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Numerical Variables Analysis and Improving Phosphorus Use Efficiency in Groundnut with Microbial Cultures in Coastal Zone of Puducherry

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ABSTRACT

Background: The precise application of phosphorus fertilizer is pivotal in determining groundnut (*Arachis hypogaea* L.) productivity. The high demand of phosphorus for energy transfer molecules involved in nitrogen fixation makes it essential for leguminous crop. A field experiment was conducted at Perunthalaivar Kamaraj Krishi Vigyan Kendra, Puducherry during 2021 to 2023 to explore the performance of groundnut by employing an optimal combination of microbial culture alongside varying levels of phosphorus.

Methods: The experiment was laid out in randomized block design with 10 treatments and replicated thrice. The treatments consisted of different doses of phosphorus (@ 20, 40 and 60 kg/ha) with and without seed treatment with DGRC culture.

Result: The experiment results of the three years study revealed that a variable response of groundnut to P fertilizer rates and rhizobium inoculant on sandy loam soil in puducherry. P fertilizer rates combined with DGRC inoculant had a significant influence on growth, root nodule, nodule dry weight, pod and kernel yield. From this study, it may concluded that combined application of P fertilizer @ 60 kg/ha and seed treatment of DGRC culture inoculants @ 20 g/kg seed have the potential to increase the productivity and profitability of groundnut. Correlation and Regression analysis also indicated that the yield attributes had a positive impact on groundnut yield.

Key words: Correlation and regression analysis, Economics, Groundnut, Growth, Phosphorus, Yield.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is one of the major oilseed crops growing in puducherry called as wonder nut and poor men's cashew nut. While being a valuable source of all the nutrients, groundnut plays a vital role in providing an inexpensive source of high quality dietary protein (26%) edible oil content in the diets (45-50%). In India, it is being grown in 11 states in an area of 4.19 million ha with a production of 5.62 million tones of pods per annum. The average productivity of groundnut in India (1341 kg ha^{-1}) can be comparable to world average. Yield of groundnut is always unpredictable for the major producers the average is not only low (t ha^{-1}) but very variable (Naik *et al*., 2022). This is because about 80% of the world production comes from rainfed areas where rainfall is small and erratic. During its growth and development, groundnut is exposed to various biotic and abiotic stresses, *i.e*., most sensitive to moisture stress and it is susceptible to a host of diseases and pests which limits the productivity along with factors like declining soil fertility; poor nutrition *etc*., In groundnut, phosphorus known to plays important role in increasing root growth, nutrient and water use efficiency and also in enhancing yield.

Among all the essential nutrient elements for crop growth, P is the second most vital element, next to nitrogen. In legume crops, P plays a important role in nitrogen fixation, energy transfer, photosynthesis, signal transduction, biosynthesis of macromolecular, respiration (Khan *et al*., 2023).

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Though P is abundant in soils its availability to crop growth is limited because of a major share of soil phosphorus present in an unavailable form. Only 0.1 percent of the total P in the soil exists in a soluble form which is available for crop uptake (Zhou *et al*., 2016). Normally, inorganic P occurs in insoluble mineral complexes in soil and these insoluble, precipitated forms cannot be absorbed by plants (Lambers, 2022), ut are made available to crops through periodical application of phosphorous fertilizers.

Crops belong to leguminous family are also able to meet a considerable portion of their nitrogen requirement when they are cultivated in the presence of effective rhizobia (Bekere and Hailemariam, 2012). Rhizobium activity is reduced when the soil deficit of phosphorus. Also, the phosphorus requirement in nodule forming legumes is higher compared to non legume crops as it significantly contributes to root development and root nodulation (Asante *et al*., 2020). Due to the vital role played by P in crop growth and development, its addition to P-deficient soils leads to an increase in growth and yield (Uchida, 2000).Thus, in the presence of rhizobium inoculants, application of appropriate dose of phosphorous fertilizer can be a helpful strategy to improve productivity of groundnut.

MATERIALS AND METHODS

The field experiments were conducted during *Kharif* season of 2021, 2022 and 2023 at Perunthalaivar Kamaraj Krishi Vigyan Kendra, Puducherry to study the growth and yield performance groundnut by using appropriate combination of microbial culture with different levels of phosphorus. The experimental field soil is sandy loam in texture and slightly acidic in reaction. The soil was low in available nitrogen 168 kg/ha, high in phosphorus 52.12 kg/ha and potash 158 kg/ha. The experiment was laid out in randomized block design and replicated thrice. The experiment consisted of ten treatment combinations of different doses of phosphorus (@ 20, 40 and 60 kg/ha) with and without seed treatment with DGRC. DGRCs are the consortia microbial cultures containing PGPR, PSB and rhizobium. The treatments *viz*., N T_1- No application of P (Control), T_2- Application of 20 kg/ha of P, T_3- Application of 40 kg/ha of P, T_4- Application of 60 kg/ha of P, T_5- Application of 20 kg/ha of P + DGRC culture, T_6- Application of 40 kg/ha of P+DGRC culture, T_7- Application of 60 kg/ha of P+DGRC culture, T_8- Application of FYM @ 2.5 t/ha, T_9- Application of FYM @ 2.5 t/ha + DGRC culture and T_{10}-Application of DGRC culture enriched FYM@100 kg/ha. Recommended dose of Nitrogen (20 kg/ha) and Potash (75 kg/ha) were applied. As per treatment schedule seed are treatment with DGRC inoculants @ 20 g/kg groundnut seed. The groundnut variety TKM-13 is used as test variety. The cultural practices, irrigation and plant protection measures were taken as and when required. All other agronomic practices were adopted as per the need of the crop. Ten plants were selected at random in each plot and were tagged for recording the observations of the growth, yield attributes and yield. Crop was harvested at maturity, threshed and plot-wise seed and yields in kg/ha was recorded. The data on the different parameters was analyzed statistically by adopting Fisher's method of ANOVA suggested by Gomez and Gomez (2010).

Numerical variables analysis

Correlation and multiple linear regressions were employed to study the value of money or profitability, the relationship between the various parameters (variables) and grain yield. The Pearson Correlation Coefficient (PCC) is the most prevalent sort of correlation coefficient and it creates a relationship between expected and observed values after a statistical investigation (Ravi *et al*., 2023). The study utilized correlation analysis to examine the relationships among several variables, including pod yield (kg/ha), pods plant^{-1} (No.), 100 kernel weight (gm), shelling (%), SMK (%), plant height (cm), dry matter production (kg/ha) and nodules plant^{-1} (Ajaykumar *et al*., 2023). It was computed using the equation:

$$r_{xy} = \frac{S_{xy}}{S_x S_y} = \frac{\Sigma\,(x_i - \bar{x})\,(y_i - \bar{y})}{[\Sigma\,(x_i - \bar{x})^2]\;[\Sigma\,(y_i - \bar{y})^2]}$$

Where,

r_{xy}= Coefficient of the linear relationship between the variables x and y.

S_x and S_y = Sample standard deviation.

S_{xy} = Sample covariance.

x_i and y_i = Values of x and y variables in the sample of the population.

$\bar{x}$ and $\bar{y}$ = Sample mean.

The study also employed regression analysis as an econometric tool to investigate the association between a dependent variable and a set of independent variables. Regression analysis was performed by;

$$\text{Pod yield (Kg ha}^{-1}) = \alpha + \beta_1 \text{ plant height (cm)} + \beta_2 \text{ dry matter production (g/plant)} + \beta_3 \text{ pods/plant (No's)} + \beta_4 \text{ 100 kernal weight (gm.)} + \beta_5 \text{ SMK (\%)} + \beta_6 \text{ Shelling (\%) (No's)} + \mu_i$$

RESULTS AND DISCUSSION

Growth parameters, yield and phosphorous fertilization

The P management had significant effect on growth parameters and yield (Table 1). The data revealed that maximum plant height (76.7 cm) and DMP (47.4 g/plant) was observed in treatment T_7 application of P @ 60 kg/ha of + DGRC culture followed by treatment T_6. This may be due to improved availability of Phosphorus. The accessibility of phosphorus also improves the utilization of N and K in the plant system. Phosphorus plays a crucial role in the energy cycle of plants, contributing significantly to enhancing plant growth. Ensuring optimal phosphorus availability is essential for sustaining crop growth, as phosphorus is integral to various aspects such as root growth and development, respiration, nucleic acid synthesis, nitrogen fixation, plant maturity and seed production (Naik *et al*., 2022). The maximum pod yield (3710 Kg/ha) and haulm yield (5601 kg/ha) was recorded with combined application of 60 kg P/ha and seed treatment with DGRC culture (Table 1). This might be due to optimum availability of nutrients with the integrated use of chemical and organic sources might speed up the growth and development processes leading to higher yield. Moreover the integrated use of organics with inorganic fertilizers leads to better utilization of soil moisture, uptake of soil nutrient and improves soil organic matters which increase the soil water holding capacity, soil aggregation, microbial activity and soil porosity ultimately leading to higher crop productivity (Yadav *et al*., 2019).

Yield attributes and phosphorous fertilization

The effects of different phosphorus fertilization treatments on groundnut were found to be significantly impactful (Table 2). The maximum number of pods/plant (28.6), 100 kernel weight (53.7 g), shelling % (74.2%) and SMK (83.9%) were registered with integrated application of 60 kg P/ha + seed treatment with DGRC culture and it was followed by application of 40 kg/ha of P + DGRC culture. The integrated utilization of organic and inorganic phosphorus sources led to improvements across various aspects of soil quality. This included enhancements in the physical attributes such as soil structure and water-holding capacity, chemical properties like buffering capacity, cation exchange capacity and the availability of macro and micronutrients, while also reducing phosphate fixation (Naik *et al*., 2022). Furthermore, there were improvements in the biological properties of the soil, such as increased organic matter content, soil microbial biomass and diversity of soil microorganisms. These combined improvements created an optimal environment conducive to the higher growth and development of plants, ultimately resulting in improved yield attributes.

Nutrient uptake and root nodules

The application of phosphorus fertilization had a significant impact on various key aspects such as nutrient uptake and

Table 1: Effect of different phosphorus management with microbial cultures on growth and yield of groundnut at harvest stage (Pooled data).

Treatments	Plant height (cm)	DMP at harvest (g plant^{-1})	Pod yield (Kg/ha)	Haulm yield (Kg/ha)
T_1- Control (no application of P)	66.8	34.8	2661	4210
T_2- Application of 20 kg/ha of P	69.1	36.9	2866	4408
T_3- Application of 40 kg/ha of P	71.0	39.9	3019	4631
T_4- Application of 60 kg/ha of P	72.9	42.5	3170	4879
T_5- Application of 20 kg/ha of P + DGRC culture	73.9	43.5	3330	5083
T_6- Application of 40 kg/ha of P + DGRC culture	75.7	45.7	3530	5352
T_7- Application of 60 kg/ha of P + DGRC culture	76.7	47.4	3710	5601
T_8- Application of FYM @ 2.5 t/ha	70.3	38.2	2953	4470
T_9- Application of FYM @ 2.5 t/ha + DGRC culture	73.8	43.1	3275	4960
T_{10}- Application of DGRC culture enriched FYM @ 100 kg/ha	72.9	42.0	3223	4980
S.Em. ±	1.32	0.81	115.47	131.61
LSD (P=0.05)	4.20	2.48	344.99	378.84
CV (%)	3.13	3.18	6.12	4.78

Table 2: Effect of different phosphorus management with microbial cultures on yield attributes of groundnut (Pooled data).

Treatments	Pods/Plant (No.)	100 kernel weight (g)	Shelling (%)	SMK (%)
T_1- Control (no application of P)	18.8	46.2	67.4	77.5
T_2- Application of 20 kg/ha of P	21.0	47.5	68.7	79.1
T_3- Application of 40 kg/ha of P	22.7	49.3	70.1	80.9
T_4- Application of 60 kg/ha of P	24.5	51.5	71.6	81.6
T_5- Application of 20 kg/ha of P + DGRC culture	25.8	52.1	72.0	82.4
T_6- Application of 40 kg/ha of P + DGRC culture	27.7	53.3	73.7	83.1
T_7- Application of 60 kg/ha of P + DGRC culture	28.6	53.7	74.2	83.9
T_8- Application of FYM @ 2.5 t/ha	22.2	48.6	69.6	79.8
T_9- Application of FYM @ 2.5 t/ha+ DGRC culture	25.0	51.9	72.2	82.1
T_{10}- Application of DGRC culture enriched FYM @ 100 kg/ha	24.6	50.7	71.6	81.8
S.Em. ±	0.48	0.98	1.27	1.44
LSD (P=0.05)	1.46	2.84	3.76	4.36
CV (%)	3.21	3.12	3.13	3.11

root nodules, as detailed in Table 3 and Table 4. Significantly higher numbers of nodules/plant (39.9 and 65.4 at 40 DAS and 80 DAS, respectively) and increased dry weight of nodules/plant (20.7 mg and 39.6 mg at 40 DAS and 80 DAS, respectively) were observed with the application of a higher dose of phosphorus (60 kg/ha) in conjunction with DGRC culture. This combination led to a 38% increase in nodule numbers per plant compared to plots without phosphorus application (Control). These results indicate that while genetic factors play a role in nodulation and plant growth, external factors such as phosphorus fertilizer, inoculants containing beneficial microorganisms like rhizobium and organic manure can also significantly influence these processes. This highlights the importance of considering both genetic and environmental factors in optimizing plant growth and nodulation in agricultural practices (Kumar *et al*., 2017).

Highest nutrient uptake of nitrogen (98.55 kg/ha), phosphorus (16.39 kg/ha) and potassium (57.85 kg/ha) in groundnut after harvest was noticed in the application of 60 kg P_2O_5/ha + DGRC culture. The integrated application of phosphorus (P) exists in various organic and inorganic forms within the soil, including soil organic matter, minerals and the soil solution. Plants absorb P primarily as orthophosphate ions from the soil solution. To maintain equilibrium, P moves from more readily available organic and inorganic pools into the soil solution. This accessible or labile P includes mineralizable organic P and readily exchangeable adsorbed P, transitioning from less accessible pools that include stable organic P and P strongly bound to soil minerals and compounds, into labile pools to maintain P equilibrium status in the soils. This process ultimately increases nutrient uptake and the biological yield of crops (Hao and Chang, 2002).

Numerical variables analysis

The correlation results revealed that all the variables included in the model were positively significant at a one percent level of significance (Table 5). These findings suggest that each variable contributes to the groundnut's grain yield. As grain yield is the most critical variable that directly reflects the yield, it was compared with other plant-

Table 3: Effect of different phosphorus management with microbial cultures on root nodules of groundnut (Pooled data).

Treatments	Nodules/plant (Nos.)		Nodules dry weight/plant (Mg)	
	40 DAS	80 DAS	40 DAS	80 DAS
T_1- Control (no application of P)	24.6	47.9	12.0	26.1
T_2- Application of 20 kg/ha of P	27.2	50.5	13.3	28.7
T_3- Application of 40 kg/ha of P	30.2	53.8	14.4	31.4
T_4- Application of 60 kg/ha of P	33.1	57.2	16.3	34.4
T_5- Application of 20 kg/ha of P + DGRC culture	34.1	59.4	16.8	35.0
T_6- Application of 40 kg/ha of P + DGRC culture	37.3	63.6	18.5	38.3
T_7- Application of 60 kg/ha of P + DGRC culture	39.9	65.4	20.7	39.6
T_8- Application of FYM @ 2.5 t/ha	28.7	52.4	13.9	30.0
T_9- Application of FYM @ 2.5 t/ha + DGRC culture	34.4	59.1	16.7	35.8
T_{10}- Application of DGRC culture enriched FYM @ 100 kg/ha	32.8	57.0	15.8	33.7
S.Em. ±	0.59	1.06	0.34	0.64
LSD (P=0.05)	1.77	3.19	0.88	1.93
CV (%)	3.27	3.18	3.31	3.26

Table 4: Effect of different phosphorus management with microbial cultures on nutrient uptake (kg/ha) of groundnut (Pooled data).

Treatments	N Uptake	P Uptake	K Uptake
T_1- Control (no application of P)	32.87	4.66	20.17
T_2- Application of 20 kg/ha of P	65.01	10.43	26.41
T_3- Application of 40 kg/ha of P	65.63	10.86	37.26
T_4- Application of 60 kg/ha of P	71.35	11.77	41.39
T_5- Application of 20 kg/ha of P + DGRC culture	83.72	13.47	45.98
T_6- Application of 40 kg/ha of P + DGRC culture	92.46	15.52	47.95
T_7- Application of 60 kg/ha of P + DGRC culture	98.55	16.39	57.85
T_8- Application of FYM @ 2.5 t/ha	96.49	9.87	37.8
T_9- Application of FYM @ 2.5 t/ha+ DGRC culture	80.74	12.56	44.82
T_{10}- Application of DGRC culture enriched FYM @ 100 kg/ha	76.59	12.36	43.17
S.Em. ±	0.41	0.23	0.29
LSD (P=0.05)	0.88	0.65	0.75
CV (%)	3.12	3.13	3.11

related parameters to determine their relationship with each other. The correlation coefficients indicate that grain yield is positively correlated with pods per plant (0.77), shelling (0.86), plant height (0.93), dry matter production (0.96) except for 100 seed kernel weight (Ravi *et al*., 2024). These results confirm that an increase in these variables would lead to an increase in groundnut yield. Therefore, all of these variables were included as independent variables in the multiple linear regression model (Ajay Kumar *et al*., 2022). Multiple linear regressions, which were employed to measure the relationship and the magnitude of the change in grain yield due to the other prescribed parameters. The multiple linear regression equation could be written as,

Grain yield = -2995.73 + 49.11 pods/plant (No's) + 8.58 100 kernel weight (gm) + 18.82 shelling (%) + 13.89 SMK (%) + 27.32 plant height (cm) + 46.71 dry matter production (gm/plant)

The R^2 value of 0.76 indicates a good fit for the model, suggesting that the independent variables accounted for 76 per cent of the grain yield (Table 6). Except for 100 kernel weight (gm) and SMK (%), all variables were found to be statistically significant. The slope coefficient of pods per plant revealed that a one per cent increase in pods per plant would lead to a significant 47.03 per cent increase in yield, holding all other variables constant. Similarly, a one per cent increase in shelling (%), plant height (cm) and dry matter production (g/plant) would result in yield increases of 17.14, 26.30 and 45.58 per cent, respectively (Tittonell *et al*., 2008). However, an increase in weed control efficiency resulted in a negative impact on yield, with a one per cent increase causing a 3.54 per cent decrease in yield.

Economics

The economic indicators including the cost of cultivation, gross return, net returns and the benefit-cost ratio were

Table 5: Correlation between yield attributes and growth characters of groundnut (Pooled data).

Variables	Yield (Kg/ha)	Pods/ Plant (No.)	100 kernel weight (g)	Shelling (%)	SMK (%)	Plant height (cm)	DMP (g/plant)
Yield (Kg/ha)	1.00	0.77	-0.06	0.86	0.01	0.93	0.96
Pods/Plant (No.)		1.00	-0.09	0.70	-0.01	0.72	0.76
100 kernel weight (g)			1.00	-0.02	0.04	-0.02	-0.03
Shelling (%)				1.00	0.09	0.83	0.83
SMK (%)					1.00	-0.02	-0.03
Plant height (cm)						1.00	0.93
DMP (g/plant)							1.00

Table 6: Multiple linear regression estimates the groundnut yield.

Source	Value	Standard error	T stat	P value
Intercept	-2995.73	951.37	-3.81	0.000
Pods/Plant (No.s)	49.11**	14.60	3.22	0.002
100 kernel weight (gm)	8.58	14.52	0.65	0.515
Shelling (%)	18.82*	8.40	2.11	0.040
SMK (%)	13.89	8.25	1.57	0.123
Plant height (cm)	27.32**	10.21	2.57	0.009
Dry matter production (g/plant)	46.71**	19.27	2.36	0.022

Table 7: Effect of different phosphorus management with microbial cultures on economics of groundnut (Pooled data).

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	Benefit cost ratio
T_1- Control (no application of P)	49369	97832	48463	1.98
T_2- Application of 20 kg/ha of P	58847	119837	60990	2.04
T_3- Application of 40 kg/ha of P	52449	116725	64276	2.23
T_4- Application of 60 kg/ha of P	50827	118358	67531	2.33
T_5- Application of 20 kg/ha of P + DGRC culture	50297	133556	83259	2.66
T_6- Application of 40 kg/ha of P + DGRC culture	50384	136064	85680	2.70
T_7- Application of 60 kg/ha of P + DGRC culture	50472	141234	90762	2.80
T_8- Application of FYM @ 2.5 t/ha	49194	102349	53155	2.08
T_9- Application of FYM @ 2.5 t/ha + DGRC culture	49282	120518	71236	2.45
T_{10}- Application of DGRC culture enriched FYM @ 100 kg/ha	49944	116713	66769	2.34

presented in Table 7. The effect of different phosphorus fertilization on the economics of groundnut cultivation showed that application of 60 kg P /ha + seed treatment with DGRC culture resulted in higher gross returns (141234 Rs. ha^{-1}), net returns (90762 Rs. ha^{-1}) and a B:C ratio of 2.80, closely followed by the treatment with application of 40 kg/ha of P + DGRC culture. Integrated phosphorus (P) management, combining chemical P fertilizer with DGRC has resulted in a reduced need for inorganic P fertilizer by plants. This reduction is likely to save farmers money by eliminating the costly use of chemical P fertilizers. The increased crop productivity achieved through this integrated approach is likely the primary driver behind the higher net returns observed under integrated P management tailored with DGRC culture. The results are consistent with the findings reported by Naik *et al*. (2022).

CONCLUSION

This study has unveiled a variable response of groundnut to phosphorus (P) fertilizer rates and rhizobium inoculant on sandy loam soil in Puducherry. The combination of P fertilizer rates with DGRC inoculant significantly influenced growth, nodule number, nodule dry weight, nutrient uptake, yield attributes and 19-39% increase in pod yield over control. Based on these findings, it can be concluded that the combined application of P fertilizer at 60 kg/ha and seed treatment with DGRC culture inoculants has the potential to enhance the productivity and profitability of groundnut cultivation. Moreover, correlation and regression analyses consistently demonstrate a positive relationship between all examined parameters and pod yield. These results suggest that focusing on these variables could be instrumental in boosting groundnut productivity.

Conflict of interest

The authors declare no conflicts of interest.

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