soil types. Organic phosphorus, due to its strong association with soil colloids, is typically inaccessible to plants and necessitates decomposition and release through mineralization processes for uptake (Filippelli, 2002). Inorganic forms of phosphorus ($H_2PO_4^-$ and HPO_4^-) are readily accessible to plants for uptake and utilization in their growth and development, but the soil solution contains very little of it (Weil and Brady, 2017). The introduction of inorganic phosphorus fertilizers into the soil effectively elevates the concentration of phosphorus in the soil solution (Sikka *et al*., 2022). One of the main elements that promotes root growth and facilitates water and nutrient uptake from deeper soil layers is phosphorus. It holds a pivotal role as an essential component within the cell nucleus, where it contributes significantly to cell division and the formation of meristematic tissue during plant development (Kumar *et al*., 2016). The groundnut crop increases soil fertility by storing atmospheric nitrogen within the nodules of its roots. Utilizing phosphorus increases plant growth, development, yield and determines how well plants reproduce (Kesh and Yadav, 2016; Bairagi *et al.,* 2017). Further, for the better growth of the oilseeds, sulphur is an essential element. After nitrogen, phosphorus and potassium, sulphur is recognized as the fourth essential plant nutrient (Kamal *et al*., 2024; Yadav *et al.,* 2018). It makes up succinyl Co-A, a crucial component in the production of chlorophyll. By promoting overall enhancements and stimulating cellular activation, it participates in the activation of numerous enzymes

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responsible for the dark reaction of photosynthesis, thereby increasing photosynthetic and meristematic activities (Solaimalai *et al.,* 2020). It plays a vital role in numerous metabolic enzyme processes within plants and affects productivity both quantitatively and qualitatively. Sulphur is indispensable for the synthesis of sulfate-containing amino acids like methionine and cysteine, making it a critical element in the production of plant proteins (Kamal *et al*., 2023b). Sulphur not only helps in promoting nodulation and N fixation but also thought to improve the nutritional and market value of the crop. Keeping in mind the aforementioned facts, the present study was undertaken to know the impact of different phosphorus and sulphur levels on growth parameters of groundnut.

MATERIALS AND METHODS

Experimental site and location

The field experiment was carried out at the drought plots area, Crop Physiology Field Lab, CCS Haryana Agricultural University, Hisar, Haryana (India) located at 29°10′N latitude and 75°46′E longitude at an elevation of 215 m above mean sea level during the *Kharif* season of 2021. The soil at the research site has a sandy texture determined by International Pipette Method (Piper, 1966), slightly alkaline in pH (8.1) determined by Glass electrode pH water method by making soil-to-water suspension of 1:2.5 ratio (Jackson, 1973), low in organic carbon (0.12%) determined by Wet oxidation method (Jackson, 1973), low in available N (131.4 kg ha^{-1}) determined by using Alkaline permanganate method (Subbiah and Asija, 1956), medium in available P (15.8 kg ha^{-1}) determined by Olsen's calorimetric method (Olsen *et al.,* 1954), medium in available K (137.6 kg ha^{-1}) determined by Flame photometric method (Richards, 1954) and low in available S (19.4 kg ha^{-1}) determined by Turbidimetric method using a spectrophotometer (Chesnin and Yien, 1950).

The experiment design included four levels of phosphorus in the main plots (Control, 40, 50, 60 kg P_2O_5 ha^{-1}) and four levels of sulphur in the sub-plots (Control, 25, 50 and 75 kg S ha^{-1}). The sixteen treatment combination were laid out in split plot design and repeated three times. At proper moisture condition, the field was ploughed twice with hand plough manually followed by planking. Layout was performed and fertilizers were applied before sowing as per treatments. Sowing of groundnut variety GNH 804 was done manually with the help of hand plough at row spacing 30 cm on June, 2021. Weeds were removed by hand pulling at 25-30 and 45-50 days after sowing (DAS) in all the plots. Three irrigations were applied to the crop during the crop season depending on the need of the crop. Last irrigation was given a few days before harvesting to facilitate the easy recovery of pods from the soil.

Observations recorded

Plant height and root length were recorded at 30, 60, 90 DAS and at maturity. Three plants in each plot were selected randomly as true representative of the whole plot and were labeled. The height of the main shoot was measured from ground level to top of the shoot of the plant with the help of meter rod (cm) to determine plant height. Three plants from each replication were taken out with roots after thorough washing of the sand by gentle water jet. The root length of three plants was measured (cm) with metre rod and their average was determined for each treatment and expressed in cm. After that nodules of all the three plants were counted. Average of three plants was worked out and expressed as nodules per plant. After counting the nodules, they were removed from the roots and after sun drying, nodules were oven dried at 80°C for 72 hours and their dry weight was recorded. The average dry weight of the nodules per plant was worked out and expressed in mg per plant. The Root Shoot ratio was calculated at 30, 60, 90 DAS and at maturity. Root shoot ratio on length basis is calculated by dividing root length to shoot length. Root shoot ratio on weight basis is calculated by dividing dry weight of below ground plant parts (root, nodule) to dry weight of above ground plant parts (stem, leaves, pods). All the data recorded were analyzed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez, 1984) for split plot design. At a 5% level of significance, the effect of treatments was examined using the least significant test.

RESULTS AND DISCUSSION

Effect of phosphorus and sulphur levels on plant height and root length

A perusal of data in Table 1 depicted that irrespective of phosphorus and sulphur levels plant height was continuously increased up to maturity but maximum increase was recorded between 30-60 DAS stage followed by marginal increase between 60 DAS to maturity. Plant height was significantly affected by phosphorus levels at all the stages of observations. With the successive increase of phosphorus levels from 0 to 60 significant increase in plant height was recorded at all the stages of observations. Non-significant variation regarding plant height was observed between 50 and 60 kg P_2O_5 ha^{-1}. Among phosphorus levels significantly higher plant height at 30 DAS (14.45 cm), 60 DAS (38.60 cm), 90 DAS (53.90 cm) and maturity (56.31 cm) was recorded with 60 kg ha^{-1} phosphorus level, which were 41.1, 20.3, 9.6 and 11.3 per cent higher over control, respectively. A delve to data given in Table 1 presented that root length increased rhythmically from sowing to 90 DAS and decreased thereafter up to maturity with the levels of both phosphorus and sulphur. With increasing dose of phosphorus root length increased at all the stages of observations except maturity and the maximum root length was obtained with the application of 60 kg P_2O_5 ha^{-1}, which was significantly higher over control and statistically at par with 50 kg P_2O_5 ha^{-1}. At maturity phosphorus levels failed to produce significant variation regarding root length. Root length of the groundnut receiving 60 kg P_2O_5 ha^{-1} was 11.9, 10.3 and 7.0 per cent higher over control at 30, 60 and 90

DAS, respectively. In order to correlate root absorption of water and nutrients, root length is a superior measure. Despite a significant endodermal thickness, water and the main nutrients (N, P and K) are absorbed relatively effectively over the length of the root. In legume crops, root development may reach its maximum at about pod-setting growth stage. This could be owing to the increased nutrient availability at greater phosphorus doses, as well as phosphorus contributes to the growth of roots with a wider root system. Kabir *et al*. (2013); Kamara *et al*. (2011) and Kesh *et al*. (2017a, b) reported similar results.

Sulphur levels have also affected plant height significantly at all the stages of observations. Plant height was significantly increased with increasing levels of sulphur up to 75 kg ha^{-1} at all the stages of observations but non-significant variation was observed between 50 and 75 kg ha^{-1}. Sulphur level of 75 kg ha^{-1} recorded significantly higher plant height at 30 DAS (13.74 cm), 60 DAS (36.94 cm), 90 DAS (53.26 cm) and maturity (55.15 cm), which were 38.9, 6.2, 6.2 and 5.3 percent higher over control, respectively. With the increasing levels of sulphur root length increased at all stages and the maximum root length *i.e*., 59.66 cm, 86.25 cm and 96.12 cm at 30, 60 and 90 DAS, respectively were observed in the treatment 75 kg S ha^{-1} closely followed by 50 kg S ha^{-1} and these were 6.2, 7.7 and 3.8 per cent higher over control, respectively. The increased growth may be related to sulphur ability to promote more easily formed roots, which in turn encouraged greater uptake of sulphur and other essential nutrients from the soil and work on metabolic movement within the plant, which may be the reason for the increase in plant height and root length. Similar results were recorded by Devi *et al.* (2022) and Yadav *et al.* (2018).

Effect of phosphorus and sulphur levels on Root: Shoot

A critical examination of data on root: shoot (length basis) of groundnut (Table 2) as influenced by different phosphorus and sulphur levels indicated that the root: shoot (length basis) was maximum at 30 DAS which decreased with the advancement of crop growth up to maturity of crop. No marked differences in root: shoot (length basis) was observed at 60 and 90 DAS between different phosphorus levels. The lower root: shoot (length basis) at all stages was recorded in the groundnut crop fertilized with 60 kg P_2O_5 ha^{-1}. A perusal of data in Table 2 depicted that no marked differences in root: shoot (weight basis) were observed at 30, 60 and 90 DAS between different phosphorus levels. The perusal of data on root: shoot (weight basis) of groundnut was maximum at 30 DAS which decreased with the advancement of crop growth up to the maturity of crop. Plants have developed a range of developmental, physiological and biochemical responses to deal with phosphorus deprivation. Inhibition of photosynthesis and a rise in the root: shoot ratio (measured in biomass or dry weight) are common responses. The decrease in shoot growth and the increase in the allocation of carbon from shoots to roots under phosphorus deprivation are the main causes of the increase in the root: shoot ratio. The findings of Hermans *et al*. (2006) and Liu, (2021) are strongly supported by the observed association. Significant differences for root: shoot (length basis) among sulphur levels were recorded at 30 DAS, while non significant difference was recorded at 60 DAS, 90 DAS and at maturity. No marked differences in root: shoot (weight basis) was observed at 30 and 90 DAS between sulphur levels. The higher root: shoot (weight basis) at 60 DAS (0.161) was recorded in control, while at maturity (0.029) recorded at 75 kg S ha^{-1}, compared to other sulphur levels. A decrease in shoot growth and an increase in the allocation of carbon from shoots to roots under control are the main causes of the rise in the root/shoot ratio. The outcomes are consistent with the conclusions reached by Kumar *et al*. (2021).

Table 1: Effect of phosphorus and sulphur levels on plant height and root length of groundnut.

Treatments	Plant height (cm)				Root length (cm)			
	30 DAS	60 DAS	90 DAS	Maturity	30 DAS	60 DAS	90 DAS	Maturity
Phosphorus levels								
Control	10.24	32.06	49.15	50.26	54.41	78.74	90.39	73.58
40 kg P_2O_5 ha^{-1}	12.79	35.56	52.10	53.96	58.42	83.86	94.67	75.58
50 kg P_2O_5 ha^{-1}	14.14	37.87	53.50	55.57	60.08	86.04	96.57	76.67
60 kg P_2O_5 ha^{-1}	14.45	38.60	53.90	56.31	60.92	86.90	97.41	76.92
SEm ±	0.47	0.30	0.29	0.28	0.87	0.85	0.46	0.69
CD at 5%	1.28	1.04	1.02	0.96	3.10	3.00	1.65	NS
Sulphur levels								
Control	10.79	34.77	50.13	52.34	56.17	80.02	92.57	74.58
25 kg S ha^{-1}	12.64	35.84	52.06	53.84	58.58	83.80	94.70	75.67
50 kg S ha^{-1}	13.44	36.55	53.19	54.77	59.42	85.46	95.64	76.17
75 kg S ha^{-1}	13.74	36.94	53.26	55.15	59.66	86.25	96.12	76.33
SEm ±	0.09	0.24	0.37	0.39	0.50	0.71	0.74	0.71
CD at 5%	0.27	0.70	1.08	1.15	1.49	2.09	2.17	NS

Effect of phosphorus and sulphur levels on number of root nodules and dry weight of root nodules

A disquisition to data given in Table 3 exhibited that irrespective of phosphorus and sulphur levels, number of root nodules per plant and dry weight of root nodules per plant continuously increased up to 90 DAS and then reduced at maturity but maximum increase was recorded between 30-60 DAS stage followed by marginal increase between 60 DAS to 90 DAS and then reduced at maturity. With the successive increase of phosphorus levels up to 60 kg ha^{-1} significant increase in number of root nodules per plant was recorded at all the stages of observations. Non-significant variation regarding number of root nodules per plant were observed between 50 and 60 kg P_2O_5 ha^{-1} and at 30 DAS non-significant variation was recorded between 40-50 kg P_2O_5 ha^{-1} also. Among phosphorus levels, significantly higher numbers of root nodules per plant at 30 DAS (15.25), 60 DAS (63.83), 90 DAS (83.75) and maturity (61.25) were recorded with 60 kg P_2O_5 ha^{-1}, which was 22.8, 29.8, 15.7 and 14.5 per cent higher over control, respectively. Dry weight of root nodules per plant was significantly affected by phosphorus levels at all the stages of crop growth. With the successive increase of phosphorus levels up to 60 kg ha^{-1} significant increase in weight of root nodules per plant was recorded at all the stages of observations. Non-significant variation regarding weight of root nodules per plant were observed between 40-50 kg P_2O_5 ha^{-1} and 50-60 P_2O_5 kg ha^{-1} at 90 DAS and at maturity and at 30 DAS non-significant variation was recorded among all the phosphorus levels. Significantly higher weight of root nodules per plant at 30 DAS (42.78 mg), 60 DAS (207.25 mg), 90 DAS (211.00 mg) and maturity (185.75 mg) was recorded with 60 kg ha^{-1} phosphorus level which was 10.7, 8.6, 7.3 and 5.9 per cent higher over control, respectively. The development of

Table 2: Effect of phosphorus and sulphur levels on Root: Shoot of groundnut.

Treatments	Root: Shoot (length basis)				Root: Shoot (weight basis)			
	30 DAS	60 DAS	90 DAS	Maturity	30 DAS	60 DAS	90 DAS	Maturity
Phosphorus levels								
Control	5.498	2.487	1.848	1.466	0.375	0.141	0.084	0.018
40 kg P_2O_5 ha^{-1}	4.643	2.362	1.817	1.400	0.334	0.146	0.085	0.027
50 kg P_2O_5 ha^{-1}	4.419	2.272	1.816	1.389	0.324	0.147	0.085	0.031
60 kg P_2O_5 ha^{-1}	4.347	2.255	1.812	1.368	0.329	0.144	0.087	0.031
SEm ±	0.207	0.058	0.034	0.019	0.027	0.001	0.001	0.000
CD at 5%	0.730	NS	NS	0.006	NS	NS	NS	0.001
Sulphur levels								
Control	5.413	2.323	1.848	1.426	0.362	0.161	0.087	0.023
25 kg S ha^{-1}	4.688	2.350	1.827	1.407	0.333	0.142	0.085	0.027
50 kg S ha^{-1}	4.428	2.350	1.807	1.398	0.324	0.135	0.085	0.028
75 kg S ha^{-1}	4.378	2.352	1.810	1.392	0.343	0.138	0.084	0.029
SEm ±	0.173	0.055	0.029	0.018	0.029	0.001	0.001	0.001
CD at 5%	0.508	NS	NS	NS	NS	0.004	NS	0.002

Table 3: Effect of phosphorus and sulphur levels on number of root nodules and dry weight of root nodules of groundnut.

Treatments	Number of root nodules per plant				Dry weight of root nodules (mg/plant)			
	30 DAS	60 DAS	90 DAS	Maturity	30 DAS	60 DAS	90 DAS	Maturity
Phosphorus levels								
Control	12.41	49.16	72.33	53.48	38.63	189.25	195.50	174.75
40 kg P_2O_5 ha^{-1}	14.50	56.50	76.91	57.83	40.00	197.75	203.50	181.08
50 kg P_2O_5 ha^{-1}	14.66	61.16	81.50	60.25	41.00	203.25	208.50	183.75
60 kg P_2O_5 ha^{-1}	15.25	63.83	83.75	61.25	42.78	207.25	211.00	185.75
SEm ±	0.20	1.12	1.03	0.61	0.45	1.30	1.74	0.81
CD at 5%	0.72	3.96	3.65	2.16	NS	4.59	6.15	2.88
Sulphur levels								
Control	13.58	53.41	75.00	54.58	40.00	193.00	199.25	177.08
25 kg S ha^{-1}	14.16	57.00	78.00	57.91	40.43	198.00	204.25	180.83
50 kg S ha^{-1}	14.50	59.50	80.25	59.58	40.78	202.25	207.00	183.33
75 kg S ha^{-1}	14.58	60.75	81.25	60.66	41.20	204.25	208.00	184.08
SEm ±	0.13	0.82	0.64	0.47	0.35	1.34	1.46	1.24
CD at 5%	0.40	2.42	1.90	1.40	NS	3.94	4.29	3.66

nodules is a key component of the Biological Nitrogen Fixation (BNF) process. In order to transfer energy during nodule functioning, metabolic processes including N-fixation that occur in Bacteroides as well as the assimilation of ammonium into amino acids and ureides that occur in the plant cell component of nodules, require a significant amount of phosphorus. These findings suggest that the capacity to nodulate and the dry weight of root nodules are not just inherited traits but can also be altered by fertiliser applications including phosphorus. Similar results have been reported by Gentili *et al*. (2006), Lira *et al*. (2015) and Singh *et al*. (2014).

Sulphur levels also affected number of root nodules per plant significantly at all the stages of observations. Number of root nodules per plant were significantly increased with increasing levels of sulphur up to 75 kg ha^{-1} at all the stages of observations but non-significant variation was observed between 50 and 75 kg S ha^{-1} and at 30 DAS non-significant variation was recorded between 25-50 kg ha^{-1} also. Sulphur level of 75 kg ha^{-1} recorded significantly higher number of root nodules per plant at 30 DAS (14.58), 60 DAS (60.75), 90 DAS (81.25) and maturity (60.66), which were 7.3, 13.7, 8.3 and 11.1 percent higher over control, respectively. Sulphur levels also affected dry weight of root nodules per plant significantly at all the stages of observations. Dry weight of root nodules per plant were significantly increased with increasing levels of sulphur up to 75 kg ha^{-1} at all the stages of observations but non-significant variation was observed between 25-50 kg S ha^{-1} and 50-75 kg S ha^{-1} at 90 DAS and at maturity. Non-significant variation was recorded among all the sulphur levels at 30 DAS. Sulphur level of 75 kg ha^{-1} recorded significantly higher dry weight of root nodules per plant at 30 DAS (41.20 mg), 60 DAS (204.25 mg), 90 DAS (208 mg) and maturity (184.08 mg), which were 2.9, 5.8, 4.4 and 3.8 percent higher over control, respectively. The maximum number of nodules and dry weight of root nodules increase with successive increase in sulphur levels might be attributed to sulphur, which is a secondary essential plant nutrient required for growth and development. Sulphur plays a crucial role in many physiological and biochemical processes that are essential for plant development, its application to deficient soil can promote overall growth. Sulphur is linked to the enhancement of amino acids and vitamins that contain sulphur and has a direct impact on the growth and nodulation of roots. Stronger apical development and an extension of the photosynthetic surface appear to be the results of increased metabolic activity in plants, which could explain the significant impact of sulphur fertilizer on the number of nodules. The observed association closely matches the results of Parakhia *et al.,* (2016) and Yadav *et al*., (2018).

CONCLUSION

The results of the present study revealed that phosphorus and sulphur application significantly improved the growth parameters in comparison to control condition. The maximum increment was recorded at 60 kg P_2O_5 ha^{-1} and 75 kg S ha^{-1} level. However, the difference between 50 and 60 kg levels of phosphorus and 50 and 75 kg levels of sulphur was found non-significant for most of the studied parameters. So, based on the observed findings, it could be concluded that the application of 50 kg P_2O_5 ha^{-1} and 50 kg S ha^{-1} was most suitable for obtaining the better growth of groundnut.

Conflict of interest

There is no conflict of interest.

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