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Soil Phosphorus Dynamics in Red Sandy Loam Soils (Entisols) of Kerala as Influenced by different Nutrient Management Practices and its Impact on Cowpea (*Vigna unguiculata*) Productivity

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Abstract

A field study was conducted in instructional Farm II, College of Agriculture, Padannakkad to study the soil phosphorus dynamics in red sandy loam soil as modified by different amendments and its impact on growth and yield parameters of cowpea. The experimental field was set up using a randomized block design, comprising eight treatments and three replications with cowpea (Variety - *Kanakamony*) as the test crop. Treatments include: T_1 (KAU POP), T_2 (Soil test based fertilizer and lime), T_3 (KAU organic POP), T_4 (T_2 + $ZnSO_4$), T_5 (T_2 + Borax), T_6 (T_2 + PSB seed inoculation), T_7 (T_3 + PSB seed inoculation) and T_8 (T_2 excluding P fertilizer + Nano P). Various phosphorus fractions in the soil werein the order: Reductant P> Aluminium bound P (Al-P)>Organic P>Iron bound P(Fe-P)>Calcium bound P(Ca-P)>Loosely bound P. Treatments had a significant effect on phosphorus fractions in the soil. Loosely bound P was maximum in T_1 and T_7, Ca-P was high in T_2 and T_3, Fe-P and Al-P were high in T_4, organic P was high in T_1 and T_3 and reductant P was high in T_3 at various growth stages. Plant nutrient content also significantly changed across the treatments. Crop grown in the T_8treatment hadthe highest phosphorus content compared to other treatments and was superior to others in the yield parameters of cowpea. The results obtained from field experiments shown that there is a significant effect of treatments on the yield of cowpea. The study revealed that applying Zn increased P pools like Al-P, Fe-P, loosely bound P and Reductant P. The combined application of soil test-based fertilizer (excluding P fertilizer) and Nano P foliar application significantly increased the yield. The combined application of organic POP and PSB treatment also gave a comparatively higher yield than the KAU POP recommendation.

Keywords : Phosphorus fractions, Phosphorus dynamics, Red sandy loam soil, Nutrient managment practices, Cowpea

Soil phosphorus exists in several forms, primarily categorized into inorganic phosphorus (Pi) and organic phosphorus (Po). The Pi fractions include forms bound to metal ions such as iron (Fe), aluminium (Al) and calcium (Ca), which can significantly affect the availability of P to plants. Research indicates that the adsorption and desorption of P are primarily controlled by soil pH and the presence of these metal ions. For instance, iron- and aluminium-bound phosphorus tends to be less available to plants than calcium-bound phosphorus, particularly in acidic soils where Fe and Al solubility increases (Penn and Camberato, 2019). The varied spectrum of inorganic phosphates present with in soil matrices includes readily soluble phosphate (S-P), aluminium phosphates (Al-P), iron phosphates (Fe-P), reductant-soluble phosphates (RS-P) and calcium phosphates (Ca-P) (Chang and Jackson, 1957). Soils characterized by strong acidity, which have typically experienced significant degrees of weathering, are primarily composed of Al-P, Fe-P and RS-P. The interaction between organic and inorganic phosphorus pools is of paramount importance, as it significantly affects nutrient cycling and the overall health of the soil ecosystem.

A study by Kerala State Planning Board, KAU and NBSS & LUP has found very high available P in Kerala soils (Rajasekharan *et al*., 2014). High available P in soils cause environmental impact and antagonistic nutrient interaction effects. Applying different treatments, such as fertilizers or organic amendments, can lead to substantial changes in the distribution and availability of phosphorus pools. Long-term studies have demonstrated that fertilization practices not only increase total P levels but also alter the proportions of labile versus stable P fractions in soil. For example, the use of nitrogen-phosphorus-potassium (NPK) fertilizers has been shown to enhance the concentration of both Pi and Po fractions, although the effects may vary depending on soil type and environmental conditions (Sun *et al*., 2022). Crops like cowpea respond well to varying phosphorus treatments and has been identified as a crop that can benefit from improved P availability due to its deep root system and symbiotic relationships with mycorrhizal fungi. Study on the effect of different amendments on P dynamics will help to evolve management strategies for generating reserve pools from excess phosphorus and also for sustainable release of available P from reserve pools for optimum crop yields while minimizing environmental impacts.

Material and Methods

The field experiment for the present study was carried out from October to December 2023 at instructional Farm II, College of Agriculture, Padannakkad, Kerala Agricultural University, Kerala. The experimental site is geographically located at 12° 24’58" North latitude, 75° 13’51" East longitude and 9 m above mean sea level. Soils in the region are sandy loam in texture and belongs to the order Entisols. The cowpea variety *Kanakamony* was used as a test crop for the field experiment. Treatments were as follows:

T_1 - KAU POP (2016) based lime and fertilizers

T_2 - Soil test based fertilizer and lime

T_3 - KAU Organic POP (2015) based lime and FYM

T_4 - T_2 + $ZnSO_4$ @ 20 kg ha^{-1}

T_5 - T_2 + Borax @ 10 kg ha^{-1}

T_6 - T_2 + Seed treatment with PSB

T_7 - T_3 + Seed treatment with PSB

T_8 - T_2 excluding P + nano P application (foliar)

Note: T_1: FYM @ 20 t ha^{-1}, lime @ 250 kg ha^{-1}, NPK @ 20:30:10 kg ha^{-1} (half quantity of N, whole P and K applied as basal and remaining quantity of N applied 15-20 days after sowing), T_2: N @ 97% of KAU POP based N, P @ 25% of KAU POP based P, K @ 60% of KAU POP based K, lime @ 350 kg ha^{-1}, T_3: Lime @ 250 kg ha^{-1}, FYM @ 20 t ha^{-1} as basal, additional dose of FYM @ 2 t ha^{-1} and rock phosphate @ 100 kg ha^{-1} (additional organic manures applied in splits at fortnightly interval), T_4 and T_5: $ZnSO_4$ and Borax were added as basal one week prior to sowing of the crop, T_6 and T_7: Seed treatment was done with commercially available strain of *Bacillus megaterium* (PSB) from KAU by making thick slurry of 1:2.5 inoculum: water mixture, T_8: Foliar application of Nano P (DAP by IFFCO) @ 10 ml L^{-1} at branching and flowering stages.

Soil samples were initially analyzed for parameters such as pH, EC (dSm^{-1}), organic carbon (%), available P (kg ha^{-1}) and different fractions of phosphorus (Ca-P, Al-P, Fe-P, organic P and Total P) (mg kg^{-1}). Phosphorus fractions in the soil at flowering and after harvest stages of the crop were analyzed. Biometric observations of the crop were taken which included leaf area, number of branches per plant, plant height, number of pods per plant, pod weight per plant, test weight (100 grain weight) and pod yield (kg ha^{-1}).

Soil and Plant Analysis

The pH and electrical conductivity of soil samples were measured on soil water suspension made at 1:2.5 ratio. Organic carbon content in the soil was estimated using Walkley-Black chromic acid wet oxidation method (Walkley and Black, 1934). Available phosphorus was estimated using Bray and Kurtz method (Bray and Kurtz, 1945). The total phosphorus content in plant was analysed by vanadomolybdate yellow colour method (Piper, 1966).

Phosphorus Fractionations

The method of soil P fractionation was based on modified and combined method as described by Chang and Jackson (1957) and Kuo and Sparks (1996) to estimate different inorganic P fractions associated with Al, Fe, Ca, Loosely bound P, Reductant P and Organic P. Loosely bound P was extracted using 1 M NH_4Cl, Al-P was using 0.5 M NH_4F, Fe-P using 0.1 M NaOH, Reductant soluble P with 0.3 M $Na_3C_3H_6O_7$+ 1 M $NaHCO_3$ and Ca-P with 0.25 M H_2SO_4. Total P was estimated by extraction from a known amount of soil by diacid digestion followed by colorimetric estimation. Organic P fraction was measured by the difference of total P and the inorganic P pool.

Phosphorus Activation Coefficient

The phosphorus activation coefficient (PAC) is the ratio of available P to total P (Wu *et al*., 2017). It is a decisive factor that is indicative of soil P availability and the transformation of P fractions.

$$PAC = \frac{Available\ P}{Total\ P}$$

Results and Discussion

Soil pH, EC and Organic Carbon (OC)

The mean values of soil pH, EC and OC at 3 stages- pre-sowing, flowering and harvest stages are given in Tables 1 and 2.

Table 1

pH, EC and organic carbon (OC) of soil at pre-sowing stage

Treatment	Pre-sowing		
	pH	EC (dSm^{-1})	OC (%)
T_1	4.893	0.207	1.005
T_2	4.850	0.200	1.007
T_3	4.880	0.183	1.007
T_4	4.910	0.160	1.006
T_5	4.880	0.177	1.006
T_6	4.870	0.180	1.003
T_7	4.860	0.203	1.008
T_8	4.893	0.210	1.006
SE (m)	0.065	0.017	0.015
CD (0.05)	NS	NS	NS

Table 2

Effect of treatments on soil pH, EC and organic carbon (OC) at flowering and post-harvest stages

Treatments	Flowering			Post-harvest		
	pH	EC ($dS\ m^{-1}$)	OC (%)	pH	EC ($dS\ m^{-1}$)	OC (%)
T_1	5.373 ^{ab}	0.279	1.290	5.090	0.201	1.225
T_2	5.323 ^{bc}	0.270	1.367	5.060	0.189	1.367
T_3	5.487 ^{a}	0.249	1.389	5.240	0.189	1.148
T_4	5.290 ^{bc}	0.219	1.225	5.000	0.219	1.257
T_5	5.000 ^{e}	0.240	1.203	5.140	0.171	1.312
T_6	5.133 ^{de}	0.240	1.115	5.057	0.189	1.432
T_7	5.303 ^{bc}	0.279	1.410	5.107	0.189	1.389
T_8	5.207 ^{cd}	0.291	1.311	5.380	0.189	1.301
SE (m)	0.051	0.008	0.155	0.081	0.006	0.111
C.D. (0.05)	0.154	NS	NS	NS	NS	NS

Soil was having very strong acidic pH with normal EC and high OC. At the flowering and post-harvest stages of crop growth, there was slight increase in pH with no much change in EC and OC among treatments. pH had a significant change at flowering stage with highest value in T_3 (5.487) which was on par with T_1 (5.373) which can be attributed to the addition of lime and organic manures in those treatments. Otieno *et al.* (2018) and Islam *et al.* (2021) found that the combination of FYM with lime often results in a greater increase in pH which brings more substantial improvements in soil nutrient availability and overall fertility compared to using either amendment separately.

Available P

Initial soil analysis showed a higher available P. At the flowering and post-harvest stages, significant difference was observed among the treatments (Table 3). At flowering, available P was highest for T_1 (147.00 kg ha^{-1}), which was on par with T_2 (143.58 kg ha^{-1}). This can be attributed to the treatment effect containing phosphatic fertilizer and the lack of interactive effect from amendments compared to other treatments. At the post-harvest stage, the available P content of the soil decreased in all the treatments. This can be due to crop uptake and transformation to organic and inorganic P forms. The highest value of available P at post-harvest stage was obtained in T_1, which was statistically similar to T_2, T_3 and T_4.

TABLE 3

Effect of treatments on available P (kg ha^{-1}) content in soil

Treatments	Pre-sowing	Flowering	Post-harvest
T_1	114.74	147.00 ^{a}	120.62 ^{a}
T_2	109.71	143.58 ^{a}	118.27 ^{ab}
T_3	108.28	137.03 ^{b}	118.94 ^{ab}
T_4	109.00	131.66 ^{c}	119.17 ^{ab}
T_5	110.43	129.70 ^{cd}	114.80 ^{bc}
T_6	108.25	128.18 ^{cd}	108.34 ^{d}
T_7	110.05	138.09 ^{b}	111.76 ^{cd}
T_8	111.91	124.71 ^{d}	110.40 ^{cd}
SE (m)	1.642	1.657	1.675
C.D (0.05)	NS	5.026	5.082

Fractions in Soil

Results of statistically analysed data for the phosphorus fractions at pre-sowing, flowering and after harvest stages are presented in Tables 4, 5 and 6, respectively.

TABLE 4

P fractions in soil at pre-sowing (mg kg^{-1})

Treatments	Loosel y bound P	Fe-P	Al-P	Ca-P	Organic P	Reductant P	Total P
T_1	27.54	60.13	100.65	41.93	82.32	112.37	420.60
T_2	27.80	60.25	102.41	41.91	80.78	111.48	425.64
T_3	28.10	59.24	100.14	41.33	83.25	105.29	417.36
T_4	27.83	60.38	100.40	39.87	85.56	113.26	428.96
T_5	26.13	60.70	100.80	41.62	85.15	111.70	426.77
T_6	26.84	59.90	101.60	39.98	87.03	110.80	427.81
T_7	28.23	59.70	101.20	39.52	85.34	112.10	426.76
T_8	25.93	60.20	101.10	40.96	88.80	110.50	427.15
SE (m)	1.035	1.137	1.608	0.65	1.375	2.004	3.746
C.D (0.05)	NS	NS	NS	NS	NS	NS	NS

TABLE 5

Effect of treatments on P fractions in soil at flowering (mg kg^{-1})

Treatments	Loosel y bound P	Fe-P	Al-P	Ca-P	Reductant P	Organic P	Total P
T_1	54.20 ^{a}	36.53 ^{f}	93.53 ^{bc}	38.67 ^{e}	103.40 ^{c}	132.90 ^{b}	459.24 ^{bc}
T_2	43.93 ^{b}	58.93 ^{b}	74.90 ^{e}	74.10 ^{a}	98.20 ^{d}	77.87 ^{f}	427.93 ^{e}
T_3	37.43 ^{c}	51.57 ^{c}	87.13 ^{d}	43.40 ^{d}	122.80 ^{a}	135.04 ^{a}	477.38 ^{a}
T_4	36.33 ^{c}	65.83 ^{a}	112.80 ^{a}	38.20 ^{e}	111.17 ^{b}	104.08 ^{d}	468.42 ^{b}
T_5	27.53 ^{f}	47.30 ^{d}	91.47 ^{c}	42.60 ^{d}	111.50 ^{b}	91.92 ^{ef}	412.32 ^{f}
T_6	30.87 ^{e}	57.27 ^{b}	85.83 ^{d}	58.40 ^{c}	97.33 ^{d}	93.14 ^{e}	422.84 ^{ef}
T_7	34.33 ^{d}	58.60 ^{b}	96.20 ^{b}	63.90 ^{b}	101.80 ^{cd}	121.90 ^{c}	476.73 ^{a}
T_8	33.20 ^{d}	41.97 ^{e}	87.10 ^{d}	44.83 ^{d}	111.70 ^{b}	126.89 ^{bc}	445.69 ^{cd}
SE (m)	0.587	1.057	1.142	0.784	1.441	2.755	3.064
C.D. (0.05)	1.781	3.208	3.464	2.379	4.369	8.358	9.294

TABLE 6

Effect of treatments on soil P fractions at post-harvest (mg kg^{-1})

Treatments	Loosel y bound P	Fe-P	Al-P	Ca-P	Reductant P	Organic P	Total P
T_1	31.37 ^{b}	50.77 ^{g}	82.33 ^{bc}	82.87 ^{d}	140.90 ^{d}	121.33 ^{a}	509.57 ^{b}
T_2	28.73 ^{c}	54.20 ^{f}	74.90 ^{ef}	91.30 ^{b}	141.90 ^{c}	70.47 ^{f}	461.50 ^{e}
T_3	21.30 ^{e}	57.00 ^{e}	80.20 ^{cd}	99.00 ^{a}	159.70 ^{a}	120.98 ^{a}	538.18 ^{a}
T_4	22.73 ^{de}	79.07 ^{a}	107.94 ^{a}	69.51 ^{f}	120.07 ^{g}	94.34 ^{c}	494.44 ^{c}
T_5	19.67 ^{f}	59.47 ^{d}	81.90 ^{c}	87.90 ^{c}	128.27 ^{f}	80.09 ^{e}	457.30 ^{f}
T_6	26.03 ^{d}	58.17 ^{de}	79.37 ^{de}	83.10 ^{d}	137.30 ^{e}	83.05 ^{d}	467.01 ^{de}
T_7	36.97 ^{a}	76.49 ^{b}	88.83 ^{b}	73.53 ^{e}	153.60 ^{b}	111.60 ^{b}	541.02 ^{a}
T_8	15.77 ^{g}	63.60 ^{c}	73.30 ^{f}	73.23 ^{e}	143.00 ^{c}	100.00 ^{c}	468.90 ^{d}
SE (m)	0.359	0.776	1.136	0.797	1.632	1.913	3.309
C.D. (0.05)	1.088	2.355	3.447	2.419	4.949	5.803	10.038

Loosely Bound P

Loosely bound P represents the inorganic P weakly adsorbed on the soil particles which can be made available directly to the plants. This fraction changed significantly in the flowering and post-harvest stages, among the different treatments. At flowering, the highest amount of loosely bound P was obtained in the T_1 treatment, whereas the T_7 treatment yielded highest value at the post-harvest stage. The highest value in T_1 can be due to the excess application of phosphorus fertilizer where the P in soil solution could have adsorbed to the soil particles, while the highest value at T_7 at the post-harvest stage could be due to the solubilisation effect of PSB as the crop growth progresses which made P available for adsorption by the soil particles.

Iron bound Phosphorus (Fe-P)

Significant difference was observed in iron bound P among the treatments at flowering and after harvest stages. The values ranged from 36.53 to 65.83mg kg^{-1} at flowering and from 50.77 to 79.07mg kg^{-1} at the post-harvest stage of the crop. Among the treatments, T_4 (soil test-based fertilizer + lime + $ZnSO_4$) had highest values at both flowering and harvest stages compared to other treatments. The presence of Zn can alter the dynamics of phosphorus (P) in soil, leading to increased Fe-P content. Organic matter plays a vital role in the interaction between Zn and P, as it can stabilize Zn and facilitate its complexation with P (Dhillon *et al*., 1975) and studies have shown that applying P along side Zn results in higher Fe-P levels than P alone (Naskar *et al*., 2023).

Aluminium Bound Phosphorus (Al-P)

At flowering and after-harvest stages, Al-P varied significantly among the treatments. The values ranged from 74.90 to 112.80 mg kg^{-1} at flowering and from 73.30 to 107.9 mg kg^{-1} at the post-harvest stage. At flowering and post-harvest stages, the highest value for Al-P was shown by T_4 (112.80 mg kg^{-1} and 107.90 mg kg^{-1}, respectively). This high amount of Al-P can be attributed application of $ZnSO_4$along with the fertilizers. A study by Naskar *et al*. (2023) also confirms the increase in the amount of Al-P in soils when combined with Zn.

Calcium-Bound Phosphorus (Ca-P)

Calcium-bound P was significantly affected by the treatments at flowering and post-harvest stages. The values ranged from 38.20 to 74.10 mg kg^{-1} at the flowering stage and from 69.51 to 99.00 mg kg^{-1} at the post-harvest stage. At the flowering stage, the highest Ca-P concentration was found in T_2 (74.10 mg kg^{-1}), while at the harvest stage, it was maximum in T_3 (99.00 mg kg^{-1}) treated plots. The increase in the values of Ca-P in T_2 at flowering stage can be attributed to the addition of higher dose of lime (based on soil test results) adding more calcium to the soil and the phosphorus thus get fixed with calcium to form phosphates of calcium in soil. Similar results were obtained by Chulo *et al*. (2023) where higher lime rates have resulted significant increase in soluble phosphorus (P-sol) and Ca-P fractions, while decreasing iron (Fe-P) and aluminium (Al-P) bound phosphorus. High Ca-P in the T_3 treatment can be due to the combined effect of FYM and rock phosphate on the formation of Ca-P in the soil. The slow rate of P release from rock phosphate might have resulted in lesser Ca-P formation at flowering stage than at the harvest stage where the release of P could have increased by the course of time, leading to higher Ca-P formation in the soil. Similar results were obtained by Neenu *et al*. (2023), where the Ca-P content in the soil was higher due to the heavy top dressing of rock phosphate into the soil.

Reductant P

Reductant P or Reductant soluble P (RS-P) fractions in soil refer to specific forms of phosphorus associated with Fe oxides that are present as inert form (Bauwin and Tyner, 1957) and can only release P in anaerobic conditions (Singh *et al*., 2016). The flowering and the post-harvest stage results showed significant changes in reductant P across the treatments. The highest amount of reductant P was obtained in T_3 treatment at both flowering and post-harvest stages. This high amount can be attributed to the application of FYM that significantly improves microbial activity in the soil. This increased microbial presence facilitates the breakdown of organic matter, leading to the release of previously unavailable forms of phosphorus, including reductant-soluble phosphorus as shown by Biradar and Salvi (2024). Also, studies by Wierzbowska *et al*. (2020) have shown that FYM application at rates like 10 t ha^{-1} can lead to significant increases in reductant P levels during various incubation periods.

Organic P

Organic P was significantly affected by treatments at the flowering and after-harvest stages. The values ranged from 77.87 to 135.04 mg kg^{-1} at the flowering stage and from 70.47 to 121.334 mg kg^{-1} at the post-harvest stage. At the flowering stage, the highest Organic P concentration was found in T_3 treatment (135.04 mg kg^{-1}), while at the harvest stage, it was maximum at T_1 (121.334 mg kg^{-1}) treated plots. This increase in organic phosphorus fraction can be attributed to application of organic manures in these treatments. The application of FYM boosts microbial biomass and activity, leading to a higher accumulation of organic P forms in the soil. Similar results were obtained by Malik *et al*. (2013).

Total P

At flowering and after-harvest stages total P varied significantly among the treatments. The values ranged from 412.32 to 477.37 mg kg^{-1} at the flowering stage and from 457.29 to 541.02 mg kg^{-1} at the post-harvest stage. At both flowering and post-harvest stage, the highest total P was obtained in T_3 and T_7 treatments, respectively. The increase of total P in T_7 (Organic POP + PSB) can be due to the combined action of both organic manure and PSB by producing organic acids and extra cellular phosphatases that dissolve the insoluble phosphorus and make it available to the plants. Aslam *et al*. (2024) got similar findings, stating that the application of PSB increases total phosphorus concentrations in soils and facilitates its availability to plants.

Variations in different Fractions of P across different Stages of Crop Growth

The various phosphorus fractions in the soil were in the order: Reductant P> Al-P > Organic P > Fe-P >Ca-P >Loosely bound P at the pre-sowing stage (Table 4). However, due to the effect of treatments, the fractions varied across the crop growth stages *i.e*., at flowering and post-harvest stage. At flowering (Table 5), the loosely bound P increased in all treatments and was lowest in T_5, Fe-P got reduced in all treatments except T_4 and the lowest was in T_1, Al-P also got reduced in all treatments except T_4 and the lowest value was recorded in T_2, Ca-P values increased except in case of T_1 an dT_4 and the highest value was obtained in T_2, reductant P values decreased except in T_3, T_5, T_8 and the organic P values increased in all the treatments except T_2 when compared to the factions at pre-sowing stage. At the post-harvest stage (Table 6), loosely bound P and organic P was lower in all the treatments, Fe-P decreased in all the treatments except T_2, Reductant P and Ca-P were high in all treatments when compared with the flowering stage. After the completion of harvest, the major fractions of P were of the order: Reductant P>Organic P>Ca-P = Al-P>Fe-P>loosely bound P for most of the treatments.

Phosphorus Activation Coefficient (PAC)

It is the ratio of available P to total P and it is a vital indicator of soil P availability and the transformation of P fractions. If PAC is smaller than 2.0 per cent, the total P is not transformed into available P (Wu *et al*., 2017). In this study, the PAC for all the treatments is higher than 2.0 per cent (Table 7) and among the treatments, the highest PAC was obtained in the T_2 treatment, which suggests that even though the available P in the soil is high, a small addition of fertilizer P as per soil test result will help in the sustainable release of P from the reserve P pools for the succeeding crops. The least PAC in T_8 at flowering could be due to the absence of P fertilizer application, while at harvest stage the least value in T_6 can be attributed to the fact that most of the total P could have been converted to available P at the flowering stage and by the time of harvest this conversion to available P might have reduced leading to lowered PAC value.

TABLE 7

Effect of treatments on PAC (%)

Treatments	Flowering	Harvest
T_1	14.293 ^{b}	10.89 ^{bc}
T_2	14.977 ^{a}	11.443 ^{a}
T_3	13.55 ^{c}	9.867 ^{d}
T_4	13.133 ^{cd}	10.437 ^{c}
T_5	14.043 ^{b}	11.21 ^{ab}
T_6	12.983 ^{d}	8.94 ^{e}
T_7	12.933 ^{de}	9.64 ^{d}
T_8	12.493 ^{e}	10.52 ^{c}
SE (m)	0.156	0.16
CD (0.05)	0.475	0.485

Plant Phosphorus Content and P uptake by Cowpea

The effect of treatments on plant phosphorus content and phosphorus uptake was significant, as shown in

Table 8. The plant phosphorus content ranged from 0.184 to 0.287 per cent with the highest phosphorus content recorded in T_8, which is treated with Nano P. The lowest value of plant phosphorus was noted in T_4 (0.184%). Similarly, the phosphorus uptake by plants ranged from 4.65 to 7.18 kg ha^{-1}, with the highest uptake of P in treatment T_8 (7.18 kg ha^{-1}) which was on par with T_7 (6.99 kg ha^{-1}) and the lowest value was recorded in treatment T_4 (4.65 kg ha^{-1}). The application of Nano P as foliar can enhance uptake and phosphorus content in the plant compared to other treatments, which are in accordance with a study conducted by Meena *et al.* (2021). Also, study conducted by Kumara Swamy *et al.* (2010) highlighted that inoculation of phosphorus solubilizing microbes (PSMs) significantly increased phosphorus uptake in cowpea plants. While the least value in T_4 can be attributed to the antagonistic effect of Zn on P availability in soil thereby reducing the P uptake and P content in the plants.

TABLE 8

Effect of treatments on total P % and P uptake by cowpea

Treatments	P (%)	P uptake by plant (kg ha^{-1})
T_1	0.212 ^{c}	5.830 ^{cd}
T_2	0.202 ^{cde}	5.750 ^{d}
T_3	0.199 ^{de}	5.540 ^{d}
T_4	0.184 ^{f}	4.650 ^{e}
T_5	0.205 ^{cd}	6.123 ^{bc}
T_6	0.192 ^{ef}	6.340 ^{b}
T_7	0.259 ^{b}	6.990 ^{a}
T_8	0.287 ^{a}	7.183 ^{a}
SE (m)	0.004	0.106
C.D. (0.05)	0.012	0.322

Growth Parameters of Cowpea

The growth parameters of cowpea are presented in the Table 9. There was no significant difference among the treatments for different growth parameters. The leaf area of the observational plants was measured using a leaf area meter. Leaf area ranged from 42.863cm^2 to 50.137cm^2 among the treatments. Similarly, plant height was measured from the shoot tip to the basal and the values ranged from 127.333 cm to 184.067 cm and there was no significant difference among the treatments. Likewise, number of branches were counted and the mean values ranged from 4.0 to 5.67.

TABLE 9

Effect of treatments on plant biometrics

Treatments	Leaf area (cm^2)	Plant height (cm)	No. of branches per plant
T_1	49.07	127.73	5.67
T_2	48.97	163.48	5.00
T_3	49.04	132.23	4.67
T_4	42.86	144.72	4.33
T_5	49.21	153.40	4.67
T_6	50.14	184.07	4.00
T_7	49.76	146.33	4.67
T_8	49.75	132.40	4.67
SE (m)	3.065	12.989	0.42
C.D. (0.05)	NS	NS	NS

Yield Parameters of Cowpea

Yield parameters of cowpea are summarized in Table 10. The number of pods per plant was counted after harvest and there was no significant difference among the treatments. The mean values ranged from 16.33 to 23.00. Test weight is measured by weighing 100-grain weight and there was no significant difference among the treatments and the mean values ranged from 9.667g to 10.200g.

Pod weight per plant and pod yield showed significant differences among the treatments. Among the treatments, T_8 (T_2+ Nano P) followed by T_7 (T_3 + PSB) had got the highest mean value for pod weight per plant and pod yield. The highest pod yield was recorded in T_8, which received Nano P (4011.111 kg ha^{-1}), which was on par with T_7 (3929.63 kg ha^{-1}) with PSB seed treatment. This can be due to the increase in plant nutrient uptake by applying nano P (Rashmi and Prakash, 2023). Application of Nano P was done

TABLE 10

Effect of treatments on plant yield characteristics

Treatments	No. of pods per plant	Pod weight per plant (g)	Pod yield (kg ha^{-1})	Test weight (g)
T_1	21.33	46 [b]	3729.63 [c]	10.18
T_2	21.67	44 [b]	3469.86 [d]	10.20
T_3	23.00	55 [a]	3841.72 [bc]	10.10
T_4	16.33	39 [c]	3182.76 [e]	9.80
T_5	19.00	37 [c]	3370.55 [d]	9.93
T_6	17.33	40 [c]	3405.54 [d]	9.87
T_7	22.00	59 [a]	3929.63 [ab]	9.97
T_8	22.33	59 [a]	4011.11 [a]	9.67
SE (m)	1.522	0.001	155.926	0.172
C.D. (0.05)	NS	0.004	51.407	NS

using nano DAP, which can deliver N and P through the aerial parts of the plant, increasing the absorption and assimilation of the nutrients. On the other hand, a high value of pod weight per plant and pod yield in T_7 treatment is due to the application of PSB, which solubilises the fixed forms of phosphorus and makes it available to plants (Mamatha and Basavarajappa, 2024) along with the application of a high amount of organic manure.

The present study assessed the effect of existing practices and other amendments on the soil phosphorus dynamics in red sandy loam soils. The study revealed that soil test-based fertilizer and liming could enhance available P in the soil. Applying Borax and $ZnSO_4$ increased P pools like Fe-P, Al-P, loosely bound P and Reductant P which suggest that use of these amendments could promote the reserve P pools in the soil, reducing the P loss and avoiding environmental impacts. Also, soil pH plays an important role in the formation and mutual conversion of Al-P and Fe-P. Combined application of organic POP along with PSB treatment gave a comparatively higher yield than the Kerala Agricultural University (KAU) POP recommendation. Combined application of soil test-based fertilizer (excluding P fertilizer) and Nano P foliar application has significantly increased yield. Even though the available P in soil is high, a small addition of fertilizer P as per soil test result will help in the sustainable release of P from the reserve P pools for the succeeding crops.

REFERENCES

ASLAM, Z., YAHYA, M., HUSSAIN, H. S., TABBASUM, S., JALALUDDIN, S., KHALIQ, S. AND YASMIN, S., 2024, Development of bacteria-based bioorganic phosphate fertilizer enriched with rock phosphate for sustainable wheat production. *Front. Micro*., **15** : 1 - 16.

BAUWIN, G. R. AND TYNER, E. H., 1957, The nature of reductant soluble phosphorus in soils and soil concretions. *Soil Sci. Soc. Am. J.*, **21** (3) : 250 - 257.

BIRADAR, S. AND SALVI, V. G., 2024, Dynamics of nitrogen and phosphorous fractions under integrated use of inorganic fertilizers and organic manure and their correlation with yield of yam bean in Alfisols. *Plant Arch.*, **24** (1) : 575 - 585.

BRAY, R. H. AND KURTZ, L. T., 1945, Determination of total, organic and available forms of phosphorus in soils. *Soil Sci.*, **59** (1) : 39 - 45.

CHANG, S. C. AND JACKSON, M. L., 1957, Fractionation of soil phosphorus. *Soil Sci.*, **84** : 133 - 144.

CHULO, F., LAEKEMARIAM, F., KIFLU, A., GIDAGO, G. AND GETANEH, L., 2023, Soil phosphorus fractions and their quantity in acidic luvisols under lime rates in Ethiopia. *Commun. Soil Sci. Plant Anal*., **54** (2) : 243 - 257.

DHILLON, K. S., SINHA, M. K. AND RANDHAWA, N. S., 1975, Organo-metallic phosphates: V. complexation of zinc and phosphorus by humic compounds. *Plant and Soil*, **43** : 317 - 326.

ISLAM, M. R., JAHAN, R., UDDIN, S., HARINE, I. J., HOQUE, M. A., HASSAN, S., HASSAN, M. M. AND HOSSAIN, M. A., 2021, Lime and organic manure amendment enhances crop productivity of wheat–mungbean–t. amancropping pattern in acidic piedmont soils. *Agron*., **11** (8) : 1595.

KAU [KERALA AGRICULTURAL UNIVERSITY], 2015, *Package of Practices Recommendations (Adhoc) for Organic Farming*. Directorate of Extension, Kerala Agricultural University, Thrissur, pp. : 209.

KAU [KERALA AGRICULTURAL UNIVERSITY], 2016, *Package of Practices Recommendations: Crops* (15th Ed.). Kerala Agricultural University, Thrissur, pp. : 393.

KUMARA SWAMY, C. A., RAGHUNANDAN, B. L., CHANDRASHEKHAR, M. AND BRAHMAPRAKASH, G. P., 2010, Bio-activation of rock phosphate vis-a-vis seed treatment with phosphorus solubilizing microbes (PSM) in enhancing P nutrition in cowpea and ragi. *Indian J. Sci. Technol*., **3** (7) : 689 - 692.

KUO, S. AND SPARKS, D. L., 1996, Methods of soil analysis. Part 3: Chemical methods. *Soil Sci. Society Am., Madison*, WI, pp. : 894 - 895.

MALIK, M. A., KHAN, K. S., MARSCHNER, P. AND ALI, S., 2013, Organic amendments differ in their effect on microbial biomass and activity and on P pools in alkaline soils. *Biol. Fertil. Soils*, **49** : 415 - 425.

MAMATHA, B. AND BASAVARAJAPPA, M., 2024, Enhancing phosphorus release in acidic soils using Biochar Enriched with PSB: A Review. *Mysore J. Agric. Sci*., **58** (3) : 24 - 34.

MEENA, R. H., JAT, G. AND JAIN, D., 2021, Impact of foliar application of different nano-fertilizers on soil microbial properties and yield of wheat. *J. Environ. Biol.*, **42** (2) : 302 - 308.

NASKAR, P., MALLICK, R. B. AND DOLUI, A. K., 2023, Interaction between P and Zn on the changes in different inorganic phosphorus fractions under waterlogged soil treated with and without organic matter. *Agric. Sci. Digest*, pp. : 1 - 7.

NEENU, S., BHAT, R., SELVAMANI, V. AND SUBRAMANIAN, P., 2023, Inorganic phosphorus fractions and phosphorus availability in long-term fertilizer cum manurial trials under coconut cultivation. *J. Plant. Crops*, **51** (2) : 89 - 95.

OTIENO, H. M. O., CHEMINING'WA, G. N. AND ZINGORE, S., 2018, Effect of farmyard manure, lime and inorganic fertilizer applications on soil pH, nutrients uptake, growth and nodulation of soybean in acid soils of Western Kenya. *J. Agric. Sci.*, **10** (4) : 199 - 215.

PENN, C. J. AND CAMBERATO, J. J., 2019, A critical review on soil chemical processes that control how soil pH affects phosphorus availability to plants. *Agric*., **9** (6) : 120.

PIPER, 1966, Aging of crystalline precipitates. *Analyst* (London), **77** : 1000 - 1011.

RAJASEKHARAN, P., NAIR, K. M., JOHN, K. S., KUMAR, P. S., KUTTY, M. N. AND NAIR, A. R., 2014, Soil fertility related constraints to crop production in Kerala. *Indian J. Fertil*., **10** (11) : 56 - 62.

RASHMI, C. M. AND PRAKASH, S. S., 2023, Effect of nano phosphorus fertilizers on growth and yield of maize (*Zea mays* L.) in central dry zone of Karnataka. *Mysore J. Agric. Sci*., **57** (2) : 286 - 293.

SINGH, Y., ROY, P., JAT, L. K. AND KUMAR, M., 2016, Forms of phosphorus in rice-wheat growing soils of indo-gangetic alluvium plains of Bihar. *Ann. Plant Soil Res*., **18** (4) : 396 - 400.

SUN, F., SUN, N., MA, X., ZHOU, B., ZHU, P., GAO, H. AND XU, M., 2022, The application of fertilizer phosphorus affected olsen P and the phosphorus fractions of Hedley method in black soil. *Agron*., **12** (12) : 3146.

WALKLEY, A. J. AND BLACK, I. A., 1934, Estimation of soil organic carbon by chromic acid titration method. *Soil Sci*., **31** : 29 - 38.

WIERZBOWSKA, J., SIENKIEWICZ, S., ZALEWSKA, M., ZARCZYŃSKI, P. AND KRZEBIETKE, S., 2020, Phosphorus fractions in soil fertilised with organic waste. *Environ. Monitoring Assess*.,**192** (5) : 315.

WU, Q., ZHANG, S., ZHU, P., HUANG, S., WANG, B., ZHAO, L. AND XU, M., 2017, Characterizing differences in the phosphorus activation coefficient of three typical cropland soils and the influencing factors under long-term fertilization. *PLoS One,* **12** (5) : e0176437.