

Phosphorus uptake of groundnut under high density plantations with graded levels of phosphorus

T.S. Kumar¹, V. Sumathi², Y. Reddiramu³, M.S.S.C. Satya⁴ and Sanjay-Swami^{4*}

¹Department of Agronomy, NMCA, Navsari Agricultural University, Navsari-396 450, India

²Department of Crop Production, Perumallapalli Research Station, Tirupati-517 502, India

³Department of Crop Production, DAATTC Centre, Kalikiri, Chittoor-517 243, India

⁴School of Natural Resource Management, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University, Umiam - 793 103, India

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*Corresponding Author Email : sanjayswamionline@gmail.com

*ORCID: <https://orcid.org/0000-0001-8961-4671>

Abstract

Aim: To determine the optimum level of phosphorus for higher yield and phosphorus uptake by groundnut at different planting densities.

Methodology: A field experiment was laid out in randomized block design with factorial concept during Rabi season 2019-20 to study the phosphorus uptake by groundnut under high density plantation (22.5 x 10 cm - 4.44 lakh ha⁻¹; 20 x 7.5 cm - 6.66 lakh ha⁻¹; 22.5 x 5 cm - 8.88 lakh ha⁻¹ with graded levels of phosphorus (25, 37.5, 50 and 62.5 kg P₂O₅ ha⁻¹).

Results: The present study revealed that 4.44 lakh ha⁻¹ registered lower phosphorus uptake and application of 62.5 kg P₂O₅ ha⁻¹ recorded a higher uptake of phosphorus and soil available nitrogen, phosphorus, and potassium. Interaction was significant only in influencing pod yield. Higher pod yield was recorded in the population density of 4.44 lakh ha⁻¹ applied along with 50 kg P₂O₅ ha⁻¹, followed by 6.66 lakh ha⁻¹ applied with 62.5 kg P₂O₅ ha⁻¹.

Interpretation: The results indicate that for better nutrient uptake and higher pod yield of groundnut, farmers should prefer a planting density of 6.66 lakh ha⁻¹ with an application of 62.5 kg P₂O₅ ha⁻¹.

Key words: Groundnut, Nutrient uptake, Plant density, Phosphorus, Pod yield



Introduction

Groundnut (*Arachis hypogaea* L.), is an important legume crop and a valuable source of protein and oil in tropical and subtropical regions of the world. Groundnut production is effected by a number of environmental conditions, including low soil phosphorus and nitrogen levels and water stress (Singh, 2011). As groundnut cultivation employs a large number of women processing, and marketing, it is sometimes referred to as a "women's crop" in the West and Central Africa, which promotes their economic involvement and empowerment (Sinare et al., 2021). Phosphorus is essential for plant growth and sustainable development (Muhaba and Dakora, 2020; Bindraban et al., 2020). According to Heuer et al. (2017), mineral phosphorus fertilizer are essential for ensuring food security, but their limited mobility results in low phosphorus use efficiency. The ongoing agricultural cultivation with inappropriate fertiliser applications deteriorates soil fertility posing a severe damage to crop yield and productivity (Bana and Shivay, 2012). In the semi-arid tropics, groundnut productivity is restricted by inadequate application and insufficient soil native phosphorus availability (Singh et al., 2004). The low yield in legumes, especially groundnuts, has been linked to phosphorus deficiency (Jahish et al., 2017).

According to Singh et al. (2004), phosphorus deficiency inhibits the establishment of auxiliary buds, shoot canopy, leaf area and leaf expansion. The ideal population for Spanish/Valencia cultivars in India was found to be 330,000 plants per hectare (30 cm × 10 cm) and 148,000 plants per hectare (45 cm × 15 cm) (Janila et al., 2015). The ICRISAT-WCA groundnut breeding programme has 166,667 plants per hectare, with inter-row spacing of 60 cm and intra-row spacing of 10 cm between plants. On the other side, those involved in participatory variety selection, field trips, and exchange visits at the ICRISAT station or on-farm fields frequently questioned whether increasing density was necessary to increase the production. Although increasing planting density reduces the amount of area available for root growth, it is a typical agronomic strategy for improving phosphorus use efficiency (Deng et al., 2017). Effective phosphorus utilisation under high planting density situation is challenging due to poor mobility of phosphorus and reduced root space (Shao et al., 2018).

Increasing soil phosphorus uptake and letting root systems reach their maximum biological potential are essential for increasing phosphorus use efficiency in intensive groundnut production. Due to the degree of rhizosphere overlap, the spatial growth of roots becomes severely compressed and there is intense competition between plant roots growing nearby at high planting densities, which may lead to nutrient deficits. According to Shao et al. (2018), high planting densities reduce the quantity of nodal roots, lateral root density, and root biomass per unit volume of soil. Additionally, because of plant competition, root system size might be decreased at high planting densities. At high planting densities, the root crown angle can become more vertical to accommodate a small growing space (Shao et al., 2018). The root-soil contact area determines phosphorus acquisition (Lynch et al., 2022). Plant productivity and phosphorus uptake may be

impacted by planting density due to differential competitiveness, and root foraging for phosphorus is defined by changes in root shape in response to soil environmental variables. Due to competition for resources and growing populations, fewer pods are produced per plant when inter row spacing is narrow (Masa et al., 2017). According to Matsuo et al. (2018), a high plant density produces much higher amount of pod mass per square metre than a low plant density. In the Nellore district of Andhra Pradesh, groundnut is grown with a high seed rate and closer spacing. The groundnut yield increases as the population grows, however, if a single plant is examined, the number of pods, kernel yields, branches, and LAI declines. Due to phosphorus fixability and difficulty in obtaining, it is deficient in most Indian soils. The groundnut yield is determined by phosphorus intake and the amount of phosphorus translocated to the kernel. Despite the usage of higher dosages, the phosphorus is not absorbed as much because of its poor mobility in the soil.

At higher planting densities, phosphorus supply has a significant impact on root plasticity in addition to growth area limitations (Wang et al., 2020). Uncertainty exists over the possibility of offsetting the loss of groundnut dry matter accumulation brought on by reduced planting density by controlling root plasticity and soil phosphorus dynamics through modified phosphorus supply. The root system and mycorrhizal infection can spread into the soil space and absorb soil phosphorus if a sufficient amount of phosphorus present in the root zone. In fact, by activating soil phosphorus, phosphorus supply has the potential to significantly increase phosphorus usage efficiency in crop production. The solubility of phosphorus fertiliser, which varies greatly, affects both the initial and residual phosphorus (Gong et al., 2022). To augment higher uptake, the crop depend more on increased root length and increased exploration of soil, which depend on greater phosphorus absorption rate and total phosphorus uptake per unit root length (Krishna, 1997).

Groundnut appear to translocate assimilated phosphorus into reproductive structures resulting in a significant increase in the root length and phosphorus uptake per unit root length at the onset of flowering until pod-filling stages. Groundnut yields were shown to be optimal or maximum at larger plant densities (Bado et al., 2016). This research specifically targets the investigation of phosphorus uptake under diverse plant densities and phosphorus nutrition in alfisols of the Southern Agro-Climatic zone of Andhra Pradesh where area under groundnut cultivation is more and rainfall is meagre. Under these circumstances, it aims to evaluate both yield and phosphorus uptake of groundnut under various phosphorus supplies and planting densities. Additionally, the study seeks to explore whether potential growth limitations of groundnut due to different planting densities could be mitigated by adjusting phosphorus supply.

Materials and Methods

Study area: A field experiment was conducted during Rabi season, 2019-20 at field number 138, dryland farm of S. V. Agricultural College, Tirupati campus of Acharya N.G. Ranga

Agricultural University, which is geographically situated at 13.5°N latitude and 79.5°E longitude, 182.9 m above mean sea level, which falls under Southern Agro-climatic Zone of Andhra Pradesh and according to Trolls classification, it falls under Semi-Arid Tropics (Troll, 1966).

Weather: During the period of study, groundnut experienced optimum temperature and relative humidity for better crop growth and development. The groundnut crop received 25.6 mm rainfall on 4.0 rainy days during the period of experimentation immediately after sowing and on third week of sowing, which might have supported in better establishment and vegetative growth of groundnut. As 25.6 mm rainfall was not sufficient to provide the required moisture for completion of crop cycle, irrigation was provided as and when required. The insight into the prevailed weather conditions indicated that the weather variables were within the cardinal range so as to enable the crop to reasonably express the effect of imposed treatments.

Experimental setup: The experiment was laid out in a randomized block design with a factorial concept, with three replications. The treatments comprised of three plant densities viz., 22.5 cm x 10 cm (D₁), 20 cm x 7.5 cm (D₂) and 22.5 cm x 5.0 cm (D₃) and four phosphorus levels viz., 25.0 kg P₂O₅ ha⁻¹ (P₁), 37.5 kg P₂O₅ ha⁻¹ (P₂), 50.0 kg P₂O₅ ha⁻¹ (P₃) and 62.5 kg P₂O₅ ha⁻¹ (P₄). Groundnut was sown on 11th December 2019 and harvested on 24th March, 2020. The variety tested was 'Dharani' which is a medium statured Spanish bunch type, determinate with erect growth habit. It has yield potential of 2600 kg ha⁻¹ and 3400 kg ha⁻¹ during *Kharif* and *Rabi*, respectively, with an average oil content of 49 per cent. It is tolerant to drought particularly mid-season and end of the season with less susceptible to sucking pests. The recommended dose of fertilizer for groundnut crop was 30 - 50 - 50 N, P₂O₅ and K₂O kg ha⁻¹. Recommended dose of nitrogen @ 30 kg ha⁻¹ was applied in the form of urea in two splits at sowing and at 30 DAS. Entire potassium @ 50 kg ha⁻¹ as muriate of potash was applied as basal dose at the time of sowing. Phosphorous was applied just as basal at sowing as per the treatments through single super phosphate. Gypsum was applied @ 500 kg ha⁻¹ just before flowering through furrow placement near the root zone.

Sampling and analyses: The composite soil sample and plant samples were collected at harvest and brought to laboratory for analyses. The physico-chemical properties of the experimental soil were analyzed using standard methods. It was sandy loam in texture (Piper, 1966), neutral (6.9) in reaction (Jackson, 1973), EC of 0.65 measured by conductivity bridge method (Jackson, 1973), low (0.24%) in organic carbon (Wet digestion method; Walkley and Black, 1934); and available nitrogen (173.9 kg ha⁻¹) and, low (16.23 P₂O₅ kg ha⁻¹) in available phosphorus and medium in available potassium (177.7 K₂O kg ha⁻¹).

The soil samples were collected again after harvesting of the crop and five plants were selected randomly in the net plot area and labelled for recording observations in each treatment.

The soil samples were air dried, grinded and passed through 2 mm sieve for the analysis of physico-chemical properties following standard protocol such as for available nitrogen (Alkaline potassium permanganate method; Subbiah and Asija, 1956), available phosphorus (Olsen *et al.*, 1954) and available potassium (Flame photometry; Jackson, 1973). Composite plant samples collected from all the net plots were dried, grinded into fine powder and used for the analysis of phosphorus content. Digestion of plant samples was carried out with di-acid mixture containing HNO₃ and HClO₄ in 3:1, ratio and further used for the estimation of phosphorus. Digested plant samples at harvest were analyzed for phosphorus content by vanado-molybdo phosphoric acid method (Jackson, 1973). The intensity of yellow colour developed was measured at 420 nm on spectrophotometer.

Nutrient uptake: The phosphorus uptake was calculated by multiplying the phosphorous content (%) with the respective dry matter production and expressed in kg ha⁻¹.

Pod yield: Pods were separated from haulms of net plot area, sun dried until a constant weight was attained and expressed in kg ha⁻¹.

Statistical analyses: The field experiment was replicated three times adopting randomized block design with the factorial concept. The data obtained from the experiment were analyzed and tested for statistical significance with an appropriate critical difference (CD) at 5% probability level (Gomez and Gomez, 1984).

Results and Discussion

There was a significant interaction effect between plant densities and phosphorus levels in influencing pod yield (Table 1). Among different treatment combinations, the maximum pod yield (3737 kg ha⁻¹) was attained with 4.44 lakh ha⁻¹ plant density with 50 kg P₂O₅ ha⁻¹. A magnitudinal increase in pod yield was observed with an increase in phosphorus dose upto 50 kg P₂O₅ ha⁻¹ in combination with plant density of 4.44 lakh ha⁻¹, thereafter, the pod yield decreased with an increase in phosphorus dose. Planting density is a key element in peanut development and output. When the plant density decreased, the pod number and pod weight per plant increased. Meanwhile, a plant density of 6.66 lakh ha⁻¹ in combination with increase in phosphorus dose up to 62.5 kg P₂O₅ ha⁻¹ resulted in increased pod yield.

The graded increase in phosphorus dose in conjugation with plant density of 8.88 lakh ha⁻¹ was not significant in altering pod yield due to over competition that existed between plants. Hence, the minimum pod yield (2442 kg ha⁻¹) was attained in combination of 8.88 lakh ha⁻¹ plant density with 25 kg P₂O₅ ha⁻¹. Jadhav *et al.* (2000), Ramesh and Reddy (2006), Zagade *et al.* (2007), Konlan *et al.* (2013) and Bhargavi *et al.* (2016) found that higher plant density increased the competition between plants

Table 1: Pod yield (kg ha⁻¹) of groundnut as influenced by plant densities, phosphorus levels and their interaction

Treatments	Phosphorus levels (P) (kg ha ⁻¹)				Mean
	P1 (25.0)	P2 (37.5)	P3 (50.0)	P4 (62.5)	
Plant densities (D)					
D1: 4,44,444 (22.5 x 10 cm)	3215	3444	3737	3405	3451
D2: 6,66,666 (20 x 7.5 cm)	2680	3013	3386	3675	3189
D3: 8,88,888 (22.5 x 5 cm)	2442	2821	2972	2754	2748
Mean	2780	3093	3365	3278	
Treatments	SE(m)±	CD (p= 0.05)			
Plant densities (D)		60.61	179		
Phosphorus levels (P)		69.99	207		
D x P		121.23	358		

Table 2: Phosphorus uptake (kg ha⁻¹) of groundnut at different stages of crop growth as influenced by plant densities and phosphorus levels

Treatments	25 DAS	50 DAS	75 DAS	Harvest
Plant densities (D)				
D ₁ : 4,44,444 (22.5 x 10 cm)	2.51	11.5	21.8	32.5
D ₂ : 6,66,666 (20 x 7.5 cm)	4.97	17.3	32.6	48.8
D ₃ : 8,88,888 (22.5 x 5 cm)	6.65	23.5	43.5	64.9
SE(m)±	0.01	0.06	0.07	0.17
CD (P = 0.05)	0.02	0.2	0.2	0.51
Phosphorus levels (P)				
P ₁ : 25 kg P ₂ O ₅ ha ⁻¹ (50 % RDP)	3.50	16.3	31.4	47.3
P ₂ : 37.5 kg P ₂ O ₅ ha ⁻¹ (75 % RDP)	4.35	16.9	32.1	48.1
P ₃ : 50 kg P ₂ O ₅ ha ⁻¹ (100 % RDP)	5.06	17.8	33.3	49.2
P ₄ : 62.5 kg P ₂ O ₅ ha ⁻¹ (125 % RDP)	5.96	18.6	33.9	50.3
SE(m)±	0.01	0.07	0.08	0.18
CD (P = 0.05)	0.03	0.2	0.2	0.54
Interaction (D x P)				
SE(m)±	0.02	0.13	0.14	0.33
CD (P = 0.05)	0.05	NS	NS	NS

and created a stress for plant growth resulting in improper filling and ill filled pods, ultimately reducing pod yield. Non uniformity in production of pod yield with densities might be due to the reason that the reduced number of pods per plant with increased plant population (Fig. 1). The responses recorded in yield attributes of groundnut demonstrates that there is significant influence on number of pods/plant, 100 seeds weight pod yield, total plant biomass through phosphorous application (Iro *et al.*, 2021).

A significant disparity was observed in plant densities on phosphorus at all stages of sampling (Table 2). Graded increment in plant densities from 4.44 lakh ha⁻¹ to 8.88 lakh ha⁻¹ resulted in significant increase in phosphorus uptake by groundnut at all stages of plant growth (Fig. 2). Adding phosphorus to soils low in available phosphorus promotes root growth, stimulates uptake of phosphorus, promotes root growth, early shoot growth, accelerates ground cover for erosion protection, enhances the quality and vital for seed formation (Ibrahim *et al.*, 2022). The probable phenomenon could be that the increase in plant

population at higher plant densities led to a greater uptake and utilization of phosphorus from the soil. Phosphorus uptake by groundnut increased with the quantity of phosphorus applied to the crop at all stages of sampling.

Higher phosphorus uptake by groundnut was achieved with the application of 62.5 kg P₂O₅ ha⁻¹, which was significantly higher than other phosphorus levels tried. Which may be due to the beneficial effect of phosphorus application on nutrient content of legume crop due to the formation of greater number of nodules and increase in cation exchange capacity of the roots which would enable the plant to extract more nutrients from the soil (Loganathan and Krishnamoorthy, 1977). Furthermore, phosphorus plays a pivotal role in nodule formation, root growth, and proliferation, as well as nitrogen fixation by facilitating the provision of assimilates to the roots. These, outcomes are in line with those of Yakadri and Satyanarayana (1995). Significant increase in phosphorus uptake might be due to the development of extensive root system which help groundnut to absorb nutrient

Table 3: Interaction between plant densities and phosphorus uptake at 25 DAS

Treatments	Phosphorus levels (kg ha ⁻¹)				
Plant densities (D)	P ₁ (25.0)	P ₂ (37.5)	P ₃ (50.0)	P ₄ (62.5)	Mean
D ₁ : 4,44,444 (22.5 x 10 cm)	1.22	2.16	2.73	3.94	2.51
D ₂ : 6,66,666 (20 x 7.5 cm)	3.90	4.66	5.33	5.96	4.97
D ₃ : 8,88,888 (22.5 x 5 cm)	5.33	6.22	7.11	7.97	6.65
Mean	3.50	4.35	5.06	5.96	
Treatments	SE(m)±	CD (p= 0.05)			
Plant densities (D)	0.01	0.02			
Phosphorus levels (P)	0.01	0.03			
D x P	0.02	0.05			

Table 4: Post-harvest soil nutrient status of nitrogen, phosphorus and potassium (kg ha⁻¹) as influenced by plant densities and phosphorus levels

Treatments	Nitrogen	Phosphorus	Potassium
Plant densities (D)			
D ₁ : 4,44,444 (22.5 x 10 cm)	178	35	151
D ₂ : 6,66,666 (20 x 7.5 cm)	172	31	142
D ₃ : 8,88,888 (22.5 x 5 cm)	162	29	141
SE(m)±		3.01	1.152.59
CD (P = 0.05)	9	3	8
Phosphorus levels (P)			
P ₁ : 25 kg P ₂ O ₅ ha ⁻¹ (50 % RDP)	163	29	135
P ₂ : 37.5 kg P ₂ O ₅ ha ⁻¹ (75 % RDP)	169	30	141
P ₃ : 50 kg P ₂ O ₅ ha ⁻¹ (100 % RDP)	173	33	145
P ₄ : 62.5 kg P ₂ O ₅ ha ⁻¹ (125 % RDP)	178	36	156
SE(m)±		3.48	1.332.99
CD (P = 0.05)	10	4	9
Interaction (D x P)			
SE(m)±	6.03	2.31	5.17
CD (P = 0.05)	NS	NS	NS

in an efficient way even under increased plant density (Ladan et al., 2020). Interaction (Table 3) between plant densities and phosphorus levels was found only at 25 DAS in influencing crop phosphorus uptake. At early stages of plant growth when roots are still developing and are sensitive to variations between plant densities and phosphorus levels, interaction between the two factors may be due to resource utilization. Plant density of 8.88 lakh ha⁻¹ in conjugation with 62.5 P₂O₅ kg ha⁻¹ registered significantly higher uptake of phosphorus over other treatments.

Lower phosphorus uptake was recorded with plant density of 4.44 lakh ha⁻¹ in conjugation with 25 kg P₂O₅ ha⁻¹. Increment in phosphorus might have promoted root growth nodulation and efficient functioning of nodule bacteria for nitrogen fixation (Maity et al., 2003), thereby resulting in higher utilization of nutrients from the soil environment to aerial plant parts. Low planting density leads to reduced leaf area index and interception of photosynthetically active radiation by the canopy, thereby decreasing the above ground dry matter accumulation (Zhang et al., 2021). Similarly, the

observations made in this study indicate that lower planting densities resulted in decreased shoot biomass accumulation and phosphorus uptake compared to higher planting densities.

Initial soil data indicated that available nitrogen was low, medium in available phosphorus and available potassium (Table 4). The post-harvest soil nutrient status indicated that the soil available nitrogen, phosphorus and potassium were higher in plots maintained with lower plant density of 4.44 lakh ha⁻¹ than other plant densities, i.e., 6.66 lakh ha⁻¹ and 8.88 lakh ha⁻¹, due to uptake of nutrients from the soil by groundnut to compensate the nutritional requirement for the plant density tested. Increased plant density increases leaf area, dry matter which causes higher uptake of soil available nutrients resulting in lower levels of nutrients after crop harvest and also the fact of nutrient erosion or nutrient fixation. Additionally, regarding phosphorus levels, soil available nitrogen, phosphorus and potassium contents were found to be higher in plots fertilized with 62.5 kg P₂O₅ ha⁻¹ whereas lower levels were observed with the application of 25 kg P₂O₅ ha⁻¹, as documented by

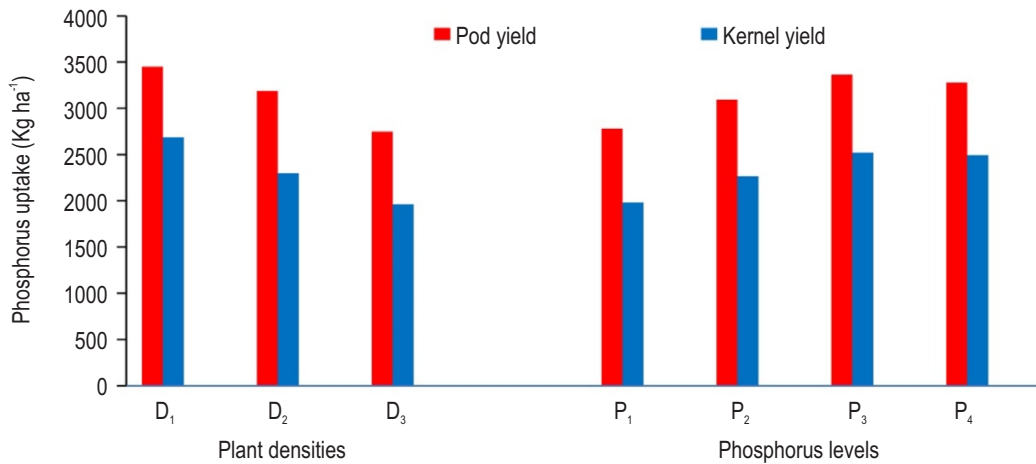


Fig. 1: Pod yield and kernel yield of groundnut as influenced by plant densities and phosphorus levels (CD ($p \leq 0.05$)).

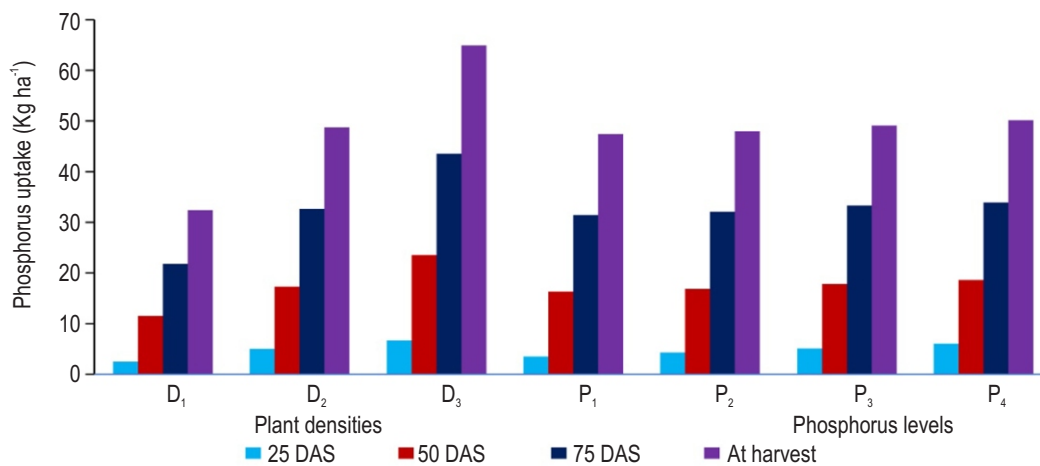


Fig. 2: Phosphorus uptake of groundnut at different growth stages of crop growth as influenced by plant densities and phosphorus levels (CD ($p \leq 0.05$)).

Gunri *et al.* (2010). These findings corroborate the notion that phosphorus application influences soil nutrient dynamics, potentially affecting the availability of nitrogen and potassium as well. Furthermore, the fixation of phosphorus in soil, leading to its unavailability for crop uptake, could contribute to the observed higher levels of phosphorus in soil at higher doses. Similar interactions were observed by Wang *et al.* (2018) between phosphorus fertilization, soil phosphorus dynamics, and crop nutrient uptake. Smith and Jones (2022) found that higher quantities of phosphorus application increase soil phosphorus availability through the addition of external phosphorus inputs. This improves the nutritional quality of the soil, creating an ideal environment for groundnut growth and development. Phosphorus is an essential mineral for plant growth and plays an important role

in a variety of physiological processes such as root development, nutrient uptake and energy transport. As a result, the observed increase in soil phosphorus availability following phosphate treatment can be attributed to the direct incorporation of phosphorus into the soil, which benefits groundnut production.

In this study, phosphorus supply and planting density significantly influenced the yield, soil nutrient status and phosphorus uptake. Growth limitation at 25 kg P_2O_5 ha⁻¹ can be understood as lower yields were recorded with increased plant density and lack of phosphorus supply. It elucidates that higher plant densities, ranging from 4.44 to 8.88 lakh ha⁻¹, and increased phosphorus levels, from 25 to 62.5 kg P_2O_5 ha⁻¹, positively influence nutrient uptake. Conversely, soil available nutrient

status diminished with higher plant densities but improved with phosphorus application. Notably, for those considering high-density planting, maintaining a groundnut population of 6.66 lakh ha⁻¹ supplemented with 62.5 kg P₂O₅ ha⁻¹ is advised to optimize productivity.

This recommendation addresses the gap identified by previous studies, such as Zhang *et al.* (2021), which highlighted the negative impact of low planting density on yield and nutrient uptake. Therefore, the findings of this study are pertinent in guiding agricultural practices towards maximizing groundnut yields in similar agro-climatic zones, emphasizing the necessity for tailored planting densities and phosphorus management strategies to enhance crop productivity and address potential growth limitations.

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