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Evaluation of Phosphorus and Sulphur Nutrition on Phosphorus Fractionation in Groundnut Cultivation on Inceptisols of Raigarh, Chhattisgarh, India

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ABSTRACT

Background: The study titled "Evaluation of Phosphorus and Sulphur Nutrition on Phosphorus Fractionation in Groundnut Cultivation on Inceptisols of Raigarh, Chhattisgarh, India" investigated the effects of phosphorus and sulphur fertilization on soil phosphorus distribution in groundnut farming. Conducted over two Rabi seasons (2020-21 and 2021-22), the research focused on acidic (pH-6.2) Inceptisols because of phosphorus fixation predominate in acidic soil, resulting in its low efficiency with low organic carbon content in Raigarh, Chhattisgarh.

Methods: The experiment was laid with a factorial randomized block design with four phosphorus levels (P0, P30, P60, P90 kg ha^{-1}) and three sulphur levels (S0, S20, S40 kg ha^{-1}), creating twelve treatment combinations replicated thrice. The study aimed to investigate the effects of these nutrient applications on soil phosphorus fractions, including Saloid-bound, Fe-P, Al-P, Ca-P and Red-P.

Result: Phosphorus application notably affected soil phosphorus fractionation, with the highest levels of Saloid-P, Fe-P, Al-P, Ca-P and Red-P observed at 90 kg ha^{-1}, surpassing the control (P0). The dominance order of phosphorus forms was Fe-P > Red-P > Ca-P > Al-P > Saloid-P, while sulphur application showed no significant impact, suggesting its limited role in this context due to different biochemical pathways.

Key words: Fertigation, Fractionation, Groundnut, Inceptisol, Phosphorous, Sulphur.

INTRODUCTION

Phosphorus is an essential nutrient for plants, playing a key role in energy transfer and storage, particularly as ATP. It is integral to plant metabolism and the structure of cells, such as in cell walls and nucleic acids (Wiedenhoeft, 2006). However, phosphorus availability in soils is typically low, ranging from 1-3% and is influenced by soil characteristics and fertilization practices (Singh *et al.,*1998). Phosphorus fertilizers can enhance plant uptake and improve crop yields, especially in Indian agriculture, where balanced fertilization is crucial (Havlin *et al.,* 2005) and (Tandon, 1991). Proper nutrient management, including sulphur, ensures sustainable soil fertility and optimal crop production (Yadav *et al.,* 2017).

Groundnuts (Arachis hypogaea L.) are the 13th most important global food crop, providing essential vegetable protein and edible oil, ranking fourth and third in these categories, respectively (Taru *et al.,* 2008). In India, groundnuts are the leading oilseed crop, representing 33% of oilseed production and 28% of total oilseed area. In Chhattisgarh, groundnut cultivation is *via*ble in both the *Rabi* and *Kharif* seasons, depending on landform conditions (Agashe *et al.,* 2018). However, phosphorus (P) and sulphur (S) deficiencies in soil, alongside inconsistent fertilizer application, hinder optimal groundnut yields, despite a cultivation area of 67.7 thousand hectares and a production of 70.2 thousand tonnes with a productivity of 1036 kilograms per hectare.

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Phosphorus deficiency in soils is widespread, with utilization efficiency rarely exceeding 20%. Despite high total phosphorus content in soils, its availability for plant uptake remains limited. In India, this deficiency is aggravated by dependence on imported raw materials (Guar, 1990). Effective phosphorus fertilizer management is essential for sustaining high-yield groundnut crops. Crops utilize only 10-30% of newly applied phosphorus, while the remainder forms compounds of varying solubility (Kanwar, 1976). Maintaining adequate soil phosphorus, through both inorganic and organic sources, is critical for sustainable agriculture (Sharpley *et al.,* 1994). The primary source of phosphorus for plants is inorganic phosphorus, comprising components like Solid-P, Al-P, Fe-P, R-P and Ca-P, whose availability depends on several factors (Jaggi, 1991). Long-term phosphorus fertilization alters soil phosphorus fractions, such as Solid-P, Al-P, Fe-P, R-P and Ca-P, enhancing availability and improving yields (Fan *et al.,* 2003).

Groundnuts require more phosphorus due to their high oil content and need sulphur for protein and vitamin synthesis. The kernels are rich in vitamins A, B and E, with 45-50% oil and 25.3% high-quality protein, exceeding that of meat and eggs (Das, 1997). While Regional Challenges in regions like Chhattisgarh, groundnut cultivation faces challenges due to the inadequate availability of phosphorus and sulphur in soils as per the reports of Chhattisgarh Environment Conservation Board, 2004. Resource-poor farmers often struggle with uneven fertilizer usage, further exacerbating these nutrient deficiencies. Given that phosphorus utilization efficiency is typically low, with only 15-25% of applied phosphorus being taken up by crops (NAAS, 2014), there's a clear need for improved nutrient management strategies, therefore this study addresses a critical gap by investigating the effects of phosphorus and sulphur nutrition on groundnut cultivation in Raigarh, Chhattisgarh during the *Rabi* seasons of 2020 and 2021,. The study's focus on phosphorus fractionation—how different phosphorus compounds in the soil become available to plants—were provide valuable insights into optimizing fertilization practices. Understanding these dynamics is essential for developing sustainable agricultural practices that enhance crop productivity while maintaining soil fertility.

MATERIALS AND METHODS

Experiment site

The experimental site, Singharpur in Raigarh district, Chhattisgarh, is situated at 215 meters above sea level, within a subtropical climate zone. It experiences an average annual rainfall of 1057 mm, primarily from the southwest monsoon (June to September) and the northwest monsoon (October and November). Temperatures range from 27°C in January to 39.9°C in April. This data was recorded during the *Rabi* seasons of 2020-21 and 2021-22.

Soil characteristic

The experimental field in Singharpur is Inceptisol, locally known as "Matasi," which is mostly level and uniform. Soil samples were collected from the surface (0-15 cm), dried, crushed, sieved and analyzed for physico-chemical properties. The sandy loam soil has a bulk density of 1.35 mg/m³, particle density of 2.28 mg/m³ and 42.77% porosity, with 52% sand, 32% silt and 16% clay. The soil's pH is 6.2, with available nutrients: 176.8 kgha-1 nitrogen, 8.25 kgha-1 phosphorus, 245 kgha-1 potassium and 23.8 kgha-1 sulphur. The electrical conductivity (EC) is 0.38 dS/m. Detailed soil characteristics are listed in (Table 1).

Table 1: Initial soil properties of experimental site.

Initial properties of soil	Value	Method of estimation
Bulk density (Mg m^{-3})	1.35	Soil core method (Black and Hartge, 1986)
Particle density (Mg m^{-3})	2.28	Pycnometer (Gupta,1981)
Texture		International pipette method (Piper, 1966)
Sand (%)	52	
Silt (%)	32	
Clay (%)	16	
Texture	**Sandy loam**	
pH - (1:2.5)	6.2	Glass electrode pH meter (Piper, 1967)
EC - (dS m^{-1})	0.38	Conductivity Bridge by (Richards 1954)
Organic carbon (g kg^{-1})	4.6	Rapid titration method (Walkely and Black,1934)
Available nitrogen (kg ha^{-1})	176.8	Alkaline permanganate method (Subbiah and Asija, 1956)
Available phosphorus ($kgha^{-1}$)	8.25	(Bray and Kurtz 1945)
Available potassium ($kgha^{-1}$)	245	Ammonium acetate method (Jackson, 1973)
Available S (kg ha^{-1})	23.8	Turbidimetric method (Chesnin and Yien, 1951)
Saloid-P (mg kg^{-1})	7.98	Sequential extraction (Chang and Jackson, 1957)
Al-P (mg kg^{-1})	25.15	
Fe-P (mg kg^{-1})	88.56	
Ca-P (mg kg^{-1})	26.74	
Rs-P (mg kg^{-1})	78.54	

Experimental details and Layout

The field experiment was laid out in a factorial randomized block design with twelve treatments which was replicated thrice. The experiment was conducted for two consecutive years (2020-21 and 2021-22) on the same site. The whole experimental field was equally divided into three blocks and each block was again divided into equal sized plots measuring 5m × 4m (20 m^2) to impose treatments as applied levels of phosphorus and sulphur on tested crop groundnut cv; TAG-24 comprising total 36 plots. The treatments were allotted randomly within the plots of each experimental block with a fallow strip of 1m on all the sides as experimental border.

Treatment details (Fertilizer application)

Treatments were allocated for 4 levels of phosphorous and 3 levels of sulphur by fertilizers as per application schedule during both years of experiment for groundnut crop with a randomization. A uniform dose of 20 kg N ha^{-1} was maintained with the combination dose of urea and DAP while 20 kg K2O ha^{-1} through MOP. However different doses of P and S as per treatment was applied in furrows through DAP and bentonite respectively at the time of sowing. The levels of phosphorous were applied P0 (C), P30, P60 and P90 kg ha-^{1} through DAP at the time of sowing and mixed thoroughly into the soil. Sulphur was applied through Bentonite sulphur as per treatment levels S0 (C), S20 and S40 kg ha-1 at the time of sowing and mixed thoroughly into the soil.

Soil analysis

Following crop harvesting, soil samples were collected from the surface soil (0-15 cm) of each plot. The samples were air-dried, ground and sieved through a 2 mm sieve before being stored in polythene bags with appropriate labeling for various analyses which was presented in (Table 1).

Phosphorous fractions

This method was described by (Chang and Jackson,1957) modified by (Peterson and Corey, 1966).

Saloid bound phosphorus (Sal-P)

To extract easily soluble Saloid bound phosphorus (P) from soil, 0.5 g of soil was mixed with 25 ml of 1N NH4Cl in a centrifuge tube, shaken for 30 minutes, then centrifuged at 2000 rpm for 10 minutes, followed by decanting the supernatant; for P determination, 5 ml of the supernatant was diluted to 25 ml with reagent B and after 30 minutes, the solution's colour intensity (480 nm) wavelength was measured using a spectrophotometer.

Aluminium phosphate (Al-P)

For the extraction of P using ammonium fluoride (NH4F), 25 ml of 0.5 N NH4F was added to the soil, shaken for 1 hour, centrifuged for 10 minutes and then decanted; P in the supernatant was measured after charcoal decolourization and treatment with boric acid to remove fluoride interference, followed by adding reagent B and assessing colour intensity with a spectrophotometer after 30 minutes.

Iron phosphate (Fe-P)

For NaOH extraction, soil samples were washed with saturated NaCl, centrifuged, then 25 ml of 0.1 N NaOH was added and shaken for 17 hours; after centrifuging and decanting, P in the supernatant was determined post-charcoal decolourization, by acidifying with H2SO4 and adding reagent B, followed by measuring the colour intensity with a spectrophotometer.

Reductant phosphorus (Red-P)

Soil samples in a centrifuge tube were rinsed with saturated NaCl solution, suspended in trisodium citrate and mixed with sodium dithionite. After shaking and heating, the suspension was centrifuged and the supernatant was oxidized with KMnO4 before P estimation using molybdate-sulphuric acid solution. The blue alcohol layer was isolated and measured for colour intensity using a colorimeter.

Calcium phosphate (Ca-P)

Soil was rinsed with saturated NaCl, shaken with 25 ml of 0.5 N H2SO4 for an hour, centrifuged and decanted; 5 ml of the supernatant was combined with reagent B and brought to 25 ml in a volumetric flask, with color intensity measured by spectrophotometer.

Total P

In a 250 ml flask, 2g of soil was digested with 30 ml of 60% HClO4 until organic matter was removed, then heated until white fumes appeared; the mixture was diluted to 250 ml and P was estimated by adding vanado-molybdate reagent to a 5 ml aliquot, with color intensity measured after 30 minutes using a spectrophotometer.

RESULTS AND DISCUSSION

Phosphorous fractions

The effects of phosphorus and sulphur fertilization on phosphorus fractions (Sal-P, Al-P, Fe-P, Ca-P, Red-P) in soil post-harvest of groundnut across seasons are detailed in (Tables 2) and (Fig 1-5).

1Saloid bound-P (Sal-P)

Saloid-bound phosphorus (Sal-P) is the smallest and most readily available inorganic phosphorus fraction in surface soil, often called solution P. Phosphorus treatments at levels of 30, 60 and 90 kg P ha^{-1} increased Sal-P by 13.4%, 30.28% and 47.85%, respectively, over the control. The highest dose (90 kg P ha^{-1}) significantly enhanced plant growth. In 2020-21 and 2021-22, soil phosphorus application increased Sal-P from 8.19 to 11.72 mg kg^{-1} and from 8.56 to 13.06 mg kg^{-1}, respectively. Higher phosphorus doses (90 kg ha^{-1}) resulted in substantially higher Sal-P levels compared to lower doses and control. The

Table 2 : Effect of phosphorous and sulphur levels on Various Phosphorous Fractionation of soil after the harvest of groundnut.

Treatments	Sal-P (mg kg-1)			Al-P (mg kg-1)			Fe bound-P (mg kg-1)			Ca-P (mg kg-1)			Red-P (mg kg-1)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
	P levels (kg ha-1)			**P levels (kg ha-1)**			**P levels (kg ha-1)**			**P levels (kg ha-1)**			**P levels (kg ha-1)**		
0	8.19	8.56	8.38	24.28	24.23	24.26	91.35	90.48	90.92	28.85	27.76	28.31	80.00	80.84	80.92
30	9.05	9.97	9.51	28.62	30.09	29.36	100.93	104.02	102.48	33.19	36.08	34.64	84.26	86.74	85.45
60	10.71	11.94	11.26	32.99	34.49	33.58	112.87	116.07	114.29	37.78	40.67	39.18	88.56	91.14	89.72
90	11.72	13.06	12.39	35.47	37.75	36.61	124.76	126.68	125.72	40.04	42.93	41.49	91.04	93.62	92.33
SEm±	0.20	0.31	0.25	1.37	1.40	1.34	1.96	2.05	2.03	1.34	1.27	1.29	1.44	1.52	1.46
CD (P=0.05)	0.60	0.90	0.72	4.01	4.09	3.93	12.76	10.88	11.45	3.94	3.71	3.79	4.20	4.36	4.25
	S levels (kg ha-1)			**S levels (kg ha-1)**			**S levels (kg ha-1)**			**S levels (kg ha-1)**			S levels (kg ha-1)		
0	9.64	10.50	10.07	28.50	29.61	29.05	104.47	106.52	105.49	33.23	35.16	34.20	83.69	86.03	84.86
20	9.87	10.93	10.35	30.20	31.71	30.83	107.26	109.15	108.07	34.77	36.69	35.69	86.63	88.63	87.53
40	10.24	11.23	10.74	32.33	33.60	32.97	110.71	112.34	111.52	36.90	38.74	37.82	88.26	89.60	88.93
SEm±	0.18	0.27	0.21	1.18	1.21	1.16	1.70	1.77	1.76	1.16	1.10	1.12	1.25	1.32	1.26
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Interaction				**Interaction**			**Interaction**			**Interaction**			**Interaction**	
SEm±	0.35	0.54	0.43	2.37	2.42	2.32	3.40	3.55	3.51	2.33	2.19	2.24	2.50	2.64	2.53
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	6.18	8.52	7.13	13.52	13.25	13.01	5.48	5.62	5.62	11.52	10.31	10.82	5.02	5.19	5.03

continuous use of phosphatic fertilizers in cropping system resulted in buildup of phosphate in soil and transformed into different inorganic P fractions which caused increase in sal-P fraction. These results are in good agreement with the findings of (Devra *et al.,* 2014, Pradhan *et al.,* 2018, Naik *et al*., 2022, Chandrakala *et al.,* 2018). While the relatively higher content of Saloid-P in case of Singharpur village as a result of inorganic fertilization and residual effect of organic could be attributed to the transformation of applied P into Saloid-P. The results are in agreement with (Sacheti and Saxena 1973, Viswanatha and Doddamani 1991, Jatav *et al.,* 2010).

Moreover It is evident from the data presented in (Table 2 and Fig 1) that different sulphur levels couldn't produce significant effect on the amount of Sal-P.

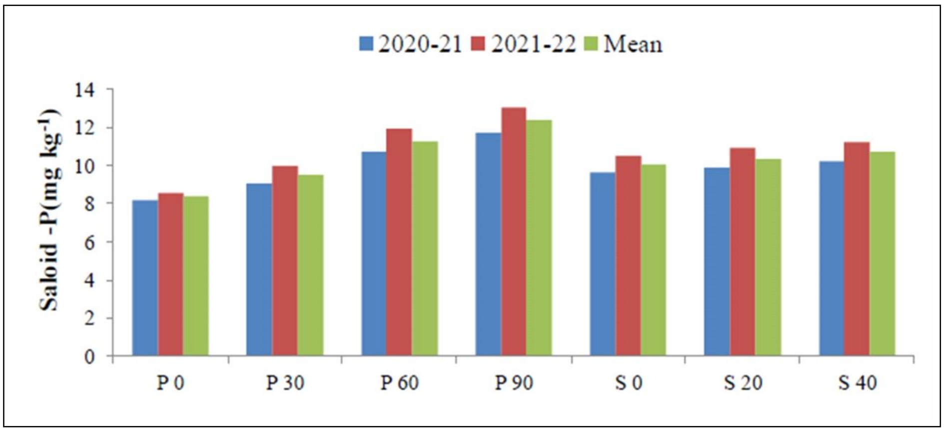

Fig 1: Effect of phosphorous and sulphur levels on Saloid-P (mg kg^{-1}) of soil after harvest of groundnut.

Fig 2: Effect of phosphorous and sulphur levels on Al-P (mg kg^{-1}) of soil after harvest of groundnut.

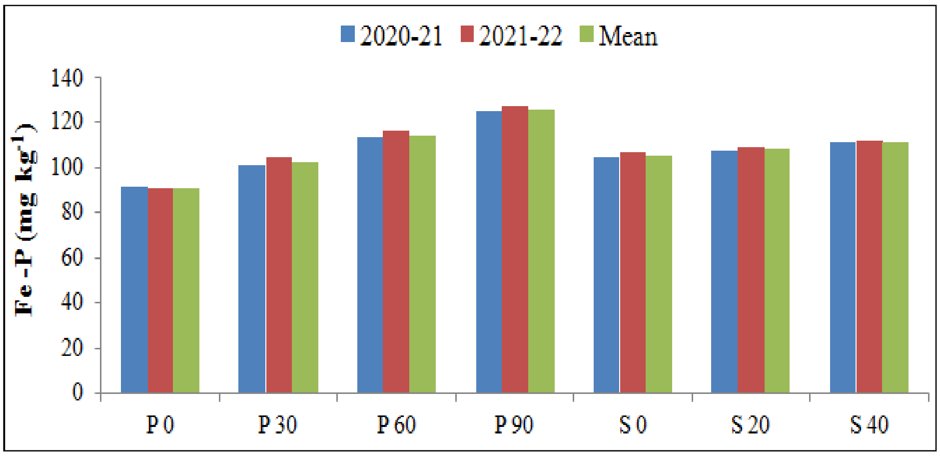

Fig 3: Effect of phosphorous and sulphur levels on Fe-P (mg kg^{-1}) of soil after harvest of groundnut.

Al-bound P (Al-P)

The data on Al-bound phosphate affected by various P and S levels are presented in (Table 2 and Figure 2). Phosphorus significantly impacted Al-P levels, with mean Al-P ranging from 24.28 to 35.47 mg kg^{-1} in 2020-21 and 24.23 to 37.75 mg kg^{-1} in 2021-22. Applying 90 kg P ha^{-1} notably increased Al-P levels to 35.47 and 37.75 mg kg^{-1} in both years, compared to lower doses and control. The lowest Al-P means were observed in the P-omitted plots (P0) at 24.28 and 24.23 mg kg^{-1} for the respective years. Fertilizer application at 30, 60 and 90 kg P ha^{-1} increased the mean Al-P fraction by 21.02%, 38.41% and 50.90% over the control. The lower Al-P content, compared to Fe-P and Ca-P, may be due to higher Fe3+ and Ca2+ ion activity in the soil.

Phosphorus fertilizers increased Al-P concentrations compared to the control, indicating that some of the added P transformed into Al-P. This may be due to organic acids from phosphorus-solubilizing microbes and acid from DAP hydrolysis dissolving Al in the clay. High Fe-P and Al-P levels were attributed to sesquioxides converting some native or added P. The findings showed Al-P levels rose with increasing phosphorus, consistent with (Singh *et al.,* 2014, Pradhan *et al.,* 2018; Naik *et al.,* 2022; Abolfazli *et al.,* 2012). who found that higher P fertilizer rates increased all P fractions. However, (Table 2 and Fig 2) indicate that repeated S dosages did not significantly affect post-harvest soil Al-P concentration.

Fe bound P (Fe-P)

The data on Fe-bound phosphate affected by different P and S levels are shown in (Table 2 and Fig 3). Phosphorus levels significantly increased soil Fe-P content, the most prevalent P fraction in the experimental field. Mean Fe-P in phosphorus-treated soil ranged from 91.35 to 124.76 mg kg^{-1} in 2020-21 and from 90.48 to 126.76 mg kg^{-1} in 2021-22. The application of 90 kg P ha^{-1} notably increased Fe-P levels compared to 60, 30 and 0 kg P ha^{-1}. Fe-P levels rose with higher phosphorus levels, peaking at 124.76 and 126.76 mg kg^{-1} for 90 kg P ha^{-1} in both years. The lowest Fe-P levels were found in the P-omitted plots (P0), with means of 91.35 and 90.48 mg kg^{-1}. P fertilizer at 30, 60 and 90 kg ha^{-1} increased Fe-P by 12.71%, 25.70% and 37.27% over the control. The soil's slightly acidic nature may have caused the increased Fe-P concentration, as applied P reacted with Fe and Al complexes to form insoluble Fe-P. These results align with findings from (Pradhan *et al*., 2018,

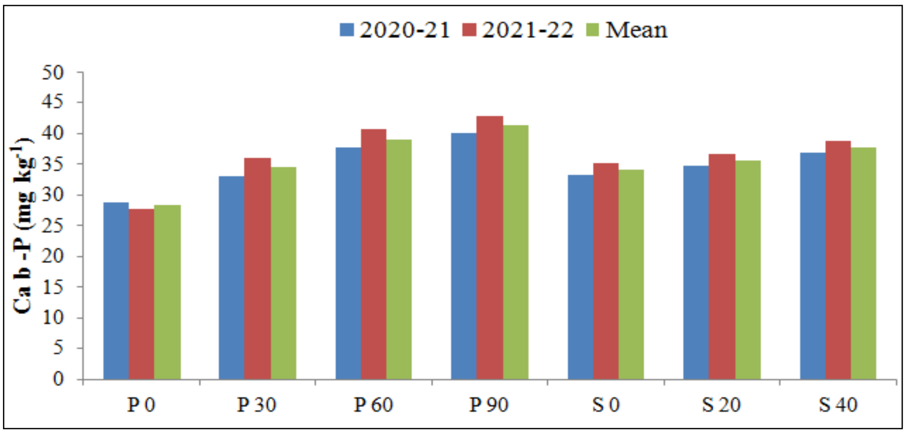

Fig 4: Effect of phosphorous and sulphur levels on Ca-P (mg kg^{-1}) of soil after harvest of groundnut.

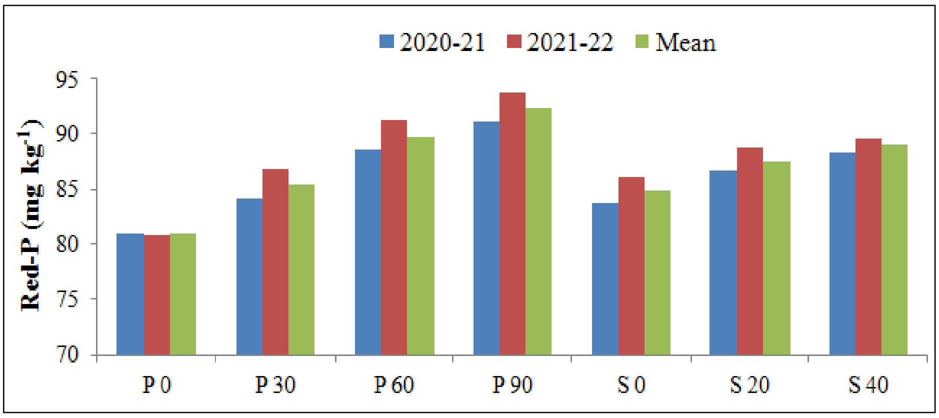

Fig 5: Effect of phosphorous and sulphur levels on Red-P (mg kg^{-1}) of soil after harvest of groundnut.

Sihag *et al.,* 2005, Naik *et al*., 2022; Ravikumar and Somashekar 2014), who reported higher soil Fe-P with increased P application.

Calcium bound P (Ca-P)

The effect of different P and S levels on soil Ca-P (mg kg^{-1}) is shown in (Table 2 and Fig 4). Phosphorus application significantly increased Ca-P content, with mean Ca-P levels ranging from 28.85 to 40.04 mg kg^{-1} in 2020-21 and 27.76 to 42.93 mg kg^{-1} in 2021-22. The highest Ca-P levels were observed with 90 kg P ha^{-1}, with values of 40.04 and 42.93 mg kg^{-1}, significantly higher than lower doses and control. The lowest Ca-P levels were found in the P-omitted plots (P0) at 28.85 and 27.76 mg kg^{-1}. Continuous P fertilizer application in intensive cropping systems led to an accumulation of Ca-P, as found by (Singh *et al.,* 2010, Pradhan *et al*., 2018, Naik *et al*., 2022, Dhage *et al*., 2014, Gupta *et al*., 2016) also reported similar increases in Ca-P fractions with P application. Sulphur application and P-S interaction had no significant impact on post-harvest Ca-P levels.

Reductant soluble P (Red-P)

The data on Reductant soluble P (Red-P) affected by different P and S levels are presented in (Table 2 and Fig 5). Phosphorus levels significantly impacted Red-P, with mean levels ranging from 80.00 to 91.04 mg kg^{-1} in 2020-21 and from 80.84 to 93.62 mg kg^{-1} in 2021-22. Applying 90 kg P ha^{-1} notably increased Red-P levels compared to 30 and 0 kg P ha^{-1}. Red-P content rose significantly with higher phosphorus levels, reaching 91.04, 93.62 and 92.33 mg kg^{-1} for 90 kg P ha^{-1} over both years. P fertilizer at 30, 60 and 90 kg ha^{-1} increased Red-P by 5.59%, 10.87% and 14.10% over the control. The lowest mean Red-P values were observed in the P-omitted plots (P0) at 80.00, 80.84 and 80.92 mg kg^{-1}.

The form of phosphorous known as reducant soluble phosphate (Red-P) occurs when P is occluded or adsorbed by the oxides and hydroxides of Fe and Al. This could be the reason why Red-P's contribution to the current study was greater than that of Sal-P and Ca-P. due to its ability to complexe Al and Fe in addition to acidification at the plant rhizosphere (Drouillon and Merckx, 2003, Naik *et al.,* 2022). The rate at which phosphorus was fixed and transformed in the soil was accelerated by the addition of phosphatic fertilizers. An insoluble Red-P rose correspondingly to an increase in the system's phosphorus content since the dosage of P application increased. This could be as a result of the water solubility of DAP and its easy reaction with ferric hydroxide to change its solubility into an insoluble state. According to (Ghosh *et al*., 2021, Pradhan *et al*., 2018, Naik *et al*., 2022, Shivhare *et al*., 2022), the results are consistent. Following crop harvest, the Red-P content was not significantly affected by the sequential doses of sulphur application.

CONCLUSION

It can be concluded that phosphorus (P) fertilization significantly enhanced soil P availability and speciation, leading to a substantial increase in total P content. The highest P application rate of 90 kg ha^{-1} resulted in a notable accumulation of all P fractions (saloid bound-P, Al-P, Fe-P, Ca-P and Red-P), indicating improved soil P retention and release of available P for plant uptake. These findings underscore the pivotal role of P management in promoting soil health.

Conflict of interest

All authors declared that there is no conflict of interest.

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