Research Article

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Inorganic phosphorus fractions and phosphorus availability in long term fertilizer cum manurial trials under coconut cultivation

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Abstract

Phosphorus is one of the major nutrients required for coconut production. The information about the fate of native and applied phosphorus in soil is essential for better management of the nutrient. The changes on inorganic P fractions and P availability in soil after 43 years of coconut cultivation were studied from a long term fertilizer cum manurial experiment at CPCRI, Kasaragod. There were 6 treatments *viz.* tillage with organic and inorganic fertilizer, tillage with inorganic fertilizer, inorganic fertilizers with basin forking, tillage alone, herbicide application without tillage and fertilizer and the control. Soil samples were taken at two depths (0-30 and 30-60 cm) from coconut basin for analysis. Phosphorus was fractionated into Easily Soluble P (ES-P), Aluminium P (AI-P), Iron P (Fe-P), Calcium P (Ca-P) and Reductant Soluble P (RS-P) through sequential extraction. The dominant phosphorus fraction in the coconut basin at 0-30 cm depth was Ca-P and the trend is as follows: Ca-P> Fe-P> RS-P>Al-P>ES-P. However, at 30-60 cm depth, Fe-P became the dominant fraction and the trend is Fe-P>Ca-P>RS-P>Al-P>ES-P. Long-term phosphorus fertilization would facilitate the accumulation of soil Ca-P, and thus improve soil P availability. In the interspaces, Fe-P was the dominating fraction in both the depths followed by Ca-P and RS-P. The difference in P fractions in fertilized and non-fertilized plots clearly showed that the fertilized plots have high content of all the inorganic phosphorus fractions in both the depths. Application of mineral P along with forking in basin showed a high concentration of all the inorganic P fractions compared to other fertilizer applied treatments.

Keywords: fertilizer, manure, long term experiment, Phosphorus, tillage

Introduction

Phosphorus is one of the vital nutrients required to plants. It involves in many plant processes like photosynthesis, synthesis of ATPs, nucleic acids and cell membrane, acts as signaling molecule, nitrogen fixation, metabolism of carbohydrate, activation/inactivation of enzyme etc. Phosphorus is known to be a decisive element in agricultural as well as natural ecosystem all over the world (Onweremandu, 2007) where its inadequate amount is a major limitation for crop growth especially in extremely weathered tropical soils (Bünemann *et al*., 2004). Phosphorus is unique due to its immobility in soil soon after application and its slow diffusion further limits its supply to root surface (Robinson, 1986). Phosphorus cycling in soil is significantly important with respect to crop production and fertilizer application. The amount of soluble phosphorus in the soil solution is extremely low, and also it is practically not a mobile element in the soil. According to Filipelli (2002), 98% of phosphorus in soil is held in different forms and there is a fast exchange of P between soil and biota with an average residence time of 13 and 600 years for soil organism and P in the soil, respectively.

Under very acidic conditions phosphorus combines with cations like aluminium and iron results in insoluble complexes and will become unavailable to plants. Soil pH plays a very vital role

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in making the soil phosphorus available to plants. At pH less than 5.5, ions like Al^{3+} and Fe^{3+} precipitate phosphorus by forming insoluble complexes, similarly at above pH 7.0 calcium ions precipitate phosphorus and making it unavailable to plants. In soil, phosphorus is present in both organic and inorganic forms. Among these, inorganic form of phosphorus is most important as it is correlated with the availability of phosphorus in soil. Primary phosphorus minerals like apatite, strengite and variscites are very stable and undergo slow weathering and contribut a little to available soil phosphorus pool. But secondary phosphorus minerals like calcium phosphates, iron phosphates and aluminium phosphates are very important in contributing soil phosphorus for plant growth. The major constraints of P availability in tropical regions including India in which the adsorption of phosphorus is extremely predisposed by oxides of aluminium and iron, presence of high amount of calcium, organic matter, soil texture etc. The kind of land utilization is also known to influence P sorption in soils (Aampu *et al.,* 2000). In soil, phosphorus is present as orthophosphate ($H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}) which may be present in soil solution in dissolved form or attached to soil particles/organic substances (Prasad *et al*., 2017, Emsley, 2000).

The organic as well as inorganic phosphorus fractions present in the soil will contribute the soil available phosphorus to plants. According to Gerke (2015) inorganic phosphorus undergoes different processes than organic P. Organic P is mainly controlled by biological system where as inorganic P dynamics depends on the chemical equilibrium. The inorganic phosphorus forms are further classified into active as well as inactive forms. The active phosphorus forms are as easily soluble P (saloid phosphorus), Aluminium bound P (Al-P), iron bound P (Fe-P), Calcium-P (Ca-P) and the organic P. Inactive phosphorus forms are occluded and reductant soluble (RS) phosphorus. As, these forms of phosphorus are having variable solubility, the plant availability as well as the uptake depend upon their concentration in the soil. Also these forms are influenced by pH, calcium carbonate, soil texture, as well as organic matter content of the soil. The better knowledge on the destiny of both the applied as well as native phosphorus present in the soil is crucial for better utilization of this particular nutrient. Hence a study was carried out on the distribution of various inorganic phosphorus fractions and its role in phosphorus availability to plants in a long term fertilizer cum manurial trial under coconut cultivation.

Materials and methods

Experimental site

To study the phosphorus dynamics and availability soil samples were collected from a 43 years old long term fertilizer cum manurial experiment under coconut cultivation at ICAR-CPCRI, Kasaragod, Kerala, India, and is situated at a latitude of 12' 30' N and 75" 00' E longitude at an altitude of 10.7 m above mean sea level during 2017-18. The trial was started in 1919 and the treatments were revised in 1973. The experimental field soil was classified as red loamy-sand texture containing on an average 86-88 per cent sand. The variety of coconut under study was West Coast Tall (WCT).

Experimental details

The experiment was conducted in block design with six treatments and four replications. The treatments comprised of:

T1-Tillage + Organic + Inorganic fertilizers
T2-Tillage + Inorganic fertilizers
T3-Inoganic fertilizer + forking in basin
T4-Tillage only
T5-Herbicide application (no fertilizer + no tillage)
T6-Neglected (no fertilizer + no tillage)

The cultural operations consist of two ploughings in September and October. Urea, Superphosphate and MOP (Muriate of Potash) were used as the sources of nitrogen, phosp horus and potassium fertilizers, respectively. Organic manure applied at the rate of 50 kg green leaves per palm per year. Paraquat (Grammaxone) and 2,4-D (Fernoxone) were the herbicides used in the study. The experiment was laid under single palm replication in a block design.

Soil sample collection and analysis

The samples were collected from two depths of the soil (0-30 and 30-60 cm) both from the basins and interspaces of coconut. The collected samples were first air dried and then sieved using a 2 mm mesh sieve. The air dried soil samples were used for analysis of soil reaction (pH), electrical conductivity (EC) available phosphorus, available potassium, exchangeable calcium and magnesium as per the procedure outlined by Jackson (1967). The percentage organic carbon was estimated by the wet digestion method (Walkley and Black's 1934). DTPA extractable iron, manganese, zinc and copper were analyzed by following the procedure outlined by Lindsay and Norvell (1978). Phosphorus fractionation was done as per the procedure depicted by Kuo, 1996.

Fractionation Procedure

Soil samples were serially extracted with 1M NH_4Cl, 0.5 M NH_4F, 0.1M NaOH, 0.3 M sodium citrate (with 1M $NaHCO_3$ and solid $Na_2S_2O_4$) and finally with 0.25 M H_2SO_4. Nomenclature used for different fractions are shown in Table 1.

Data Analysis

Differences in the concentrations of phosphorus fractions and the 2 sampling depths were evaluated by analysis of variance (ANOVA). When there is significant (p.0.05) difference in treatments, Fisher's LSD and DMRT were used to distinguish the differences amongst the treatment means.

Results and Discussion

Inorganic P fractions in coconut basin (0-30 cm)

Inorganic phosphorus fraction in sequential extraction at 0-30 cm depth is shown in Table 1. All the phosphorus fractions were significantly high in the fertilized plots than the non fertilized plots.

Table 1. Nomenclature of the inorganic P fractions as Kuo (1996).

Sl. No.	Extractant used	Name of fraction
1.	Extraction with 1M NH4CI	Soluble and loosely bound P (Saloid -P)
2.	Extraction with 0.5M NH4F	Al-phosphate
3.	Extraction with 0.1M NaOH	Fe-phosphate
4.	Extraction with citrate-bicarbonate dithionite	Reductant soluble-P
5.	Extraction with 0.25M H2SO4	Ca-phosphate

Among that, the lowest concentrations were recorded by easily soluble P (ES-P) and the Al-P. Among the phosphorus fractions the maximum portion of extractable Pi was present as the calcium fractions in the 0-30 cm depth. Also it was significantly high in fertilized plots than the non fertilized plots. This might be due to continuous addition of phosphate fertilizer like rock phosphate in the past. The easily soluble fractions even though it is significantly high in fertilized plots, the overall concentration was very low compared to the other major fractions. Soil P concentration can be influenced by phosphorus fertilization through the competition for sites of adsorption among organic-P compounds and orthophosphates (Anderson *et al*., 1974). Majumdar *et al*. (2007) reported that the calcium and aluminium phosphate contents in soil might show variations in concentration due to the residual effect of inorganic and organic fertilizers. Singh and Sarkar (1986) also reported that application of phosphate fertilizers improved ES-P, Al-P, Fe-P and Ca-P status of soil. The easily soluble P fraction (ES-P) which has a direct impact on the biologically active phosphorus in soil will affect the plant growth and production ranges from 1.57-10.23 mg kg^{-1}. The Al-P also showed significant difference between treatments but the concentrations were comparatively low in the 0-30 cm depth (1.93 - 4.02 mg kg^{-1}). According to Sarkar *et al*. (2014), the low Al-P concentration in the soil is a clear sign of profound weathering in regions of well humid tropics. Comparatively high concentration of Fe-P (49.0 - 112.06 mg kg^{-1}) was found in the soil which might be owing to the presence of variable Fe content in the soil and their reaction with soil P. The RS-P (42.4-111.45 mg kg^{-1}), which is less important in P availability was found one of the major P fractions in acid soils. The Ca-P which was a major fraction in fertilized soil ranges from 43.4-751.08 mg kg^{-1}. Kaila (1969) reported that heavy top dressing with phosphorus fertilizer like rock phosphate may result in marked increase in Ca-P. Comparable results were obtained by Triptinayak *et al.* (2015). The amount of P recovered in all P fractions in the unfertilized plots (T4, T5 and T6) was found significantly lower compared to fertilized plots. The total inorganic phosphorus content was found significantly high in

Table 1. Inorganic P fractions in coconut basin (0-30 cm)

*T	ES-P ($mg\ kg^{-1}$)	Al-P ($mg\ kg^{-1}$)	Fe-P ($mg\ kg^{-1}$)	RS-P ($mg\ kg^{-1}$)	Ca-P ($mg\ kg^{-1}$)	Tpi (sum) ($mg\ kg^{-1}$)
T1	3.68	3.74	92.21	61.00	171.36	331.99
T2	3.84	2.99	97.93	51.95	258.08	414.78
T3	10.23	4.02	112.06	111.45	751.7	989.42
T4	1.55	2.75	51.96	48.55	74.79	199.68
T5	1.76	2.35	48.95	42.95	38.63	134.95
T6	1.57	1.93	49.00	42.40	43.24	138.14
CD	1.63	0.74	20.49	12.78	23.96	39.42

*T : Treatments

fertilized plots than the non-fertilized plots. The highest value of total Pi was recorded by the treatment T3 (Inorg fertilizer+forking in) followed by T2. The treatments received no fertilizers recorded the lowest values of total Pi.

Inorganic P fractions in coconut basin (30-60 cm)

The inorganic phosphorus fractions in the 30-60 cm depth are shown in the Table 2. Compared to the first depth the fractions were correspondingly low in the second depth. Here it is very clear that the Fe-P is becoming the major fraction (29.14 - 96.06 $mg\ kg^{-1}$) compared to Ca-P in the first depth. It was very interesting that the inorganic fertilizer + forking in (T3) recorded a high concentration of all the P fractions in both the depths. This treatment found to allow the applied nutrients in the root zone for more time, hence can be treated as one among the best treatment in case of coconut. Here also the fertilized plots recorded significantly high values of all phosphorus fractions than the unfertilized treatments.

Per cent Pi fractions in Coconut Basin (0-30 cm)

Among the per cent P fractions at 0-30 cm of depth, it was found that Ca-P (31.29-75.99 per cent) was contributing more toward the total inorganic P (Pi) in treatments receiving chemical fertilizers and

Table 2. Inorganic P fractions in coconut basin (30-60 cm depth)

*T	ES-P ($mg\ kg^{-1}$)	Al-P ($mg\ kg^{-1}$)	Fe-P ($mg\ kg^{-1}$)	RS-P ($mg\ kg^{-1}$)	Ca-P ($mg\ kg^{-1}$)	Tpi (sum) ($mg\ kg^{-1}$)
T1	3.42	3.71	84.40	46.20	77.60	215.32
T2	2.50	2.42	89.61	42.15	88.86	225.53
T3	4.95	3.96	96.06	65.65	95.28	266.90
T4	1.38	2.78	51.40	37.15	53.28	145.98
T5	1.34	2.02	46.89	31.65	37.91	119.80
T6	1.26	1.90	29.14	27.50	38.61	98.40
CD	0.80	1.06	10.39	7.21	19.14	22.75

*T : Treatments

the highest Ca-P (75.99 per cent) was recorded by the treatment T3 (Inorganic fertilizer + forking in). Singh *et al.* (2010) reported similar results of phosphorus fractions. Second important contributor toward the total Pi is the Fe-P (11.34-36.34 per cent) followed by RS-P (11.24-31.77 per cent). But these fractions were high in treatments not receiving any chemical fertilizers. The less contributors are the ES-P (0.89-1.52 per cent) and Al-P (0.41 - 1.75 per cent) in the first depth of soil.

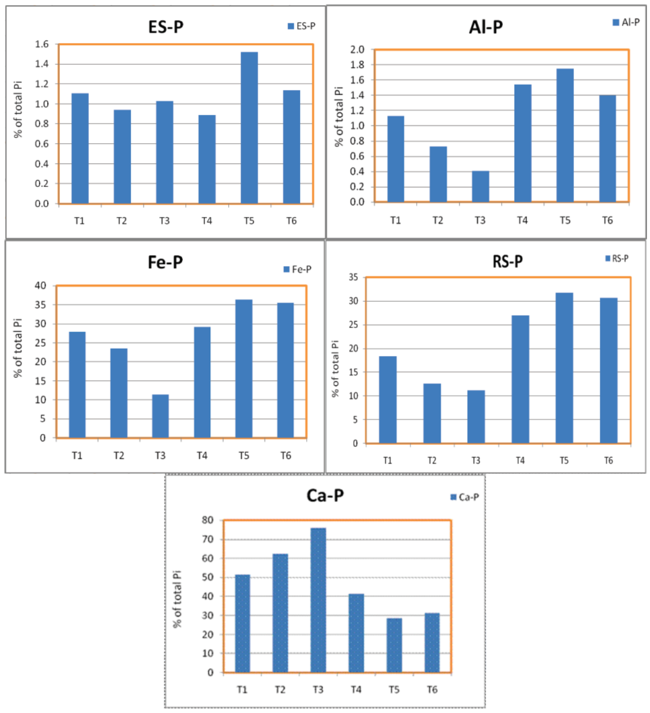

Fig 1. Per cent Pi fractions at 0-30 cm depth in Coconut Basin

Per cent Pi fractions in Coconut Basin (30-60 cm)

In the second depth (30-60 cm) the Fe-P (29.84 - 40.07 per cent) was found the major percent contributor followed by Ca-P (35.91-39.16 per cent). The easily soluble P (0.95-1.85 per cent) and Al-P (1.08-1.99 per cent) were the lowest percent fractions towards the total Pi similar to that of first depth. Al-P and Ca-P did not show significant difference between the treatments in percent fractions at the 30-60 cm depth. The lowest percent RS-P (18.73 per cent) was recorded by the treatment T2 followed by T1 (21.64 per cent) which were fertilized plots. While these treatments contributed the highest percent Fe-P (40.07 and 39.27 per cent correspondingly) toward the total Pi, the percent Al-P was found slightly higher in non fertilized plots but were not significant.

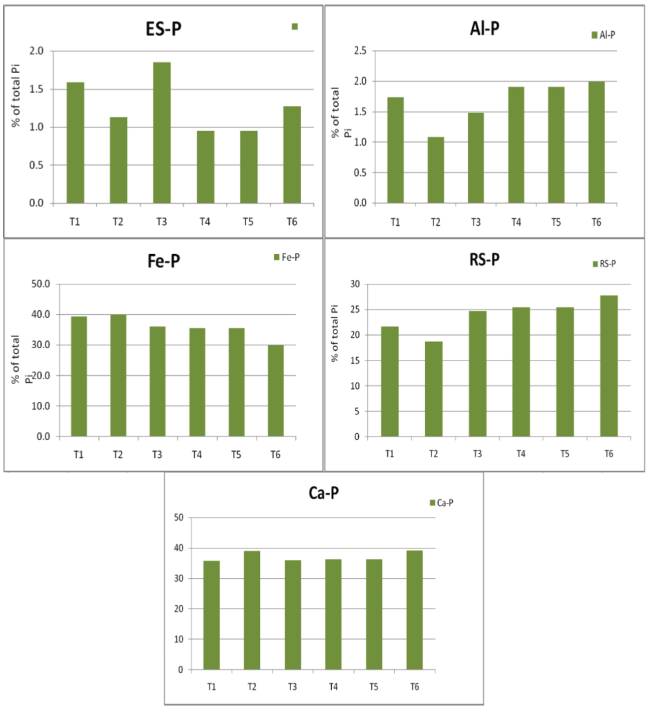

Fig 2. Per cent Pi fractions at 30-60 cm depth in Coconut Basin

Inorganic P fractions in coconut interspaces (0-30 cm depth)

The soil samples from the interspaces of coconut plants showed different trend in the phosphorus fraction concentration. The ES-P and Al-P fractions recorded slightly higher values than the corresponding basin samples. This may be due to the absence active root zone in the interspaces of the plants. In the interspaces, the highest fraction recorded was Fe-P (69.28 mg kg^{-1}), this is followed by Ca-P (35.75 mg kg^{-1}). Here the increasing trend of fractions were in the order Al-P<ES-P<RS-P<Ca-P<Fe-P. It was reported that Fe-P concentration is one among the most important fraction of P controlling its availability in soils (Gupta *et al*., 2020).All the fractions except Ca-P were not significantly different between treatments. The ES-P values ranges between 3.77- 6.56 mg kg^{-1} and the highest value was recorded by T1 (6.56 mg kg^{-1}). Al-P also showed similar trend. But in case of Fe-P the highest value was recorded by T2 (69.28 mg kg^{-1}) followed by T1 (56.88 mg kg^{-1}). RS-P fraction also showed comparable results. But in case of Ca-P the highest value was recorded by T4 (35.75 mg kg^{-1}) and it was significantly different between treatments.

Inorganic P fractions in coconut interspaces (30 - 60 cm depth)

In the second depth the fractions showed more or less similar trend and the fractions like ES-P, Al-P and RS-P were not shown significant difference. Ca-P and Fe-P showed significantly different values in the deeper soils (30-60 cm depth). As the depth increases the concentration of each fraction decreased significantly. Similar trend was reported by Singh and Omanwar (1987), Dongale (1993), and Trivedi *et al*. (2010). These fractions showed slight increase in values as the depth increased. The total Pi also showed decrease in concentration than the first depth.

Per cent Pi fractions at 0-30 cm depth in the interspaces

The per cent inorganic P fractions (Pi) in the coconut interspaces of 0-30 cm depth are presented in Fig 3. Among the fractions, Fe- P (50.18 per cent) was recorded the highest per cent fractions and Al-P and ES-P (3.93-4.80 and 3.51-5.11 per cent respectively) were recorded the lowest per cent fractions. The per cent fractions like Ca-P and RS-P recorded almost similar trend in the 0-30 cm depth. In the interspaces the application of inorganic

Table 3. Inorganic P fractions in coconut interspaces (0-30 cm depth)

*T	ES-P (mg kg^{-1})	Al-P (mg kg^{-1})	Fe-P (mg kg^{-1})	RS-P (mg kg^{-1})	Ca-P (mg kg^{-1})	Tpi (sum) (mg kg^{-1})
T1	6.56	5.78	56.88	26.15	33.03	128.39
T2	6.01	5.57	69.28	28.33	32.69	141.87
T3	5.01	5.01	49.74	22.96	33.48	116.19
T4	4.34	4.85	57.58	20.98	35.75	123.49
T5	4.78	4.81	47.81	16.95	25.81	100.15
T6	3.77	4.98	53.13	20.48	23.53	105.87
CD	N/A	N/A	N/A	N/A	1.90	19.51

*T : Treatments

Table 4. Inorganic P fractions in coconut interspaces (30-60 cm depth)

*T	ES-P (mg kg^{-1})	Al-P (mg kg^{-1})	Fe-P (mg kg^{-1})	RS-P (mg kg^{-1})	Ca-P (mg kg^{-1})	Tpi (sum) (mg kg^{-1})
T1	4.53	6.66	50.27	18.48	28.37	108.29
T2	5.81	6.81	70.82	26.96	27.50	137.89
T3	4.32	8.37	34.45	21.96	23.66	92.75
T4	4.66	7.35	50.25	21.86	20.44	104.56
T5	3.98	7.71	35.57	26.46	18.27	91.98
T6	4.16	3.75	47.60	21.79	15.28	92.57
CD	N/A	N/A	18.64	N/A	2.22	21.82

*T : Treatments

fertilizers and manures are practically nil and hence the Fe-P naturally dominates in this acidic soil due to weathering of soil. The treatments did not show significant difference between per cent fractions of P in the interspaces. It was reported that the allocation of phosphorus in different type of fractions is generally decided by factors like parent material, extent of weathering, and various soil characteristics (Ncoyi, 2019).

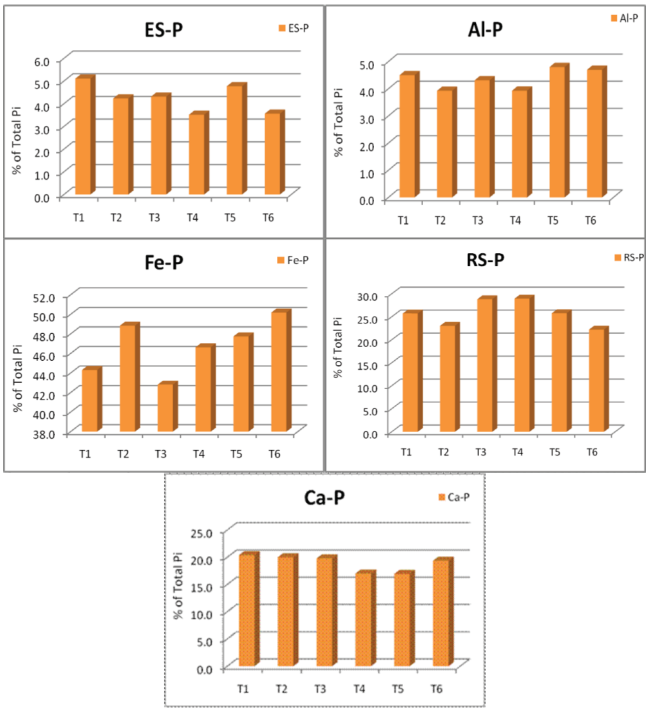

Fig 3. Per cent Pi fractions at 0-30 cm depth in Interspaces

Per cent Pi fractions at 30-60 cm depth in the interspaces

As the depth increases the per cent fractions of Fe-P and Al-P found improved and percentage of the other fractions remain more or less same as that of 0-30 cm depth. This may be due to the presence of acidic parent material which is rich in Fe and Al. According to Buckingham *et al.* (2010) comparative buildup of more steady form of phosphorus in lower layers of soil is due to P fixation by secondary minerals and clay minerals present in the soil. The highest per cent fraction of Fe-P recorded was 51.4 per cent by the treatment T2. ES-P did not significantly different between treatments. The highest values of ES-P, Al-P and RS-P were recorded by the treatment T3. As the depth increased there was slight variation in per cent fraction of P between treatments but were not significantly different.

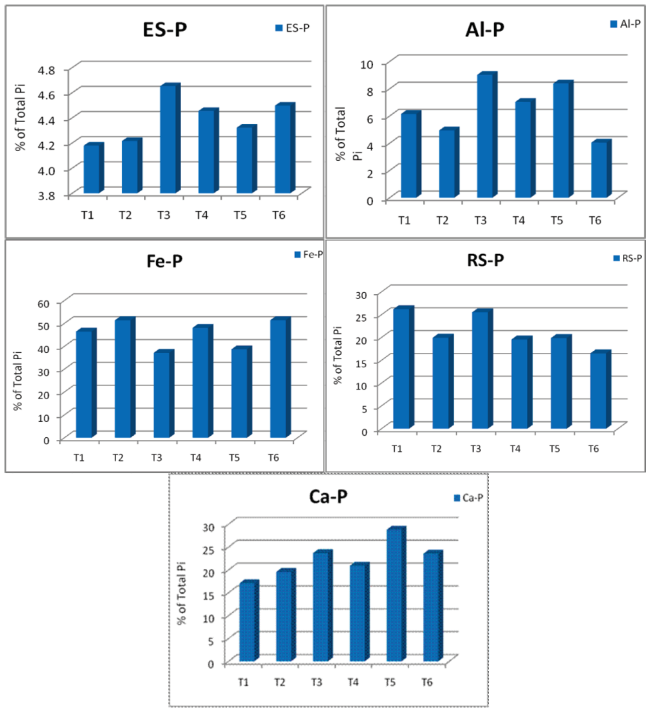

Fig 4. Per cent Pi fractions at 30-60 cm depth in Interspaces

Correlation of Inorganic P fractions with Soil Properties of Coconut basin

Relative proportion of various forms of Pi fractions depend on different soil properties like soil pH, EC, soil organic carbon sesquioxide, calcium carbonate etc (Trivedi *et al.*, 2010). Table 5 presents the correlation of Pi fractions and soil properties of coconut basin soil. pH found negatively correlated to all the inorganic phosphorus fractions where as EC showed highly positive correlation with all the inorganic P fractions. Organic carbon also positively correlated to the Pi fractions and the fraction Ca-P showed the highest correlation with OC. Available P and Fe showed highly positive

Table 5. Correlation between Pi fractions and Soil properties (coconut basin)

Selected Soil Properties	P fractions				
	ES-P	**Al- P**	**Fe-P**	**Ca-P**	**RS-P**
pH	-0.94	-0.90	-0.88	-0.97	-0.94
EC	0.71	0.73	0.62	0.74	0.82
Organic C	0.49	0.37	0.29	0.70	0.37
Available P	0.94	0.90	0.85	0.81	0.93
Exch. Ca	-0.08	-0.10	-0.32	0.12	-0.14
Available Fe	0.98	0.85	0.88	0.88	0.88

correlation with the Pi fractions in the basin soils. Exchangeable calcium was negatively correlated to all the phosphorus fractions except with Ca-P fraction.

Conclusion

The concentration of ES-P, Al-P and Fe-P showed a considerable role with respect to the availability of the phosphorus in the experimental soils under study. The variation in Pi fractions in fertilized and non-fertilized fields evidently showed that the fertilized fields have more of all the Pi fractions in the two depths. Application of mineral P along with forking in basin showed a high concentration of all the inorganic P fractions compared to other fertilized treatments. The results of this study may help in proper phosphorus fertilizer management practices by considering the various pools of phosphorus fraction in the soils.

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