QUANTITY – INTENSITY RELATIONS OF PHOSPHORUS WITH REFERENCE TO ITS BIOAVAILABILITY IN LATERITIC SOILS

By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Quantity –Intensity relations of phosphorus with reference to its bioavailability in lateritic soils"** is a bona-fide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or society.

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CERTIFICATE

Certified that this thesis, entitled **“Quantity –Intensity relations of phosphorus with reference to its bioavailability in lateritic soils”** is a record of research work done independently by **Ms. Geetha. P.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the Advisory Committee of **Ms. Geetha, P.** a candidate for the degree of **Master of Science in Agriculture** with major in **Soil Science and Agricultural Chemistry,** agree that the thesis entitled **“Quantity –Intensity relations of phosphorus with reference to its bioavailability in lateritic soils”** may be submitted by Ms. Geetha, P. in partial fulfilment of the requirements for the degree.

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Dedicated to my dearest Achan, Amma, Chechi and Kuttan

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LISTS OF PLATES

Introduction

INTRODUCTION

Phosphorus is often described as the second limiting nutrient for crop production, after nitrogen (Mallikarjuna, *et al*. 2003). It is an essential nutrient element required for plant growth and development. Phosphorus plays a major role as a structural component of the cell constituents and metabolically active compounds. It is an essential component of ATP and hence often called 'energy currency' of the living system. Adequate P supply is associated with increased root growth, maturation of fruits, seeds etc.

Plants absorb either $H_2PO_4^-$ or HPO_4^{2-} depending up on soil pH. However due to highly reactive nature of these anions, they may be immobilised through sorption and/ or precipitation with cations such as Ca^{2+}, Mg^{2+}, Fe^{2+} and Al^{3+} again depending on the soil pH. As a result of this immobilisation, P concentration in soil seldom exceeds 0.1ppm. (Peoples, *et al*.1995)

Phosphorus cycle in soil system can be simplified to the following relationship (Tisdale *et al*., 1997)

$$\text{Soil solution P} \underset{\text{rapid}}{\rightleftharpoons} \text{Labile P} \underset{\text{slow}}{\rightleftharpoons} \text{Non labile P}$$

In this relationship labile and non labile P represents both organic and inorganic fractions. Labile P is readily available portion of the quantity factor, that exhibits a high dissociation rate and rapidly replenishes solution P. Depletion of labile P causes some non labile P to become labile, but at a slow rate.

Available P is generally medium to low in majority of Indian soils, so also the case with those of Kerala. Though there are reports indicating high total P status in Kerala soils, the available P comprises of only 1 to 2% of total P (Jacob, 1987., Krishnakumar, 1991. and Sureshkumar, 1993). This low availability status is attributed to low pH, high P fixing capacity, low CEC and low exchangeable bases. Laterite soils (Ultisols) covering more than 60% of the Kerala state occupying midlands and mid upland regions are also confronted with low available P status. In addition to the reasons mentioned above, excess of exchangeable Al, Fe and Mn as well as excess levels sesquoxides and hydrous oxides of these elements also causes high rates of phosphorus precipitation and fixation resulting in low availability. Thus it is clear from the previous reports that not the total phosphorus, but its availability, which in turn are governed by many soil factors, is to be addressed to tackle the problems of P fertility in lateritic soils. The high rate of P fixation and precipitation under acidic lateritic environments that compete with the crop results in lack of response to applied P even under deficient soil environment.

Assessment of fertility status with respect to phosphorus requires knowledge of the dynamic equilibrium existing between reserve quantities and solution P which can be unravelled through studies pertaining to quantity intensity relationship in lateritic soils which essentially opens up the buffering capacity and phosphate potential of these soils. These studies ultimately enable us in predicting the fertility status. Under the above circumstances, to improve P fertility, there should be a three pronged approach – i) solubilising the precipitated and fixed P, ii) minimising the fixation and precipitation through manipulation of soil environment and iii) sustaining the total P status in soils.

In order to practically execute this strategy, with the objective of assuring sufficient levels of plant available P for optimum crop growth, a thorough understanding of the fate and transformations of applied and native P in acidic lateritic environment is necessary. Keeping the above scenario in view, to have practical solutions with respect to P fertility the present study was under taken with the following objectives:

1. To study the Quantity/ Intensity relations of phosphorus in different lateritic soils
2. To evaluate the effects of different amendments on phosphorus availability
3. To trace out the fate of applied phosphorus in soil plant system using radiotracer techniques

Review of Literature

2. REVIEW OF LITERATURE

Phosphorus is often described as the second limiting nutrient in crop production after nitrogen. The phosphorus status of the Kerala soil varies widely. Koshy and Thomas (1972) reported that laterite soils in general were poor in available phosphorus and had high P-fixing capacity. P fixation capacity of Kerala soils is very high due to the high acidity, dominance of kaolinitic fractions in the mineral composition as well as due to the presence of excess quantities of hydrous oxides of Fe, Al and Mn.

The deficiency is not due to low levels of total P alone but rather due to its fixation as a result of soil acidity (Geves, 1973). Two mechanisms, chemical adsorption and P fixation are considered to be responsible for this non availability of applied P (Udo and Uzu, 1972). Juo and Fox (1977) reported that Ultisols have moderate to high phosphorus fixing capacity.

The deficiency problem is compounded by the widespread P fixing capacity. These soils possess low cation exchange capacity and require a large initial dose of P fertilizer to obtain acceptable high yields (Sanchez *et al*., 1982).

One of the key constraints to production is P deficiency often associated with high P fixation and severe soil acidity (Gupta and Toole, 1986).

Krishnakumar (1991) and Deepa (1995) reported the low available P status in laterite soil, in spite of continuous application of fertilizer P. The presence of high amounts of clay, Al, Fe and sesquioxides is responsible for fixation of applied P (Doddamani and Rao, 1996). The plant available P and fertilization potential of Ultisols are affected by the presence of lateritic nodules and sesquioxides which act as P sinks (Tiessen and Abekoe, 1998).

Phosphorus deficiency is the most widespread constraint in an Ultisol (Sreekala, 1996). Sajnanath (2000) reported that the available phosphorus content in the soil of the main campus of Kerala Agricultural University (laterite) was generally low. It was due to high P fixing capacity in these soils, attributed to high contents of oxides and hydrous oxides of iron and aluminium. Seena (2000) found that the available P content in the surface soils of the main campus of Kerala Agricultural University (laterite) ranged from 1.25 to 19.6µg g^{-1}. High phosphorus fixing capacity to the tune of 80 per cent or more was found in this soil. In acid soils, the availability of P is a major limiting factor for crop production as these soils are immensely prone to the problem of P fixation (Mallikarjuna *et al*., 2003).

2.1. Effect of levels of applied phosphorus to available P

Peoples *et al*., (1995) observed an increase in the P content of the soil with an increased level of P_2O_5 (20 kg P_2O_5 ha^{-1}). Higher level of P gave significant increase in the pasture level in clover (*Trifolium subterraneum*). Viswambharan (1995) observed that available P content in red loam soil increased with increase in level of P from 30 days after sowing to harvest of cowpea. Bahl and Toor (1997) found that the available P in the soil increased significantly with respect to the level of fertilizer added to the soil. The levels of fertilizer applied were, 6 kg ha^{-1}, 12 kg ha^{-1} and 18 kg ha^{-1}. The available P content in the soil was increased from 5.50 mg kg^{-1} to 14.50 mg kg^{-1}, when the fertilizer level was increased from 6 kg ha^{-1} to 18 kg ha^{-1}. Anilkumar *et al*., (1999) also found that, the soil available P content in the soil was increased with the level of applied P.

Dhillon *et al*. (2004) reported that the amount of P desorbed from the soils of Punjab ranged from 0.2 to 1.5, 0.3 to 2.5, 0.5 to 4.8, 1.2 to 7.1, 2.5 to 12.5 and 3.8 to 16.5 mg P kg^{-1} soil against an application of 25, 50, 75, 150 and 200 mg P kg^{-1} soil. The amount of P desorbed increased with increase in level of P. Laltalanmawia *et al*. (2004) observed that application of phosphorus at 30, 60 and 90 kg ha^{-1} in acid soils of Nagaland recorded the P uptake by soybean to the tune of 17.6, 20.1 and 19.4 kg ha^{-1} respectively over the control.

Akande *et al*. (2005) reported an increase in dry matter production and fruit yield in okra due to application of varying levels of phosphorus in an acidic soil. The highest fruit yield was observed in the field applied with highest level of fertilizer. Smitha (2005) found an increase in available P from 7.94 to 14.21 mg kg^{-1} as applied P increased from 15 to 45 kg P_2O_5 ha^{-1}. Zhao *et al*. (2007) reported that white clover production was increased by 580 kg dry matter ha^{-1} when P application was increased from 39 to 118 kg ha^{-1}. Morari *et al*. (2008) reported that the available P increased significantly with respect to the level of fertilizer added to the soil. The inputs were 70 kg P_2O_5 ha^{-1} and 90 kg P_2O_5 ha^{-1}. The corresponding available P content was 15.6 mg P kg^{-1} and 25.4 mg P kg^{-1} respectively

2.2. Effects of amendments on P availability

2.2.1. Organic manure

Several studies have shown that the availability of P can be increased through the incorporation of green manures to the soil under laboratory conditions (Blair and Boland, 1978; Hundal *et al*., 1987; Yadvider-Singh *et al*., 1988). The mobilization of phosphorus occurs by conversion of insoluble Ca, Al and Fe forms of P to soluble forms through action of organic acids and chelates that are produced during decomposition of manures (El-Baruni and Olsen, 1979). Gardner *et al*. (1982) observed that green manures may enhance P nutrition by converting relatively unavailable native and residual fertilizer phosphorus to chemical forms more available to crops.

Kurumthottical (1982) reported that in permanent manurial experiment in rice at Pattambi, available P content of treatment with NPK and green leaves was higher than inorganic fertilizer as ammonium phosphate alone. Easterwood and Sartain (1990) reported that in soils with high P fixing capacities, organic acids released during the decomposition of the crop residue, may increase phosphorus availability by blocking the phosphorus adsorption sites. Sanyal and De Datta (1991) observed a positive correlation between the organic matter content of soils and phosphorus sorption.

Bahl and Singh (1993) reported that addition of green manure to the soil resulted in enhanced P availability in soil. Savithri *et al*. (1996) found out that P uptake by rice plant increased over the control (24.7 kg ha^{-1}) when treated with neem leaves along with farm yard manure and Mussorie rock phosphate (44.7 kg ha^{-1}) and *Leucaena* leaves along with farmyard manure and Mussorie rock phosphate (34.6 kg ha^{-1}). This might be due to the steady release of P from this source (MRP) due to liberated organic acids and other products of decomposition applied manures. Sudhir *et al*. (1996) reported that application of green manure with P fertilizers considerably increased P utilization from fertilizer and hence increased the percentage P derived from fertilizers and percentage phosphorus utilization by rice crop. Sudhir *et al*. (1996) also found that application of green manure along with P fertilizers increase in the grain yield as well as crop P uptake substantially by rice.

Selles *et al*. (1997) reported that changes in management practices including organic matter incorporation methods altered P dynamics and increased P availability in oxisols. Use of phosphate based fertilizers in combination with an appropriate quantity of manures could prove beneficial since the manures, besides supplying a small amount of P, also help in mobilizing the native soil P. (Toor and Bahl, 1997). Toor and Bahl, (1999) while conducting an experiment by using three representative soils, observed an increase in the cumulative P desorbed with increasing P level with the application of organic manure indicating the mobilization and desorption of phosphorus.

Lupwayi *et al*. (1999) observed an increase in the P content in the leaf, stem and kernel of groundnut due to the application of organic manures into the soil. Anilkumar *et al*. (1999) reported an increase in inorganic phosphorus was more in green manure amended soil than in soil incubated with out green manure. Sureshkumar(1999)reported that incorporation of *Pongamia* was found to be beneficial in reducing Fe and Mn toxicity and and in increasing P availability in lowland laterite soil. Since P mineralization is depend upon the C:P ratio, use of low C:P ratio manure supply is imperative (Bahl and Toor, 2002). Krishna (2002) found that the decomposition of green manure released P in available forms into the soil.

Erich *et al*. (2002) examined the effect of organic matter additions on soil phosphorus chemistry in a potato based cropping system and concluded that manure application increased both inorganic and organic soil P levels. Cavigelli and Thien (2003) found that during cover crop decomposition, Bray-1 P increased by about 4 mg kg^{-1} in the soil cropped to pea, vetch and wheat which was greater than increase in Bray-1 P of 1.6 mg kg^{-1} observed in control soil. Ponnaiyan (2003) reported that laterite soil (Ultisol) treated with *Pongamia* leaves registered higher concentration of available P in soil than the control.

A study by Ohno *et al*. (2005) revealed that the available P status of the soil was significantly influenced by the addition of organic matter to the soil. The soluble inorganic P levels in the amended soils were also higher than the unamended soils. Mohanty *et al*., (2006) observed that organic manures had a significant direct and residual effect compared to inorganic single superphosphate on the biomass, P content and uptake in both groundnut and corn. Organic manures had greater effect on P uptake from applied fertilizer and P use efficiency in both the crops. This is in line with the observations of Mohanram *et al*. (1999) and Singh and Sharma (1999). Garg and Bahl (2008) conducted an experiment to compare effect of organic manures on the P availability and concluded that green manure addition along with inorganic P fertilizers, increased the Olsen extractable P in the soil.

2.2.2. Lime

Kothandaraman *et al*. (1969) obtained results of high availability of phosphorus in superphosphate by application of lime as CaO. Petrovic (1969) reported that the availability of soil phosphorus from superphosphate was increased by liming. Maximum release of native phosphorus was noticed by liming from an acidic soil (Kar, 1974).

Liming in acid soil results in the precipitation of exchangeable Al^{3+} as polymeric hydroxyl-Al cations which can coat soil colloids and cause a significant decrease in the net negative soil charge. Such polymers may also precipitate independently or get complexed with soil organic matter components. Whatever be their exact nature, it is apparent that liming can result in the precipitation of new, positively charged, hydroxyl-Al-surfaces, which can adsorb added P (Amarasiri & Olsen, 1973).

Mathan and Raj (1975) reported that in laterites and kaolinites with higher anion exchange capacity, lime supplied the anions (OH) for anion exchange resulting in the release of phosphorus and liming @ 3000 kg ha^{-1} even without the addition of any fertilizer was beneficial in releasing sufficient phosphorus. Smyth and Sanchez (1980) found that the effect of applied phosphate to an Oxisol was greater when soils were simultaneously limed. Similar observations were made by Haynes (1983).

Friesen *et al*. (1980) observed that liming up to a pH of 6.5 or so, often increased P adsorption. When the same soil was limed and air-dried before reaction with phosphate, liming decreased P adsorption. Maria *et al*. (1985), Holform (1985) and Wang and Yuan (1989) reported that available P content was increased by the addition of lime. Marykutty (1986) found an increase in available p content by graded levels of lime in lateritic alluvial soils. The overall effects of lime on soils include, increased soil pH, Ca and Mg saturation, neutralization of toxic concentrations of Al, increase pH dependent CEC resulting in absorption and hydrolysis of Ca^{2+} and Mg^{2+}, increase in P availability and improved nutrient uptake by plants (Nicholaides *et al*., 1983)

Lijungstrom and Nihlgard (1995) reported that application of lime in soil increased foliar P, Ca and Mg concentrations and decreased those of Al, Fe, K, Mn, Na and Zn. Available phosphorus content of soil increased from sowing to 30 days after sowing and then decreased at the time of harvest of cowpea, when lime was added alone @ 400 kg ha^{-1} or in combination with phosphorus (Viswambharan 1995). Application of lime significantly increased soil pH from 4.2 to 4.9 and had significantly decreased concentration of extractable Al, Fe and Mn. Total uptake of P was significantly increased by the highest rate of superphosphate application at all sites except in the absence of lime (Oguntoyinbo, 1996).

Rattan *et al*. (2001) reported that liming of acid soils resulted in enhanced, level of native P. Paliyal and Verma (2002) found that lime application increased P adsorption. Liming could result in the precipitation of hydroxyl Al surfaces which can adsorb added P.

Venkatesh *et al*. (2002) recorded that available P content in soil and P uptake by grains and straw of maize increased when lime was added to the soil alone or in combination with different levels of P. Akande *et al*., (2005), reported that the plant growth, dry matter production and fruit yield of okra were significantly increased due to application of low rates of lime or P and varying combinations of both, when compared with the control. Kumar *et al*., (2007) reported that the application of lime along with phosphorus produced significantly higher seed and straw over control in pea (*Pisum sativum*).

2.3. Phosphorus fractions in soil

Chai Moocho and Cladwell, 1959 noted that i) majority of available P came from the inorganic P fraction (ii) there was a high degree of correlation between available P and inorganic P fraction; and (iii) significant correlation existed between Al-P and Bray No.1 and 2 extractable P. They noted mostly Fe and Al-P predominated in acid soils, Ca-P in alkaline soils and an equal representation of all above three forms in neutral soils of Minnesota.

Al Abbas and Barber (1964) studied the relationship between plant uptake of phosphorus and the various phosphorus fractions in soil. According to them Fe-P was highly correlated with plant uptake. Bapat *et al*. (1965) reported significant correlation between available phosphorus and calcium phosphate in soils containing high amount of $CaCO_3$, but iron and aluminium phosphates were related to available phosphorus in other soils. According to Chang (1965) iron phosphate was the main source of phosphate absorbed by rice under submergence in acidic and calcareous soils.

Smith (1965) and Talati *et al*. (1975) reported that none of the inorganic forms of soil phosphorus except aluminium phosphate could serve as an index of phosphorus availability. Chu and Chang (1966) clearly proved that calcium phosphate was not an important source of available P either in acidic soil or in calcareous soils. Jenkins (1966) and Jose (1973) in their phosphorus uptake studies obtained a very close correlation between labile phosphorus, aluminium phosphate and iron phosphate.

Nair and Aiyer (1966) found that the form of phosphorus taken up by rice plants from waterlogged acid soils was iron phosphate. From the study on the evaluation of iron phosphate as a source of P in rice soils Khanna (1967) studied the relationship between inorganic P fractions and soils test values for P using several extractants. He found that Bray No.2 extractable P was positively correlated with Ca-P, Olsens-P with Al and Fe-P fractions. The Al and Fe-P were positively correlated with Ca-P. Kar and Hussain (1971) concluded that the insoluble iron phosphates were not readily available to plants in welldrained soils. However, they underwent reduction to more soluble ferrous forms in water logged soils, and therefore Ca-P was a good source of P to lowland rice.

Raghupathy and Raj (1973) conducted pot culture experiments with soils of Tamil Nadu to study the fluctuations of soil phosphorus fractions during paddy growth under flooded conditions. The study showed that available P and Al-P were higher on the 15th day after transplantation than at post harvest stage in the soils. Choudhari *et al*. (1974) reported the correlation between various inorganic fractions and phosphorus uptake by different crops. Calcium phosphate and aluminium phosphate significantly correlated with the phosphorus uptake of jowar, cowpea and black gram, while in maize calcium phosphate and phosphorus uptake was correlated.

Sacheti and Saxena (1974) reported that the saloid bound phosphorus and aluminium phosphate significantly correlated with available phosphorus while iron phosphate correlated significantly in a few cases only. However, Singh and Brahman, (1976) reported that the phosphorus uptake by plants was highly correlated with the amount of iron phosphate but not with the amount of other fractions. Thakur *et al*. (1975) found that Fe-P fraction formed the major portion of native inorganic phosphorus. Al-P, Fe-P and Ca-P fractions increased at both flowering and harvesting stages of rice. Kothandaraman and Krishnamoorthy

(1977) found that iron phosphate, reductant soluble P and occluded P were high in laterite soil of Tamil Nadu.

Mandal and Khan (1977) obtained 60 to 75 per cent of applied phosphate is fixed in the form of aluminium, iron and calcium phosphates after the harvest of rice and they stated that these fractions would significantly contribute to available phosphorus to the succeeding crop. Using four major soils viz., alluvial, black, red and laterite, Singhania and Goswami (1978b) studied the relationship between inorganic phosphate fractions and available phosphorus, and reported that Al-P was found to be the main source of Olsen and Bray extractable P based on the multiple correlation and regression.

Aiyer and Nair (1979) in their studies on the phosphate fractions of Kerala rice soils observed that the total P content varied between 816 and 917 ppm and the variation was only to the extent of 10 to 12 per cent between the highest and lowest content of total P. They further found that Fe-P was the most abundant fraction accounting for 21.8 to 39.8 per cent of the total P, Al-P was the second most abundant fraction of P accounting up to 12.7 to 25.8 per cent of total P. The third abundant fraction was Ca-P, which varied between 5.9 to 10.3 per cent. Singh *et al*. (1979) revealed that the P uptake by rice was significantly correlated with saloid-P and Al-P. Calcium-P had a negative correlation with P uptake by rice.

Laveerty and Mc Lean (1983) reported that Al-P was considerably more available to plants. Fe-P and phosphorus availability were highly correlated to iron and aluminium contents as well as ammonium chloride extractable forms. Laterite soil contained relatively higher amounts of Fe-P and Al-P, reductant soluble P, and occluded P (Mathews and Jose, 1984.). Sharma and Tripathi (1984) reported that Al-P and Bray-P were significantly correlated to each other. Agarwal *et al*. (1987) found that Al-P was the most important fraction contributing towards the availability of phosphorus in soils followed by reductant soluble-P (Red-P) and saloid-P.

Tiwari (2002) reported that inorganic P constituted a dominant part of total P, being 40 to 55 per cent of total P in laterite soils of Tamil Nadu. The inorganic P could be divided into different pools. Al-P, Fe-P and Ca-P constituted the major active fractions of inorganic P. The relative less active are occluded and reductant soluble forms of P. The various pools were inter- related and contributed to plant available P.

Crews (1996) conducted an experiment to determine the sources of P that supply the labile P pools, by using Alfalfa plants. The results showed that Alfalfa consistently depleted labile inorganic phosphorus fractions in all soils and concluded that the inorganic P fractions are critical sources of phosphorus. Lilienfein *et al.* (1999) showed that most of the fertilizer was recovered in the bicarbonate extractable P (weekly adsorbed P extracted by 0.5M $NaHCO_3$) and NaOH-P (Al/Fe-P) fractions Linquist *et al*., (1997) recovered almost 40 per cent of the applied triple superphosphate fertilizer in the hot HCl and H_2SO_4 fractions one year after fertilizer application in a field study conducted on a Hawaiian Ultisol. Iyamuremye *et al*. (1996) found an increase in resin-P, bicarbonate extractable P, organic P as well as NaOH-P after addition of green manure residues to acid low-P soils from Rwanda.

In the study of Guo and Yost (1998) resin-P, bicarbonate extractable P (Bic-P) and NaOH-P were found to be the most depleted fractions by plant uptake on highly weathered soils. NaOH-P was important in buffering available P supply, while significant depletion of organic fractions could rarely be measured. A study conducted by using ^{33}P showed that, resin-P, bicarbonate extractable P and NaOH-P represented most of the exchangeable P. Label P transformed with increasing incubation time from the resin to the Bic-P and NaOH-P fractions. The organic or recalcitrant inorganic fractions contained almost no exchangeable-P (Obserson 2002).

A study conducted by Bravo *et al*. (2006) by comparing the amounts of P extracted from the surface horizons of Brazilian Oxisols showed that HCl extractable P (P in poorly soluble Ca phosphates) was found to account for more than 80 per cent of total extractable inorganic P.

In a field experiment conducted by Majumdar *et al*., (2007) showed that, application of FYM increased the organic and total P by 6 and 3.7 per cent respectively over no – FYM control. The saloid-P and Ca-P in the soil increased by 1.25 to 4.5 and 1.5 to 2 times, respectively over initial status with P and FYM application. The interaction between P sources × FYM and P sources × P levels × FYM were significant which is reflected in the release of saloid-P and Ca-P from different sources with FYM.

A study conducted by Laxminarayana (2007) showed that distribution of various inorganic P fractions as a constituent of total followed the order: Rs-P (34.0%), > Fe-P (15.8%) > Ca-P (12.0%) > Al-P (19.6%), > S-P (2.46%). The Al-P, Occluded-P, Fe-P and Ca-P fractions contributed mostly to the available P pool.

2.4. Transformation of phosphorus in soil

Murphy (1939) explained the retention and low availability of phosphate in kaolinite and kaolinitic soil as due to the exchange of added phosphate with OH ion of the hydroxyl layer in kaolinitic crystal lattice. Stout (1939) and Coleman (1942) concluded that the failure of crops to respond to added phosphate could be attributed to the rapid fixation of phosphate by the soil.

Ghani and Aleem (1943) and Kurtz *et al*. (1946) found that in acid soil phosphorus become unavailable due to the formation of iron and aluminium phosphate and accumulation of organic compounds. Bray and Kurtz (1945) found that incubation produced an increase in extractable inorganic P that was greater in the presence of added inorganic P than in its absence. Chang and Jackson (1958) found that phosphorus fertilizer added to soil was transformed into all three forms Al-P, Fe-P and Ca-P according to the principle of solubility. According to Hsu and Jackson (1960) the phosphorus transformation in the soil was mainly controlled by pH. Iron phosphate and aluminium phosphate dominated in acid soils, while calcium phosphate dominated in alkaline soils.

Yuan *et al*. (1960) and Bapat and Badekar (1965) investigated the rate of fixation of applied P by soils and found that more than 80 per cent of applied phosphorus was fixed as Fe-P and Al-P. Only 10 per cent of the applied P remained in available form in the soil. Enwezor (1966) observed that the addition of inorganic phosphorus as KH_2PO_4 before incubation resulted in mineralization of soil organic phosphorus.

Debnath and Hajra (1972) reported that added phosphorus is transformed in the order of Al-P > Fe-P > Ca-P. On ageing the quantity of Fe-P increased and that of Al-P decreased. Jose (1973) in his studies on phosphorus transformation, found a decrease in available phosphorus, saloid bound phosphorus and aluminium phosphate with increase in period of incubation. He also observed that irrespective of pH of soil, aluminium phosphate was found in high amount initially, a part of which was transformed to iron phosphate in soils of relatively low pH.

Mandal and Mandal (1973) reported that the total amount of P recovered as saloid-P, Al-P, Fe-P and Ca-P in different soils accounted for 55 to 98 per cent of the added amount. Approximately 45 per cent of added P was transformed into reductant soluble Fe-P and or occluded Al-P. Singh and Ram (1977) showed that the conversion of added phosphorus to aluminium phosphate was more pronounced in the laterite soil and calcium phosphate was low in acidic soil in a study of the transformation of P added to three acid soils of Himachal Pradesh. Jose (1973) observed a close correlation between labile P and Al-P and Fe-P in acid soils. He also observed a decrease in available P, saloid P and Al-P with increase in period of incubation.

Singhania and Goswami (1978a) found that in soils with acid to neutral pH, the highest amount of applied P was recovered in Fe and Al-P fractions after 20 days. Sharma *et al*. (1980) found that most of the added P was transformed into Al-P which increased upto 7 days and later decreased slowly with time upto 90 days at all levels of application. The conversion of added P into Fe-P fraction increased slowly with time upto 90 days and very little change occurred to Ca-P. The transformation of added P to Al-P and Fe-P was found to be related to the sesquioxide content of the soil.

Kumaraswamy (1981) reported that at all the levels of applied P, most of the P was fixed initially as aluminium phosphate. The recovery of fixed phosphate as calcium phosphate was negligible in rice soils. With passage of time a portion of aluminium phosphate was transformed into iron phosphate. Nair and Padmaja (1982) in rice soils of Kerala found that the added phosphate was mainly converted to aluminium phosphate and iron phosphate. Yaduvanshi *et al*. (1986) found that the major portion of the added P was not utilized by wheat crop, got converted into Al-P (41.5 per cent) followed by Fe-P (23.1 per cent). The transformation into Ca-P occurred in a low magnitude.

Sudhir *et al*. (1987) revealed that graded doses of NPK fertilizer increased the saloid-P, Al-P, Fe-P, Red-P and available P status of soil. However, Ca-P remained at the original level. Among Al-P, Fe-P and Ca-P fractions, Fe-P showed highest increase over the control (29.5 ppm) indicating a shift from Al-P and Ca-P to Fe-P. Al-P was found to be the most important fraction contributing towards available phosphorus. Sushama (1990) observed in increase in the Al-P and Fe-P with the period of incubation after the addition of P in the coastal laterite of Karnataka. Added phosphate in the form of inorganic fertilizer was found to be transformed and fixed to Fe-P and Al-P.

Viswambharan (1995) reported an increase in saloid P from sowing to flowering of cowpea in red loam soil of Kerala by the addition of P and various amendments. There was a corresponding increase in Al-P, Fe-P and Org.-P content of soil. Sushama *et al*. (1996) reported in coastal laterite of Karnataka at lower levels of applied P, available P increased 60 days after incubation and then decreased. Saloid-P and Ca-P followed the same trend, Fe-P and Al-P continuously increased on waterlogging. Increase in Al-P was due to the conversion of reductant soluble-P, occluded-P and Ca-P into Al-P. Thomas (1997) reported that the available P slightly increased with periods of incubation, reached a maximum and then decreased.

Santhoshkumar (1997) reported that in an incubation study with different phosphatic fertilizers that Al-P was the most dominant fraction in the laterite soil. Al-P content showed a steady increase throughout the period of incubation. Bhardwaj *et al*. (2000) observed that the major portion of the water soluble and inorganic P was not utilized by the apple in an orchard soil and was transformed into Al-P followed by Fe-P and application of rock phosphate with farmyard manure increased the transformation of P. Tomar (2000) reported that when the soil was incubated with organic matter, the amounts of native saloid-P and available P were relatively much higher than the available P in organic matter untreated soils. Transformation of added P into saloid–P, Al and Fe-P increased, whereas Ca-P decreased with increasing solubility of the fertilizer.

2.5. Quantity intensity relation of P in soil

Intensity refers to the strength of an ion in solution. It could be either concentration or activity. Quantity refers to the amount of ions which are adsorbed or on exchange sites which in turn are in some sort of dynamic equilibrium with those of soil solution. Q/I relationship for a particular element gives the idea of the relative availability of that nutrient to the plant. Schofield (1952) proposed the concept of phosphate potential. This term refers to the activity of monocalcium phosphate.

An alternative model to describe soil-P equilibria is the quantity – intensity (Q/I) model (Peaslee and Phillips, 1981). The advantage of using Q/I relationships is that, they allow the prediction of both P retension and release in soils (Kpomblekou and Tabatabai, 1997). The Q/I model can be applied to either adsorption or desorption experiments (Peaslee and Philips, 1981; Okajima *et al*., 1983). Hartikainen (1991) and Kpomblekou and Tabatabai (1997) used low concentrations of P in solution to yield a single, straight Q/I line that crossed sorption and desorption ranges to overcome the discrepancies created by sorption-desorption hysteresis.

Sui and Thompson (2000) found that over the large range of initial P concentrations employed, biosolids amended soil samples sorbed less P from the solution, than did the amended soil samples. A study conducted by McDowell e*t al*., (2001) showed that the sorption/desorption of P by colloids in solution were greatly affected by the rate of amendment application. More P was sorbed by superphosphate treated soil compared to manure amended soil solutions and was attributed to the saturation of colloidal P sorption sites by organic matter.

McDowell *et al*., (2001) investigated the existence and behaviour of a change point in soil P release for a range of variously managed soils. Soil P release was determined by $CaCl_2$ extraction (5:1 solution to soil ratio for 30 minutes). For all soils, $CaCl_2$-P increased with soil test P representing a quantity intensity relationship typical of sorption-desorption isotherms.

2.6. Isotopically exchangeable phosphorus

Radioactive phosphorus is widely used by agricultural research workers in studies concerning the phosphorus nutrition of plants. Plant available phosphorus (labile phosphorus) has been measured by isotopic dilution technique both in laboratory and field conditions.

Chemical reagents extract only a fraction of the available P together with significant amounts of unavailable forms of P. Therefore, in order to accurately characterize the available phosphate, a method that does not modify the equilibrium between the various P compartments is necessary (Fardeau and Jappe. 1988).

The isotopic exchange method allows the determination of an unknown quantity of a given compound present in a complex mixture without extracting it from the mixture. (Sheppard, 1972, Shipley and Clark, 1972).

An alternative to chemical extractants is the use of isotopic techniques. Walbridge and Vitousek (1987) and Lopez-Hernanddez and Nino (1993) labeled the soil solution with ^{32}P and measured the quantities of P and ^{32}P extracted after various incubation times.

The concept of A value was introduced by Fried (1964). A value data are quantitative criteria on which evaluation can be made to assess the comparative phosphorus fertility status of different soils, the availability to the plant of number of phosphorus carriers, and the optimum placement of fertilizers.

The concept of L value was proposed by Larsen (1967). It is based on the assumption that labeled phosphorus added to a soil is isotopically diluted with a clearly definable fraction of soil phosphorus called labile soil phosphorus and is measured in terms of fertilizer units per unit area of soil.

The concepts of A value and L value differ primarily in the degree of mixing between the labeled fertilizer and the soil, and time dependent distribution of plant roots with in the soil mass.

Materials and Methods

3. MATERIALS AND METHODS

3.1. Soil sampling

In order to achieve the objectives of the present investigation, surface samples (0-20 cm) of five benchmark soils of lateritic soils coming under Ultisol were collected. The details of soil taxonomy and location of these samples are given below.

Table 1. Taxonomy and locations of the selected soil samples for the study

Soil	Taxonomy
Kunnamangalam soil series	Clay, Skeletal, Kaolinitic isohyperthermic Ustic Kandihumult
Angadippuram soil series	Clay, Skeletal, Kaolinitic isohyperthermic Ustic Haplohumult
Vellanikkara soil series	Clay, Skeletal, Kaolinitic isohyperthermic Ustic Kandihumult
Pattambi soil	Clay, Skeletal, Kaolinitic isohyperthermic Ustic Kandihumult
Thirumittakkodu series	Clay, Skeletal, Kaolinitic isohyperthermic Typic Kandihaplustult

These soils were characterized with respect to pH, EC, CEC and exchangeable cations, AEC, available nutrient status (organic carbon, P, K, Ca, Mg, Fe, Ca, Mn, Zn), P-fixing capacity and major fractions of P. Quantity – intensity relations of P in these soils were also characterized.

The materials used and methods adopted to assess the above said chemical characteristics, are detailed below.

3.1.1. Soil pH

The pH of the soils were determined in a 1:2.5 soil water suspension, potentiometrically using a pH meter (Jackson, 1958).

3.1.2. Electrical conductivity

Electrical conductivity was estimated in the supernatant liquid of the soil water suspension (1:2.5) used for pH estimation with the help of a conductivity meter (Jackson, 1958).

3.1.3. Organic carbon

Organic carbon of the soil was estimated by wet digestion method (Walkley and Black, 1934).

3.1.4. Available phosphorus

Available phosphorus in the soil samples were extracted using Bray No.1 reagent (Bray and Kurtz, 1945) and estimated colorimetrically by reduced molybdate

Ascorbic acid blue colour method (Watanabe and Olsen, 1965) using a spectrophotometer (Model: Genesys 20)

3.1.5. Available potassium

Available potassium in the soil samples were extracted using neutral normal ammonium acetate and its content in the extract was estimated by flame photometry (Jackson, 1958).

3.1.5. Available Micronutrients (Fe, Cu, Mn and Zn) in soil

Available micronutrients in soil samples were extracted using 0.1M HCl (Sims and Johnson, 1991). 4 g soil with 40 ml of 0.1M HCl was shaken for 5 minutes. It was filtered through Whatmann No.1 filter paper and the filtrate was collected and analysed for Fe, Cu, Mn and Zn using Perkin Elmer Atomic Absorption Spectrophotometer (Model: Analyst 400).

3.1.6. Exchangeable cations and cation exchange capacity

The cation exchange capacity in the soil was estimated by the method proposed by Hendershot and Duquette (1986). The cations (Ca, Mg, Na, K, Al, Fe, Mn, Cu and Zn) present in the exchangeable sites in the soil were replaced by 0.1M $BaCl_2$ solution and thus extracted cations were estimated. Four grams of soil samples were taken in a centrifuge tube and 40 ml of 0.1M $BaCl_2$ was added. It was shaken for two hours and filtered through Whatman No.42 filter paper. Filtrate was used for aspiration to a Perkin Elmer Atomic Absorption Spectrophotometer (Model: Analyst 400) for the determination of exchangeable Ca, Mg, Fe, Mn, Cu and Zn. Exchangeable Na and K were estimated with the help of flame photometer (Model: Elico CL361). Exchangeable Al was estimated colorimetrically using Aluminon (Hsu, 1963, Jayman and Sivasubramanian, 1974). The sum of exchangeable cations expressed in cmol (p^+) kg^{-1} was recorded as the CEC of the soils.

3.1.7. Anion exchange capacity

10 g of the soil samples were taken and leached with 100 ml TEA. The soil samples were again leached with 100 ml $CaCl_2.2H_2O$ solution. The Ca saturated soil was dried at 45°C. Then 20 ml 0.01M phosphoric acid was added and shaken for 30 minutes. Then it was allowed to stand for 24 hours and again shaken for 30 minutes. Then the suspension was centrifuged and the supernatant solutions were decanted. 1 ml of aliquot was pipetted out and P was estimated using ascorbic acid blue colour method. AEC was recorded as cmol (e^-) kg^{-1} (Baruah and Borthakur, 1997).

3.2. Fractionation of soil Phosphorus

Fractions of soil P was extracted by the method proposed by (Peterson and Corey, 1966). The extraction procedure involves sequential extraction with

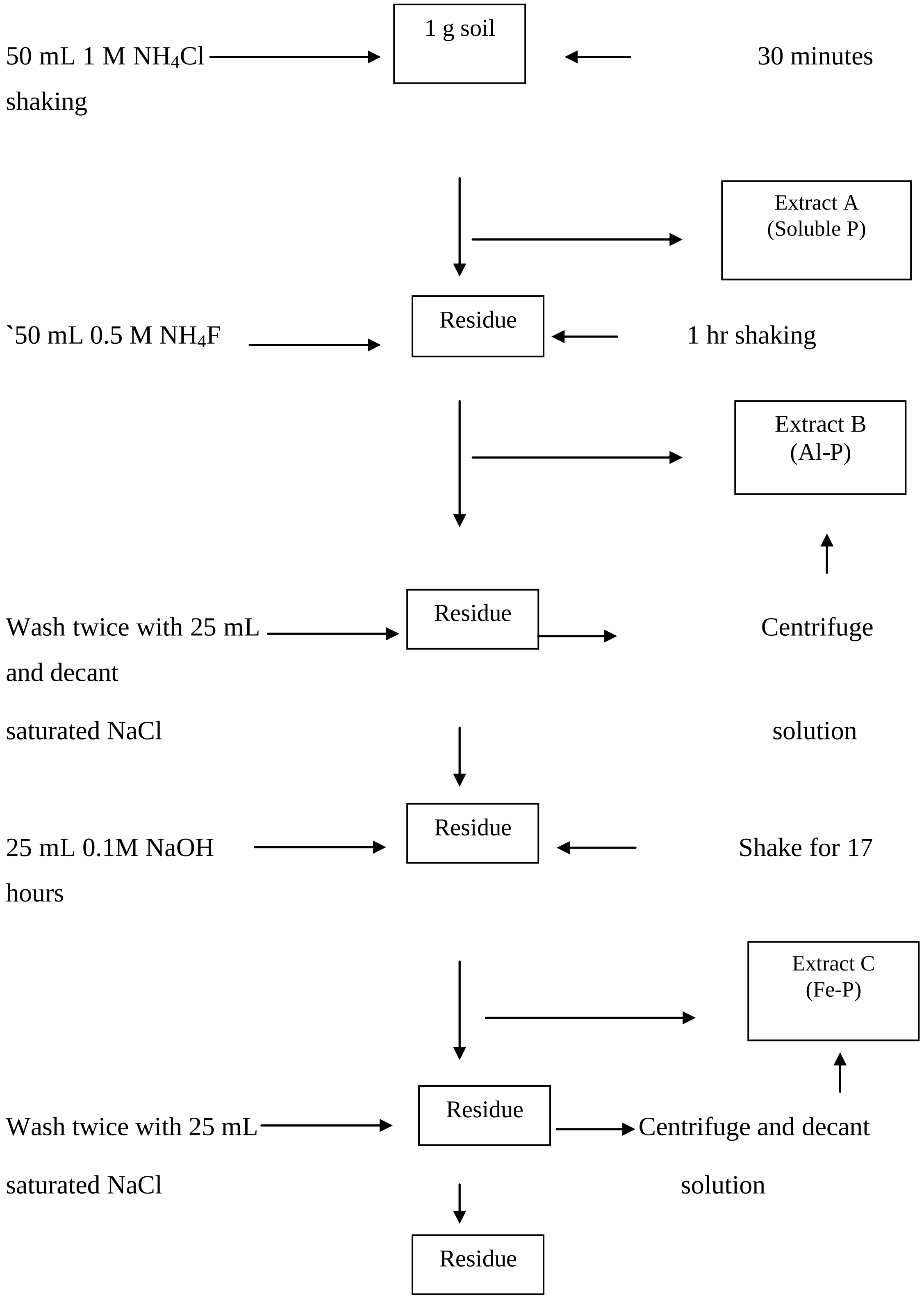
i) 1M NH_4Cl to remove soluble P

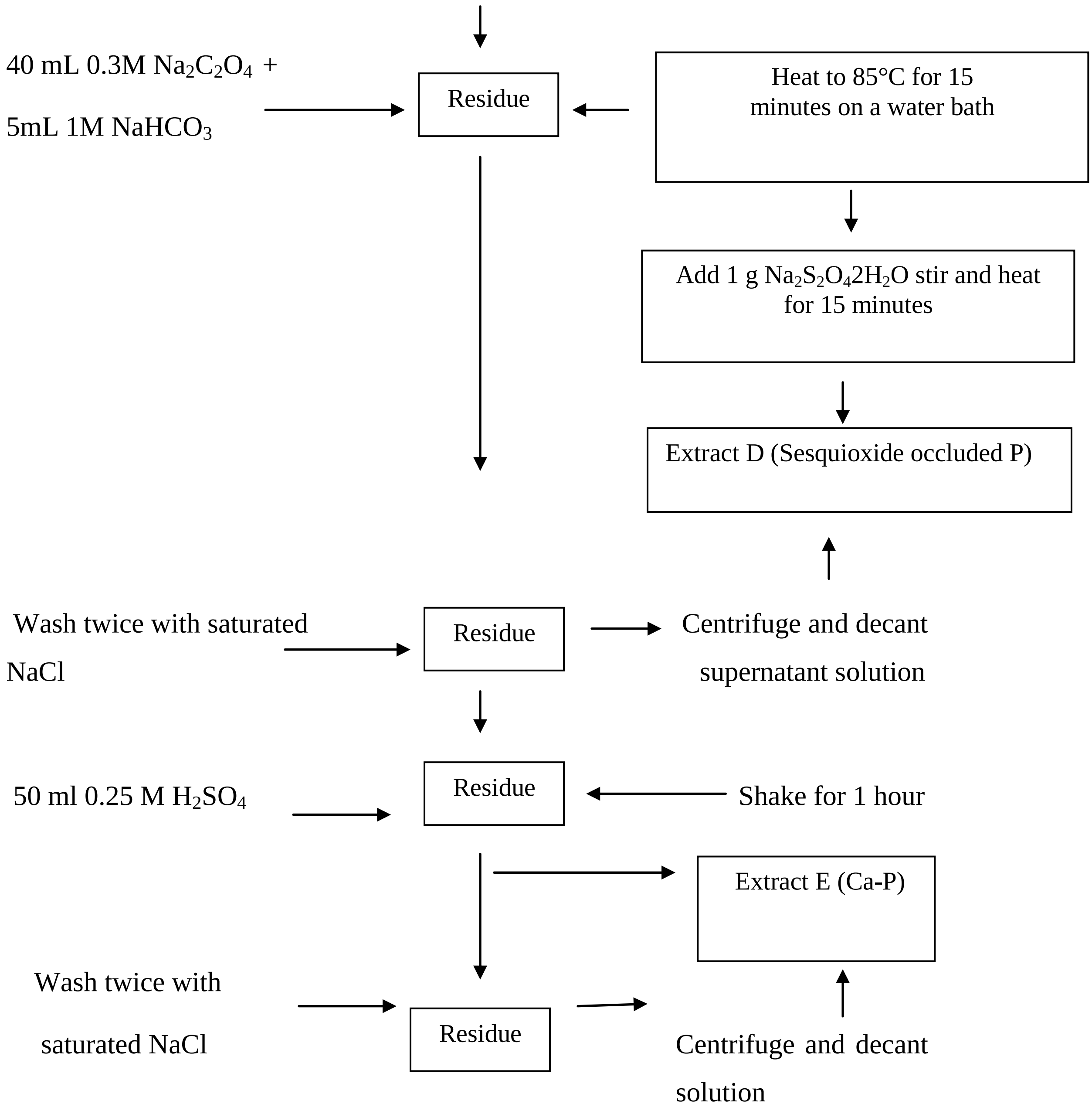
ii) 0.5M NH_4F and saturated NaCl to remove Al-P

iii) 0.1M NaOH and saturated NaCl to remove Fe–P

Figure 1. Flow chart of fractionation of soil phosphorus

(Soil 1 g < 2 mm) in to100 mL centrifuge tube




40 mL 0.3M $Na_2C_2O_4$ +
5mL 1M $NaHCO_3$
Residue
Heat to 85°C for 15 minutes on a water bath
Add 1 g $Na_2S_2O_4 2H_2O$ stir and heat for 15 minutes
Extract D (Sesquioxide occluded P)
Wash twice with saturated NaCl
Residue
Centrifuge and decant supernatant solution
50 ml 0.25 M H_2SO_4
Residue
Shake for 1 hour
Extract E (Ca-P)
Wash twice with saturated NaCl
Residue
Centrifuge and decant solution

iv) Sodium citrate–dithionate–bicarbonate to remove sesquioxide occluded P

v) 0.25M H_2SO_4 to remove the Ca-P

3.2.1. Extractions of P fractions

Flow chart for the P fractionation is depicted in Fig.1. The sequential path of extraction of one gram soil was taken in a 100 mL centrifuge tube. To this 50 mL of 1M NH_4Cl solution was added and shaken for 30 minutes. The tubes with the extract were then centrifuged. The solution was decanted into another tube (Soluble P, Extract A).

The soil residue in the centrifuge was added with 0.5M NH_4F and shaken for 1 hour. Then the tube was centrifuged and the solution was decanted. The soil residue was washed twice with 25 mL saturated NaCl and these two extracts were combined together and made up the volume (Al - P, Extract B).

To the soil residue 50 mL 0.1M NaOH was added and shaken for 17 hours. The solution was centrifuged and decanted. The residue was again washed twice with 25 mL saturated NaCl solution and after centrifugation and decanting; they were mixed together and made up the volume to 100 mL (Fe bound-P, Extract-C).

To the soil residue, 40 mL of 0.3M citrate solution and 5mL of 1M $NaHCO_3$ solution were added and heated in a water bath to 85°C. To this, 1g of $Na_2S_2O_4.2H_2O$ was added with rapid stirring and the heating was continued at 85°C for 15 minutes. The solution was decanted into another flask after centrifugation. The soil residue was washed with 25 mL of saturated NaCl. This was centrifuged and decanted the supernatant solution to the above flask (occluded P, Extract-D).

50 mL 0.25M H_2SO_4 was added to the soil residue and shaken for 1 hour on a shaker. The solution was centrifuged and decanted into another flask. The soil residue was washed twice with 25 mL saturated NaCl, centrifuged and decanted. This was decanted to the above flask and volume made up to 100 mL (Ca - P, Extract E).

3.3. Estimation of P fractions

3.3.1. Concentration P in soluble and Ca-P fractions

5 mL of each of the extracts were pipetted out into a 50 mL volumetric flask. To this, distilled water was added to increase the volume to 20 mL. 4 mL of reagent B (ascorbic acid in ammonium molybdate and potassium antimony tartarate with 5 N H_2SO_4) was added. The volume was made up and the absorbance was read at 660 nm.

3.3.2. Concentration of P in Al-bound P (Extract-B)

5 mL of the extracts were pipetted out into 50 mL volumetric flask. To this 7.5 mL 0.8M Boric acid was added. Then blue colour was developed using reagent B. The intensity was read in spectrophotometer at 660 nm.

3.3.3. Concentration of P in Fe-bound P and sesquioxide occluded P

5 mL of the extracts were pipetted out. The solution pH was adjusted using 2M HCl in the presence of 0.25% p- nitrophenol. For this a separate 5 mL aliquot was pipetted out to which 2 drops 0.25% p-nitrophenol was added and 2M HCl was added drop wise from a burette till the colour changed from yellow to colourless. This estimated amount of 2M HCl was added to the aliquot (5 mL) pipetted for estimation. The P was estimated using ammonium molybdate ascorbic acid reduced blue colour method. The intensity of blue colour was read in spectrophotometer at 660 nm.

3.4. Extraction of organic P

2 g of soils were taken in porcelain crucible. It was ignited in a muffle furnace at a temperature of 550°C for one hour. The samples were cooled and transferred to centrifuge tubes. A duplicate set of 2 g of soils were taken in centrifuge tubes. 50 mL 0.5M H_2SO_4 was added to both sets of soil samples, and shaken for 16 hours. Then the samples were centrifuged and supernatant solution was decanted.

3.4.1. Estimation of organic P

1mL of the decanted solution was transferred into 25 mL volumetric flask and organic phosphorus content was estimated by phosphomolybdate method using ascorbic acid in sulphuric acid medium and blue colour was developed by using reagent B. The intensity of the colour was read in spectrophotometer at 660 nm. The difference in quantities of P on ignited and non-ignited samples gives the amount of organic P.

3.5. P fixing capacity of soil

P fixing capacity of the soils were determined by incubating two gram each of soil samples for 96 hours with various concentrations of phosphorus solution prepared using KH_2PO_4. The graded concentrations of P used were 0 mg L^{-1}, 25 mg L^{-1}, 50 mg L^{-1}, 75 mg L^{-1}, 100 mg L^{-1}, 125 mg L^{-1}, 150 mg L^{-1}, 200 mg L^{-1}, 250 mg $L^{-1}$and 375 mg L^{-1}. One milliliter of each these P solutions was added to 2 g soil sample in batches and kept for incubation. After incubation, labile P was extracted using Bray No.1 and estimated the P concentration by reduced phosphomolybdate ascorbic acid blue colour method (Ghosh *et al*., 1983).

3.6. Selection of soil for pot culture experiment

The soil which has the highest ‘P’ fixing capacity and has the lowest available P status, *ie*., Vellanikkara soil was selected for conducting the pot culture experiment.

3.7. Pot culture experiment

A pot culture experiment was carried out at the glass house of the Radiotracer Laboratory, College of Horticulture using the above selected soil from the five benchmark soils. Plastic containers of uniform size were used for the study. These containers were filled with 100g of processed soil.

The treatments were superimposed in these soils as detailed below:

1. Three level of P

    a) 15 kg P_2O_5 ha^{-1} (L_1)

    b) 30 kg P_2O_5 ha^{-1} (L_2)

    a) 45 kg P_2O_5 ha^{-1} (L_3)

2. Three sources of amendments

    a) *Pongamia pinnata* leaves @ 20 tons ha^{-1} (P_1)

    b) *Cleistanthus collinus* leaves @ 20 tons ha^{-1} (P_2)

    c) Lime @ 9.1 tons ha^{-1} (P_3) estimated by SMP buffer method (Shoemaker *et al*., 1962)

    d) No amendment (P_4)

3. Methods of Application

a) ^{32}P labeled KH_2PO_4 (^{32}P @ 1 mCi g P^{-1}) was applied and thoroughly mixed with 100 g soil (M_1) (L value)

b) Labeled P source ($KH_2\,^{32}P\,O_4$) was placed in bands around seedlings (M_2) (A value)

Treatment combinations

3 x 4 x 2 = 24 + 1 (absolute control)

The experiment was laid out in a completely randomized design with 25 treatments and 6 replications

Plate 1 *Pongamia pinnata* (Source of amendment)

Plate 1 *Pongamia pinnata* (Source of amendment)

Plate 2.*Cleistanthus collinus* (Source of amendment)

Table 2. Treatment combinations in the experiment

Treatment	Notations	Treatment	Notation		
T_1	$P_1L_1M_1$	T_9	$P_2L_3M_1$	T_{17}	$P_3 L_2 M_2$
T_2	$P_1 L_2 M_1$	T_{10}	$P_2L_1M_2$	T_{18}	$P_3 L_3 M_2$
T_3	$P_1 L_3 M_1$	T_{11}	$P_2L_2M_2$	T_{19}	$P_4 L_1 M_1$
T_4	$P_1 L_1 M_1$	T_{12}	$P_2L_3M_2$	T_{20}	$P_4L_2M_1$
T_5	$P_1 L_2 M_2$	T_{13}	$P_3L_1M_1$	T_{21}	$P_4L_3M_1$
T_6	$P_1 L_3 M_2$	T_{14}	$P_3 L_2 M_1$	T_{22}	$P_4L_1M_2$
T_7	$P_2 L_1 M_1$	T_{15}	$P_3 L_3 M_1$	T_{23}	$P_4L_2M_2$
T_8	$P_2L_2M_1$	T_{16}	$P_3 L_1 M_1$	T_{24}	$P_4L_3M_2$

T_{25} - Absolute control

Amendments, viz. *Pongamia* leaves, *Cleistanthus* leaves and lime were incorporated in respective treatments. The soil was then subjected to wetting and drying cycles for three weeks so as to ensure thorough mixing of added amendments with possible decomposition and other chemical changes and incorporation throughout the soil system. Soil samples were drawn after three weeks of incorporation of amendments.

Soil samples were collected for chemical analysis before the application of the treatments. The fertilizer for the supply of P as a basal dose through ^{32}P labelled KH_2PO_4 (^{32}P @ 1 mCi g^{-1} P) was applied as per the treatments. Nitrogen and potassium were applied in the form of urea and muriate of potash as per the Package of Practices Recommendations (KAU, 2007). The seeds of cowpea variety Kanakamony were sown @ 3 seeds pot^{-1} and it was assured that three seedlings were maintained in each container.

Crop was maintained only for one month and both soil and plant samples were drawn at 15th and 30th day after sowing The soil samples were assayed for both radioactive and stable P in available pool, in inorganic fractions and in organic fraction The non radioactive phosphorus in the available fractions, in inorganic fractions, and in organic fractions was estimated by reduced molybdate blue colour method. Radio active phosphorus (^{32}P) in these pools was assayed following Cerenkov counting in a liquid scintillation counter (Model Hidex – Triathler –Three in one counter).

3.8. Plant analysis

Plant samples were collected from different treatments on 15th and 30th day after sowing. Destructive sampling of three replications was done in both the stages. The samples were oven dried to a constant weight and ground for analysis.

3.8.1. Total phosphorus in plant samples

Total P in the plant sample was estimated after digestion of the sample with 2:1 nitric – perchloric acid mixture. P in the digest was determined by the vanadomolybdate yellow colour method (Koening and Johnson, 1942) measuring the colour intensity in a spectrophotometer (Model: Analyst 400). The radioactive P in the digest was estimated following Cerenkov counting in a liquid scintillation counter (Model Hidex – Triathler –Three in one counter).

3.9. Radio assay

Radio assay of the extracts of available P, P fractions, organic P and plant P was carried out in liquid scintillation system. The counts per minute (cpm) for all samples were corrected for background and decay. The specific activity in the applied fertilizer and that in plant sample were computed using the count rates (cpm g^{-1}) of the fertilizer and of the plant sample. The A value and L value were computed utilizing these specific activities, that is in the case of banded application, A value was computed as

$$\text{A value} = \frac{\%\ \text{P derived from soil}}{\%\ \text{P derived from fertilizer}} \times \text{Amount of P applied in g/pot, where,}$$

$$\text{Percentage P derived from fertilizer} = \frac{\text{Specific activity in plants}}{\text{Specific activity in fertilizer}} \times 100$$

Percentage P derived from soils = 100 – Percentage P derived from fertilizer.

In the case of treatments where labeled fertilizer was thoroughly mixed with soil, L value was computed using the equation

$$\text{L value} = \frac{\text{Specific activity in fertilizer}}{\text{Specific activity in plant}} - 1 \times \text{Amount of fertilizer P applied (mg pot}^{-1}\text{)}$$

3.9.1. Radio activity in fractions

The count rate in different fractions and the count rate of applied P were used to compute percentage distribution of applied P in different ‘P’ fractions.

3.10. Q / I relationship

Five gram each of soil was weighed out in to 250 ml conical flasks and 50 ml each of P solutions (0, 10, 20, 40, 60, 80 and 100 ppm P solutions were prepared by using $CaCl_2$ solution for dilution) of varying concentrations were added. The flasks were shaken for one hour. Half of the suspension was used for determination of pH. The remaining halves were filtered and used for determination of P. Phosphorus was estimated by ascorbic acid method.

3.11. Statistical analysis

Analysis of variance in CRD was done using MSTAT C package. Correlation studies of data were carried out by the method suggested by Panse and Sukatme (1978).

Results

4. Results

The data generated from the characterization of five selected benchmark soils and analytical data from the pot culture experiments are given below.

4.1. Electrochemical properties and available nutrient status

4.1.1. pH

The pH of the five selected benchmark soils of lateritic origin collected for the present study is given in table 3.The pH of the soils ranged from 4.6 to 5.8.The lowest pH was recorded in Thirumittakkodu soil and the highest in Angadippuram soil.

4.1.2. Electrical conductivity

The electrical conductivity of the soils soils ranged from 0.05 to 0.1 dSm^{-1} (Table 3) indicating that these soils are not saline in nature.

4.1.3. Available nutrient status

The organic carbon content of the soils ranged from 0.49 to 1.25 percent. The lowest organic carbon content was recorded in Vellanikkara soil series.

The available phosphorus of the soils ranged from 3.7 to 20 mg kg^{-1}.The lowest available phosphorus was recorded in Vellanikkara series and the highest was recorded in Angadippuram series (Table 3).

The available potassium content of the soils ranged from 182 to 332 mg kg^{-1}. The lowest available potassium was recorded in Pattambi soil and highest was recorded in Thirumittakodu soil (Table 3)

4.1.4. Available micronutrient status

The available (0.1N HCl extractable) micronutrient status of the selected soils is given in table 3. Available Fe content of the soils ranged from 13.8 to 26.9 mg kg^{-1}. The lowest available Fe content was recorded in Thirumittakkodu soil and highest value was recorded in Angadippuram series. Available Mn content of the soils ranged from 19.4 to 83.6 mg kg^{-1}. Lowest available Mn content was

Table 3. Electrochemical properties and available nutrient status of the five selected benchmark soils

Soil	pH	EC (dSm^{-1})	OC (%)	Available Nutrient status ($mg\ kg^{-1}$)					
				Av.P	K	Fe	Mn	Cu	Zn
Kundamangalam series	5.8	0.1	0.64	17.8	210	22.6	19.4	4.9	1.6
Angadippuran series	5.9	0.1	1.17	20	259	26.9	42.6	6.9	1.6
Vellanikkara series	5.4	0.05	1.25	3.7	296	15.2	27.1	12.2	2.2
R A R S Pattambi soil	4.6	0.05	0.66	18.1	182	19.3	83.6	32.4	1.0
Thirumittakkodu soil	5.7	0.05	0.49	7.9	332	13.8	54.0	18.8	0.9

recorded in Kunnamangalam series and the highest value was recorded in Pattambi soil. Available Cu content of the soils ranged from 4.9 to 32.4 mg kg^{-1}. Kunnamangalam series recorded the lowest available Cu content and Pattambi soil recorded the highest value. The amount of available Zn in the soils ranged from 0.9 to 2.2 mg kg^{-1}. The lowest available Zn was recorded in Thirumittakkodu soil and the highest value was recorded in Vellanikkara soil series.

4.2.1. Exchangeable cations

The $BaCl_2$ exchangeable cation status of the selected soils under study is given in table 4. The exchangeable Na content of the soils ranged from 0.53 to 1.31 cmol(p+)kg^{-1}. Exchangeable Na content in Vellanikkara soil series was 0.98 cmol(p+)kg^{-1}. Exchangeable K content of the soils ranged from 0.21 to 0.51 cmol(p+)kg^{-1}. Vellanikkara soil series recorded 0.46 cmol(p+)$kg^{-1}$of exchangeable K.

The amount of exchangeable Ca in the soils ranged from 0.76 to 2.89 cmol(p+)kg^{-1}. Exchangeable Ca content in Vellanikkara soil was 2.21 cmol(p+)kg^{-1}. Exchangeable Magnesium content of the soils ranged from0.08 to 0.011 cmol(p+)kg^{-1}. Vellanikkara soil series recorded 0.010 cmol(p+)$kg^{-1}$of exchangeable Mg.

Exchangeable Al content of the soils ranged from 0.09 to 0.79 cmol(p+)kg^{-1}. Fe content in the exchangeable pool ranged from 0.002 to 0.08 cmol(p+)kg^{-1}. Exchangeable Cu content of the soils varied from 0.001 to 0.006 cmol(p+)kg^{-1}. Vellanikkara soil series recorded the highest value. Mn content of in the exchangeable pool in the benchmark soils ranged from 0.07 to 0.56 cmol(p+)kg^{-1}.Vellanikkara soil recorded Mn content of 0.03 cmol(p+)kg^{-1} in the exchangeable pool. Exchangeable Zn content in all the five soils were in non-detectable range.

5.2.2. Cation exchange capacity

The cation exchange capacity of the selected benchmark soils varied from 2.69 to 5.13 cmol (p+) kg^{-1}.The CEC of Vellanikkara soil was 4.69 cmol (p^+) kg^{-1}.

Table 4. AEC, CEC and exchangeable cations of the soils

Soil	AEC	CEC	Exchangeable cations [cmol(p+)kg^{-1})]								
	[cmol(-)kg^{-1}]	[cmol(p+)kg^{-1}]	Na	K	Ca	Mg	Al	Fe	Cu	Mn	Zn
Kunnamangalam series	10.9	3.54	1.10	0.51	1.66	0.11	0.09	0.002	0.001	0.07	N.D.
Angadippuran series	11.1	5.13	1.04	0.51	2.89	0.10	0.08	0.004	0.001	0.15	N.D.
Vellanikkara series	9.6	4.69	0.98	0.46	2.21	0.10	0.27	0.02	0.006	0.21	N.D.
Pattambi soil	13.1	2.69	0.53	0.21	0.76	0.08	0.79	0.04	0.002	0.56	N.D.
Thirumittakkodu soil	12.5	4.43	1.31	0.51	2.10	0.09	0.09	0.08	0.001	0.21	N.D.

Table 5. P fixing capacity and Phosphorus fractions

Soil	P fixing capacity (%)	P fractions (mg kg^{-1})						
		Sol-P	Al-P	Fe-P	Occluded P	Ca-P	Org – P	Total P
Kunnamangalam series	87.4	76	322	212	66	57.3	140.3	894.4
Angadippuran series	88.6	74	318	226	93.3	67	166.6	897.3
Vellanikkara series	91.6	19.2	185	106.8	76	34	98.3	605.3
Pattambi soil	90.1	74.0	280	308	14	62	156.5	927.5
Thirumittakkodu soil	88.4	75.2	266	183	18.6	27	126.3	813.8

Pattambi soil recorded the lowest CEC and highest value was recorded in Angadippuram series.

5.2.3. Anion exchange capacity

The anion exchange capacity of the selected benchmark soils varied from 9.6 to 13.1 cmol (e^-) kg^{-1}. The AEC of Vellanikkara soil recorded the lowest value and Pattambi soil recorded the highest value.

4.3. Availability indices of Phosphorus

4.3.1. P fixing capacity and available P

The data on P fixing capacity and available P status of the selected soils is given in table 3 and 5. P fixing capacity varied from 87.4 to 91.6%. Highest P fixing capacity was recorded in Vellanikkara soil and lowest was recorded in Kunnamangalam series.

4.3.2. Fractions of phosphorus

The data on various inorganic P fractions, and that of organic P are presented in table 3. The soluble P fraction in the soils ranged from 19.2 mg kg^{-1} to 76 mg kg^{-1}. The soluble P fraction of Vellanikkara soil series recorded the lowest value. Al-P fraction of the soils varied from 185 mg kg^{-1} to 322 mg kg^{-1}. The Al-P fraction of Vellanikkara soil series recorded the lowest (185 mg kg^{-1}). These selected soils had Fe-P fraction in the range of 106.8 to 308 mg kg^{-1}.Vellanikkara soil recorded lowest value here also. The occluded P fraction in the soils varied from 14 mg kg^{-1} to 93.3 mg kg^{-1}. The occluded P fraction of Vellanikkara soil used for pot culture experiment recorded 76 mg kg^{-1}. The Ca- P fraction in the soils ranged from 27 mg kg^{-1} to 67 mg kg^{-1} with a value of 34 mg kg^{-1}soil recorded in case of Vellanikkara soil.

The organic P content of the soils varied from 98.3 to 166.6 mg kg^{-1}. Vellanikkara soil recorded the lowest organic P status among all the five-benchmark soils. The total P content of the soils varied from 605.3 mg kg^{-1} to 927.5 mg kg^{-1}.

4.3.3. Quantity- Intensity studies.

Quantity- Intensity relationships with respect to phosphorus in the above soils were studied. The equilibrium phosphate potential and buffer power of the soils were estimated from Q/I relationship. The data is given in table 4. The Equilibrium phosphate potential and buffer power of Vellanikkara soil was 1.47 and 2.54 L kg^{-1} respectively.

4.3.3.1. Adsorption studies

The data obtained from phosphate adsorption experiments (Q-I studies), were tried to be fitted in to different adsorption isotherms like Freundlich and Langmuir isotherms. The data for all the soils could be described by Langmuir equation. The data in table 4 give different parameters of Langmuir adsorption isotherm such as bonding energy coefficient (K) and adsorption maxima (M).

The adsorption maximum was highest in Vellanikkara soil. The bonding energy coefficient recorded lowest value in Vellanikkara soil. The Langmuir equations are given in table 4. Freundlich equation with 48% of variability explained could describe the data for only one soil. The equation is given below:

$$\log x/m = 0.6399 + 0.2492 \log C \qquad (R^2 = 48.263)$$

4.3.4. P fractions expressed as percent of total inorganic P

The soluble P fraction of Vellanikkara soil at the initial stage was 4.6% of the total inorganic P. Al-P fraction recorded 43.9 per cent of the total inorganic P. Twenty five percentage of the total inorganic P was from Fe-P. Occluded P fraction recorded 18% of the total inorganic P.Ca P recorded 8.1 per cent the total inorganic P.

Table 6. Equilibrium phosphate potential, Buffer power and adsorption characteristics of the soils

Soil	Equilibrium phosphate potential	Buffer power (L kg^{-1})	Langmuir equation	K (mL g^{-1})	M (mg kg^{-1})	R^2
Kundamangalam series	1.468	2.14	C/x/m=0.2678+0.0891C	0.333	11.2119	26.39
Angadippuran series	1.469	2.71	C/x/m=0.4486+0.0291C	0.2052	10.856	49.83
Vellanikkara series	1.470	2.54	C/x/m=0.1850+0.0548C	0.0296	182.59	93.17
R A R S Pattambi soil	1.469	1.73	C/x/m=0.2007+0.0701C	0.0349	142.75	92.17
Thirumittakkodu soil	1.469	1.73	C/x/m=0.2879+0.0103C	0.036	96.457	92.42

Table 7. P fractions expressed as percent of inorganic P

Soil	Sol-P (%)	Al-P (%)	Fe-P (%)	Oc P (%)	Ca-P (%)
Kunnamangalam series	10.36	43.9	28.9	9	7.8
Angadippuran series	9.5	40.9	29.0	11.9	8.6
Vellanikkara series	4.6	43.9	25.4	18	8.1
R A R S Pattambi soil	10.03	37.9	41.7	1.9	8.4
Thirumittakkodu soil	13.2	46.7	32.1	3.3	4.7

4.4. Pot culture experiment

The experiment was conducted as detailed in Chapter 2. The soil with high P fixing capacity and low available P status was selected for the pot culture experiments. (Vellanikkara soil with P fixing capacity 91.6% and available P status 3.7 mg kg^{-1}).

The samples were taken for both soil and plant as well as counts of radioactive P were taken at 4 stages of the experimentation *viz.* i) initial stage, ii) 15 days after incorporation of amendments just before sowing, iii) three replications used as samples at 15 days after sowing and iv) three replications at 30 days after sowing.

4.4.1. Available P

4.4.1.1. Available P just before sowing after incubation with amendments

Available P was estimated at 4 stages, Available P content in the initial soil sample was 3.74 mg kg^{-1}. The data on available P status at just before sowing is given in table 7. At this stage, the available P status was found increased from the initial content. At this stage, none of the amendments were found to be significantly different in influencing the levels of available P.

4.4.1.2. Available P at 15 days after sowing

The data on available P in soil, at 15 days after sowing are presented in table 9. The amendments had a significant influence on the available P at this stage. Incorporation of lime was found to enhance the available P (6.9 mg ha^{-1}), which was higher than the other two treatments. However, *Pongamia* (6.1mg P ha^{-1}) and *Cleistanthus* (6.6 mg P ha^{-1}) application had a significantly better influence on improving the available P in comparison with the treatment without any amendments (3.8 mg P ha^{-1}).

At this stage, available P content of the soil increased significantly from 4.81 mg P $ha^{-1}$to 6.81 mg P ha^{-1}as the applied P level was enhanced from 15 to 45 kg ha^{-1}. Band placement (5.9 mg P ha^{-1}) had a significant influence (5.5 mg P ha^{-1} soil) on the available P status in comparison to thorough mixing of phosphorus with soil

4.4.1.3. ^{32}P counts in the available P pool at 15 days after sowing

The data on ^{32}P counts (cpm g^{-1} soil) in the available P content is given in table 11.At this stage, the ^{32}P count in the treatment without any amendment recorded the highest count (253.5 (cpm g^{-1}) which was significantly superior to the other three treatments. Among the other three, lime application recorded significantly better counts (55.5 (cpm g^{-1}) in comparison to that in *Pongamia* (18.5 cpm g^{-1}) and *Cleistanthus* (21.2 cpm g^{-1}) application. The ^{32}P in the available P fraction increased significantly with the higher levels of P application.

The count rate increased from 7.6 cpm g^{-1} to 178.7 cpm g^{-1} as the level of phosphorus increased from 15 to 45 kg ha^{-1}.

The methods of application had no significant effect on the ^{32}P count in the available P fraction at this stage.

4.4.1.4. Available P at 30 days after sowing

The data on available P in soil, at 30 days after sowing are presented in table 10. As in the case of available P at 15 days after sowing, at this stage also the amendments had a significant influence on the available P. Application of lime was found to improve the available P (7.6 mg P ha^{-1}) status of the soil, which was on par with that in case of application of *Cleistanthus* (7.4 mg P ha^{-1}). These two amendments were significantly superior to application of *Pongamia* leaves, which in turn had a significantly better influence of on the available P status of soil (6.6 mg ha^{-1}) than that of the treatment without any amendments (3.0 mg ha^{-1}).

At this stage also, as in the case of 15 days after sowing, Higher levels of P, significantly improved the available P i.e., the available P levels were 5.3, 5.9 and 6.2 mg P ha^{-1} at 15, 30 and 45 kg ha^{-1} levels of applied P respectively. The methods of application had no significant influence on the available P status at this stage.

4.4.1.5. ^{32}P count in the available P pool at 30 DAS

The treatment with out any amendment recorded maximum count rate (5260.2 cpm g^{-1}) (Table 12) which is significantly higher than that in the other three treatments. *Pongamia* recorded significantly higher count rate (4395.4 cpm g^{-1}) which is on par with that in *Cleistanthus* (4355.1 cpm g^{-1}) and the counts in both these treatments were significantly higher than that in the case of lime (1790.6 cpm g^{-1}).

The levels of phosphorus had no significant influence in the ^{32}P count in the available P pool at this stage. The methods of application also did not differ significantly with reference to ^{32}P counts in the available P content.

Table 8. Effect of amendments on available P (mg kg^{-1}) just before sowing, 15 days after incubation

Treatments	Mean
P1(*Pongamia*)	4.6
P2(*Cleistanthus*)	4.3
P3(Lime)	4.3
P4(No amendment)	4.2
CD(P= 0.05)	NS

Table 9. Effects of levels of P and amendments on available P (mg kg^{-1}) 15 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	5.4	5.8	6.4	2.9	4.9
	L2	6.5	7.3	6.2	3.9	5.8
	L3	7.5	8.2	9.0	4.6	7.1
		6.4	6.9	7.1	3.4	5.9
M2	L1	4.6	5.6	5.6	3.4	4.7
	L2	6.0	6.1	6.7	3.8	5.5
	L3	6.8	7.1	8.6	4.3	6.5
Mean		5.7	6.2	6.9	3.8	5.5
Overall mean		6.1	6.6	6.9	3.8	5.7

Absolute control – 2.9 mg kg^{-1}

Level	Mean		
1	4.81	C.D (P)	0.043
2	5.69	C.D (L)	0.065
3	6.81	C.D (M)	0.031

Table 10. Effects of levels of P and amendments on available P (mg P kg^{-1}) 30 days after sowing

Method/ Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	5.8	5.3	6.6	2.3	4.7
	L2	6.7	7.1	7.7	3.5	5.9
	L3	7.4	6.5	9.2	3.6	6.4
		6.6	6.3	7.8	3.1	5.6
M2	L1	6.6	12.1	6.6	2.8	6.1
	L2	6.4	7.2	7.6	3.1	5.8
	L3	7.1	8.0	8.3	2.9	6.1
Mean		6.6	8.8	7.5	2.9	5.9
Overall mean		6.6	7.4	7.6	3.0	5.8

Absolute control – 2.7 mg kg^{-1}

Level	Mean		
1	5.33	C.D (P)	0.062
2	5.88	C.D (L)	0.022
3	6.24		

Table 11. Effects of levels of P and amendments on ^{32}P counts (cpm g^{-1}) in the available fraction at 15 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	5.9 (0.78)	1.00 (0.0)	8.34 (0.9)	99.8 (1.99)	8.4 (0.92)
	L2	453.9 (2.66)	7.8 (0.89)	530.8 (2.73)	1318.3 (3.12)	222.8 (2.35)
	L3	79.9 (1.9)	81.9 (1.9)	743.0 (2.87)	30.5 (1.49)	110.4 (2.04)
Mean		59.9 (1.78)	8.6 (0.93)	148.94 (2.17)	104.9 (2.20)	59.2 (1.77)
M2	L1	4.6 (0.66)	1 (0.0)	7.3 (0.866)	63.8 (1.81)	6.8 (0.83)
	L2	1 (0.0)	285.1 (2.46)	2.7 (0.43)	1364.6 (3.14)	31.9 (1.51)
	L3	41.1 (1.6)	503.5 (2.7)	444.6 (2.65)	763.8 (2.88)	289.7 (2.46)
Mean		5.7 (0.76)	52.4 (1.71)	20.7 (1.32)	404.6 (2.61)	39.8 (1.6)
Overall mean		18.5 (1.27)	21.2 (1.33)	55.5 (1.74)	253.5 (2.40)	48.53 (1.69)

Levels	Means		
1	7.6(0.88)	C.D (P)	0.608
2	84.5(1.93)	C.D (L)	0.571
3	178.7(2.25)		

The data in the parenthesis are log-transformed values

Table 12. Effects of levels of P and amendments on ^{32}P counts (cpm g^{-1}) in the available P pool at 30 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	3.4 (3.38)	14859.4 (4.17)	3935.5 (3.59)	3935.5 (3.66)	5023.4 (3.70)
	L2	3.8 (3.75)	5701.6 (3.76)	3515.6 (3.55)	4549.9 (3.66)	4753.4 (3.68)
	L3	3.9 (3.89)	1845.0 (3.27)	6053.4 (3.78)	6165.9 (3.79)	4819.5 (3.68)
Mean		4709.8 (3.67)	5382.7 (3.73)	4375.2 (3.64)	5046.6 (3.70)	4864.1 (3.69)
M2	L1	5997.9 (3.78)	3539.9 (3.55)	225.9 (2.35)	11830.4 (4.07)	2741.6 (3.44)
	L2	6123.5 (3.79)	3349.7 (3.53)	1355.2 (3.13)	4731.5 (3.68)	3388.4 (3.53)
	L3	1883.7 (3.28)	3681.3 (3.57)	1288.3 (3.11)	2958.0 (3.47)	2264.6 (3.36)
Mean		4102.0 (3.61)	3523.7 (3.55)	732.8 (2.87)	5495.4 (3.74)	2760.6 (3.44)
Overall mean		4395.4 (3.64)	4355.1 (3.64)	1790.6 (3.25)	5260.2 (3.72)	3664.4 (3.56)

Level	Mean		
1	3715.4 (3.57)	C.D (P)	0.36
2	4017.9 (3.60)		
3	3303.5 (3.52)		

The data in the parenthesis are log-transformed values

4.4.2. Fractions of phosphorus in soil

Samples were drawn at four stages viz. (i) before the incorporation of amendments, (ii) 15 days after application of amendments just before sowing, (iii) 15 days after sowing (iv) 30 days after sowing

Table 13. Effects of amendments on P fractions (mg kg^{-1}) just before sowing, 15 days after incubation

Treatments	Soluble P	Al-P	Fe-P	Occluded P	Ca-P	Organic P
P1(*Pongamia*)	12.6	139.6	65.7	73	34.2	188.2
P2(*Cleistanthus*)	11.6	136.6	70.7	71	33.4	227.3
P3(Lime)	12.9.	133.4	68.8	65	39.6	169.9
P4(No amendment)	6.3	138.9	78.1	79	28.2	103.4
CD (P= 0.05)	1.29	1.0	1.12	1.11	1.12	1.28

4.4.2.1. Soluble P just before sowing

Soluble P fraction in the initial soil sample was 19.2 mg P kg^{-1}. The soluble P showed a steady decrease when compared to that in the initial soil sample before application of the amendments (Table 13). The soluble P fraction in the respective samples was significantly different in case of different amendments with that in lime applied treatment showing the highest value (12.9 mg P kg^{-1}).

4.4.2.2. Soluble P 15 days after sowing

The data on the soluble P fractions 15 DAS are given in table 14. The amendments had a significant influence on the soluble P fractions at this stage. Lime incorporation was found to increase the soluble P fraction (38.1 mg kg^{-1}) which was superior to other two treatments. However, *Pongamia* application (29.0 mg kg^{-1}) and *Cleistanthus* application (26.9 mg kg^{-1}) which among themselves had a better influence in improving the soluble P fraction than the treatment without any amendment (15.7 mg kg^{-1})

Table 14. Effects of levels of P and amendments on Soluble P (mg kg^{-1}) at 15 days after sowing

Method/Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	29.1	37.5	27.9	12.5	24.9
	L2	29.3	21.2	22.0	13.1	20.7
	L3	30.1	32.3	25.2	16.2	25.2
Mean		29.5	29.6	25.0	13.9	23.5
M2	L1	22.9	30.6	53.7	16.6	28.2
	L2	26.3	17.9	54.0	10.1	22.5
	L3	38.4	26.1	67.4	32.5	38.5
Mean		28.5	24.3	58.0	17.6	29.0
Overall mean		29.0	26.8	38.1	15.7	26.1

Absolute control –17.8 mg kg^{-1}

Level	Mean		
1	26.5	C.D (P)	1.31
2	21.6	C.D (L)	1.26
3	31.1		

Table15. Effects of levels of P and amendments on Soluble P (mg kg^{-1})30 days after sowing.

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	17.8	18.6	18.8	7.6	15.7
	L2	16.9	21.5	19.2	11.2	17.2
	L3	16.4	22.5	20.4	12.1	17.9
Mean		17.0	20.9	19.5	10.3	16.9
M2	L1	17.6	18.6	18.5	8.1	15.7
	L2	17.8	17.5	19.8	10.2	16.3
	L3	18.7	17.9	21.2	11.9	17.4
Mean		18.03	18.0	19.8	10.1	16.5
Overall mean		17.5	19.5	19.7	10.2	16.7

Absolute control –11.9 mg kg^{-1}

Level	Mean		
1	15.7	C.D (P)	1.12
2	16.8	C.D (L)	1.17
3	17.7	CD (P= 0.05)	

Table16. Effects of levels of P and amendments on ^{32}P counts (cpm g^{-1}) in the soluble P fraction at 15 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	1798.9 (3.26)	2594.2 (3.41)	2786.1 (3.45)	4688.1 (3.67)	2792.5 (3.45)
	L2	1534.6 (3.19)	2249.1 (3.35)	4613.2 (3.66)	3971.9 (3.59)	2818.4 (3.450)
	L3	1761.9 (3.25)	3006.1 (3.48)	3863.7 (3.59)	3380.6 (3.53)	2884.0 (3.46)
Mean		1694.3 (3.23)	2594.2 (3.41)	3672.8 (3.57)	3981.1 (3.60)	2831.4 (3.45)
M2	L1	2535.1 (3.40)	3083.2 (3.49)	3296.1 (3.52)	2409.9 (3.38)	2805.4 (3.45)
	L2	1786.5 (3.252)	1541.7 (3.188)	4466.8 (3.65)	5610.5 (3.75)	2884.0 (3.46)
	L3	2074.9 (3.32)	3499.5 (3.54)	2937.6 (3.45)	2177.7 (3.34)	2606.2 (3.42)
Mean		2100.6 (3.32)	3507.5 (3.41)	3507.5 (3.55)	3090.3 (3.49)	2766.9 (3.44)
Overall mean		1892.3 (3.28)	3589.2 (3.56)	3589.2 (3.56)	3507.5 (3.55)	2798.9 (3.45)

C.D (P) 0.139

The data in the parenthesis are log-transformed values

Table17. Effects of levels of P and amendments on ^{32}P counts (cpm g^{-1}) in the soluble P fraction at 30 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	65162.8 (4.81)	48194.8 (4.68)	45814.2 (4.66)	42756.3 (4.63)	49773.7 (4.69)
	L2	87700.1 (4.94))	53579.7 (4.73)	42854.9 (4.63)	36643.8 (4.56)	52119.5 (4.72)
	L3	53703.2 (4.73)	57809.6 (4.76)	29991.3 (4.48)	25703.9 (4.41)	39264.5 (4.59)
Mean		67452.8 (4.83)	53088.4 (4.73)	38904.5 (4.59)	34276.8 (4.54)	46773.5 (4.67)
M2	L1	65162.8 (4.81)	57147.9 (4.76)	31405.1 (4.49)	37844.3 (4.58)	45814.2 (4.66)
	L2	51404.4 (4.71)	80537.8 (4.91)	57676.7 (4.76)	27415.7 (4.44)	50582.5 (4.70)
	L3	64120.9 (4.81)	129419.6 (5.11)	54325.0 (4.74)	25527.0 (4.41)	58210.3 (4.77)
Mean		59841.2 (4.78)	84139.5 (4.93)	46131.8 (4.66)	29785.2 (4.47)	51286.1 (4.71)
Overall mean		63533.1 (4.80)	66834.4 (4.83)	42364.3 (4.63)	31988.9 (4.51)	48997.9 (4.69)

C.D (P) 0.117

The data in the parenthesis are log-transformed values

The levels of phosphorus had a significant influence on the soluble P fractions. The application of phosphorus at 45 kg ha^{-1} recorded the highest soluble P (31.1 mg kg^{-1}).

The methods of application had no significant influence in the soluble P fraction at this stage.

4.4.2.3. ^{32}P counts in the soluble P fraction at 15 days after sowing.

The data on the ^{32}P counts in soluble P (cpm g^{-1} soil) fraction is given in table 16. Application of lime had a significant influence on improving the ^{32}P count in soluble P fraction (3589.2 cpm g^{-1}) compared to other two treatments i.e. application at *Pongamia* and *Cleistanthus* (1892.3 and 2576.3 cpm g^{-1} soil respectively) The levels of phosphorus did not show any significant difference in the ^{32}P counts in the soluble P fractions. The methods of application of phosphorus also had no significant influence on the soluble P fraction at this stage

4.4.2.4. Soluble P 30 days after sowing

The data on soluble P fraction at 30 days after sowing are given in table 15. The data showed that the soluble P fraction was decreased when compared to that at 15 days after sowing.

The application of amendments had a significant influence on the soluble P fraction of the soil at this stage. Application of lime and *Cleistanthus* recorded highest content of soluble P (19.7mg P kg^{-1}, 19.5mg P kg^{-1} respectively). However, application of *Pongamia* also recorded more soluble P (17.5 mg P kg^{-1}) than the treatment without any amendment (10.2 mg P kg^{-1}).

The soluble P fraction in the soil increased with the levels of phosphorus applied from 15.7 to 17.7 mg P kg^{-1} when the phosphorus applied increased from 15 to 45 kg ha^{-1}.

The methods of application did not show any significant difference in the soluble P fraction at this stage.

4.4.2.5. ^{32}P count in the soluble P fraction 30 days after sowing

The data given in the table 17 shows that the count was highest in *Cleistanthus* applied treatment (66834.4 cpm g^{-1}) which was on par with that in case of application of *Pongamia* (63533.1 cpm g^{-1}). These two treatments gave significantly superior counts in comparison with that of lime (42364.1cpm g^{-1}) and the treatment without any amendment (31988.9 cpm g^{-1}) which in turn are significantly different among themselves.

Neither levels of phosphorus nor methods of application had any significant effect on ^{32}P counts in soluble P fraction at this stage.

4.4.3. Al-P fraction

4.4.3.1. Al-P fraction at just before sowing 15days after incubation

The Al-P fraction of the initial soil was 185 mg P kg^{-1}. The Al-P fraction just before sowing, 15 days after incubation is given in table 13. At this stage, the application of amendments had a significant influence on reducing the Al-P fraction. Application of lime significantly reduced the Al-P fraction (133.4 mg kg^{-1}), when compared to all other amendments. Incorporation of *Cleistanthus* leaves also reduced significantly the Al-P fraction (136.6 mg kg^{-1}) when compared to the incorporation of *Pongamia* leaves (139 mg kg^{-1}) which in turn is on par with the treatment without any amendment.

4.4.3.2. Al-P fraction at 15 days after sowing.

The data on the Al-P fraction 15 days after sowing is given on table 18. The application of lime had the most significant effect in reducing the Al-P fraction (118.5 mg kg^{-1}). However, the application of *Cleistanthus* also showed a significant effect in reducing the Al-P fraction (123.8 mg kg^{-1}) which is on par with that in case of application of *Pongamia* (123.3 mg kg^{-1}).

The levels of phosphorus applied had a significant effect in increasing the Al-P fraction at this stage. The Al-P fraction increased from 121.2 mg kg^{-1} to 33.3 mg kg^{-1} when the levels of phosphorus applied increased from 15 to 45 kg ha^{-1}.

Table18. Effects of levels of P and amendments on Al- P (mg kg^{-1}) 15 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	110.2	115.3	115.3	132.5	118.3
	L2	121.2	116.5	115.3	138.6	122.8
	L3	131.2	136.3	121.4	141.3	132.5
Mean		120.9	122.7	117.3	137.3	124.5
M2	L1	119.2	121.4	115.3	135.3	122.8
	L2	125.2	121.4	118.3	138.6	124.3
	L3	132.6	132.3	125.3	145.9	134.0
Mean		125.7	124.9	119.6	139.9	127.5
Overall mean		123.3	123.8	118.5	138.6	126.1

Absolute control –149.3 mg kg^{-1}

Level	Mean		
1	121.3	C.D (P)	1.09
2	123.6	C.D (L)	1.08
3	133.3	C.D (M)	1.06

Table 19. Effects of levels of P and amendments on Al- P (mg kg^{-1}) 30 days after sowing

Method / level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	153.5	137.1	157.0	151.7	149.6
	L2	127.6	151.4	167.1	161.4	151.0
	L3	155.9	173.8	169.0	188.4	171.4
Mean		145.2	153.5	164.1	166.3	157.0
M2	L1	145.2	128.3	151.7	162.5	140.9
	L2	116.9	140.3	177.0	161.1	146.9
	L3	117.5	155.2	169.4	162.9	149.9
Mean		119.4	140.9	165.6	162.2	145.9
Overall mean		131.5	147.2	164.8	164.4	151.4

Absolute control –176.8 mg kg^{-1}

Level	Mean		
1	145.2	C.D (P)	1.08
2	148.9	C.D (L)	1.07
3	156.5	C.D (M)	1.05

The methods of application had a significant effect in reducing the Al-P fraction also. Band placement of phosphorus recorded a significantly small quantity of Al-P fraction (124.5 mg kg^{-1}) than that in thorough mixing of P fertilizers (127.5 mg kg^{-1}).

4.4.3.3. ^{32}P count in the Al-P fraction 15 days after sowing

The ^{32}P counts in the Al-P fraction, 15 days after sowing was significantly influenced by the application of amendments (Table 20). Application of *Pongamia* had a significant effect in reducing the ^{32}P counts in the Al-P fraction (528.4 cpm g^{-1}) than the treatments with and without amendments.

The levels of phosphorus also had a significant effect. The counts in the Al-P fraction had increased from 1909.9 cpm g^{-1} to 9397.2 cpm g^{-1} when the amount of phosphorus was increased from 15 kg ha^{-1} to 45 kg ha^{-1}.

The methods of application had no effect in the ^{32}P counts in Al-P fraction at this stage.

4.4.3.4. Al-P fraction 30 days after sowing.

The Al-P fraction had an increase at this stage when compared with the previous stage (Table 19). Application of *Pongamia* had the most significant effect in reducing the Al-P fraction (131.5 mg kg^{-1}) at this stage. Application of *Cleistanthus* also had a better effect in reducing the Al-P fraction (141.6 mg kg^{-1}) compared with the application of lime (158.5) which is also significantly superior to the treatment without any amendment (164.4 mg kg^{-1}).

The P content in Al-P fraction increased significantly when the levels of phosphorus applied was increased. The Al-P fraction increased from 145.2 mg P kg^{-1} to 156. 5 mg P kg^{-1} when the level of phosphorus applied increased from 15 to 45 kg ha^{-1}.

Band placement of phosphorus recorded more Al-P fraction (157 mg kg^{-1}) than thorough mixing of phosphorus with the soil (145.9 mg kg^{-1}) at this stage.

Table 20. Effects of levels of P and amendments on ^{32}P counts in Al- P ($cpmg^{-1}$) at 15 days after sowing

Method/ Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L 1	15.5 (1.19)	30269.1 (4.48)	11091.7 (4.05)	712.8 (2.85)	1386.8 (3.14)
	L2	683.9 (2.84)	12560.3 (4.10)	12971.8 (4.11)	13273.9 (4.12)	6194.4 (3.79)
	L3	20892.9 (4.32)	13396.8 (4.13)	14028.1 (4.15)	739.6 (2.87)	7345.1 (3.87)
Mean		605.3 (2.78)	17218.7 (4.24)	12647.4 (4.10)	1914.3 (3.28)	3981.1 (3.60)
M2	L1	12.1 (1.08)	39627.8 (4.59)	8669.6 (3.94)	10471.3 (4.06)	2630.3 (3.42)
	L2	849.2 (2.93)	13995.9 (4.15)	12764.4 (4.11)	20370.4 (4.04)	7447.3 (3.87)
	L3	9571.9 (3.981)	9375.6 (3.972)	27352.7 (4.137)	8491.8 (3.929)	12022.6 (4.080)
Mean		461.3 (2.66)	17298.2 (4.24)	14487.7 (4.16)	12589.3 (4.10)	6180.2 (3.79)
Overall mean		528.4 (2.72)	17258.4 (4.24)	13520.7 (4.13)	4909.1 (3.69)	4954.5 (3.69)

Level	Mean		
1	1909.6	C.D (P)	0.403
2	6792.0	C.D (L)	0.349
3	9397.2	C.D (M)	0.285

The data in the parenthesis are log-transformed values

Table 21. Effects of amendments and levels of phosphorus on ^{32}P counts in Al- P ($cpmg^{-1}$) at 30 days after sowing

Method/ Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L 1	420.7 (2.62)	22.9 (1.36)	7655.9 (3.88)	389.1 (2.59)	412.1 (2.62)
	L2	13931.6 (4.14)	3228.5 (3.51)	11324.00 (4.05)	14354.9 (4.16)	9246.9 (3.97)
	L3	19998.2 (4.30)	2564.5 (3.41)	31045.6 (4.49)	237.7 (2.38)	4405.6 (3.64)
Mean		4897.8 (3.69)	575.4 (2.76)	13899.5 (4.14)	1099.0 (3.04)	2558.6 (3.41)
M2	L1	430.5 (2.63)	15.8 (1.19)	6792.0 (3.83)	22961.5 (4.36)	1013.9 (3.01)
	L2	24..4 (1.39)	835.6 (2.92)	27164.4 (4.43)	200.9 (2.30)	578.1 (2.76)
	L3	550.8 (2.74)	12793.8 (4.11)	2147.8 (3.33)	2349.6 (3.37)	2443.4 (3.39)
Mean		179.5 (2.25)	553.4 (2.74)	7345.1 (3.87)	2213.1 (3.35)	1127.2 (3.05)
Overall mean		937.562 (2.972)	563.64 (2.751)	10115.79 (4.005)	1559.55 (3.193)	2089.29 (3.32)

Level	Mean		
1		C.D (P)	N.S
2		C.D (L)	N.S
3		C.D (M)	N.S

The data in the parenthesis are log-transformed values

4.4.3.5. ^{32}P counts in the Al-P fraction 30 days after sowing.

There was no significant difference among the levels and method of application at this stage with reference to the count rate of ^{32}P in Al-P fraction. However, incorporation of lime recorded a significantly higher count rate suggesting that lime induced precipitation of part of applied P as Al-P (Table 21).

4.4.4. Fe-P fraction

4.4.4.1. Fe-P fraction, just before sowing 15 days after incubation.

The treatments had a significant effect in reducing the Fe-P fraction (Table 13) The Fe-P fraction was reduced when compared with the initial soil sample after incubation. Application of *Pongamia* significantly reduced the Fe-P fraction (65.7 mg kg^{-1}) when compared with other treatments. However, the application of lime and *Cleistanthus* was significantly less effective in reducing the amount of Fe-P fraction (68.8 mg kg^{-1} and 70.7 mg kg^{-1} respectively) with reference to *Pongamia*. The highest quantity of Fe-P was recorded in treatment without any amendment (78.1 mg P kg^{-1} soil).

4.4.4.2. Fe-P fraction 15 days after sowing

The data (Table 22) show that application of amendments had a significant effect in reducing the Fe-P fraction in the soil at this stage. Application of lime had a significantly superior effect in reducing the Fe-P fraction (50.5 mg kg^{-1}) than the other treatments. Application of *Pongamia* also reduced significantly the Fe-P fraction (75.7 mg kg^{-1}) in comparison with the application of *Cleistanthus* (78.1 mg kg^{-1}) where there was increase in Fe-P, which in turn is on par with the treatment without the amendment (77.6 mg kg^{-1}) where there was no change in Fe-P. However, application of green manures, viz, *Pongamia* and *Cleistanthus* resulted in an increase in Fe-P when compared to that at just before sowing.

The application of phosphorus at different levels significantly increased the Fe-P fraction in the soil. The Fe-P fraction in the soil increased from

60.5 mg kg^{-1} to 80.4 mg kg^{-1} when the rate of application increased from 15 to 45 kg^{-1}.

Band placement of phosphorus recorded the Fe-P fraction (70.7) mg kg^{-1}, which is significantly more than that of thorough mixing of P fertilizer (70.1 mg kg^{-1}).

4.4.4.3. ^{32}P counts in the Fe-P fraction 15 days after sowing.

There was no significant difference among the treatments, and levels of phosphorus applied in this stage (Table 24). Band placement had a better significant effect in reducing the ^{32}P counts in the Fe-P fraction (42169.7 cpm g^{-1}) 15 days after sowing, than that obtained incase of thorough mixing of phosphorus with soil (56363.8 cpm g^{-1}).

4.4.4.4. Fe-P fraction 30 days after sowing

Application of all the amendments significantly reduced the Fe-P fraction. Among the amendments, lime was most effective (41.5 mg P kg^{-1}) followed by *Pongamia* (61.8 mg P kg^{-1}) and *Cleistanthus* (70.9 mg P kg^{-1}) in that order (Table 23).

The Fe-P fraction increased significantly with the levels of phosphorus. The Fe-P fraction increased from 55.6 to 66.5 mg kg^{-1} when the application of phosphorus increased from 15 to 45 kg ha^{-1}.

4.4.4.5 ^{32}P counts in the Fe-P fraction 30 days after sowing

Addition of lime significantly reduced the ^{32}P counts in Fe-P fraction (30.8 cpm g^{-1}) than the counts in all other treatments including that without any amendment (17947.3 cpm g^{-1})(Table 25).

Neither the application of *Pongamia* nor that of *Cleistanthus* gave significant reduction in ^{32}P counts in Fe-P fraction when compared the treatment without any amendment.

Both the levels of P as well as the methods of application did not give significant effect in reducing the count rate in Fe-P fraction.

Table22. Effects of amendments and levels of phosphorus on Fe-P (mg kg^{-1}) at 15 days after sowing

Method/ Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	71.7	68.9	38.9	69.8	62.3
	L2	76.2	80.1	46.5	76.9	69.9
	L3	81.6	92.1	61.2	85.9	80.2
Mean		76.5	80.0	48.9	77.5	70.7
M2	L1	78.2	56.1	40.2	69.9	58.6
	L2	70.2	74.0	52.6	78.2	68.8
	L3	86.2	87.2	63.5	84.9	80.5
Mean		74.8	76.2	52.1	77.6	70.1
Overall mean		75.7	78.1	50.5	77.6	92.7

Absolute control – 81.1 mg kg^{-1}

Level	Mean		
1	60.5	C.D (P)	1.27
2	69.4	C.D (L)	1.17
3	80.4	C.D (M)	0.56

Table23. Effects of amendments and levels of phosphorus on Fe-P (mg kg^{-1}) at 30 days after sowing

Method/level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	53.9	43.5	39.2	98.9	54.9
	L2	61.7	83.6	53.3	96.4	71.8
	L3	72.6	98.8	45.7	83.6	72.3
Mean		62.2	71.1	45.7	92.7	65.8
M2	L1	46.5	58.5	41.4	89.3	56.4
	L2	69.0	78.7	37.7	67.3	60.9
	L3	71.9	76.9	34.4	73.9	61.2
Mean		61.4	70.8	37.8	76.4	59.4
Overall Mean		61.8	70.9	41.5	84.1	62.5

Absolute control – 80.1 mg kg^{-1}

Level	Mean	
1	55.6	C.D (P) 1.12
2	66.1	C.D (L) 1.10
3	66.5	C.D (M) 1.09

Table 24. Effects of amendments and levels of phosphorus [32]P counts in the Fe- P ($cpmg^{-1}$) at 15 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	77624.7 (4.89)	109900.6 (5.04)	52239.6 (4.72)	12133.9 (4.08)	20464.5 (4.31)
	L2	74131.02 (4.87)	104472.0 (5.02)	46558.6 (4.67)	48640.7 (4.69)	77090.4 (4.89)
	L3	57147.9 (4.76)	89125.1 (4.95)	38459.2 (4.59)	45498.8 (4.66)	47533.5 (4.68)
Mean		69023.9 (4.84)	95060.5 (4.87)	20606.3 (4.31)	29922.7 (4.48)	42169.7 (4.63)
M2	L1	46344.7 (4.67)	95060.5 (4.98)	184501 (5.27)	41686.9 (4.62)	55718.6 (4.75)
	L2	(59156.2 (4.77)	69823.2 (4.84)	27989.8 (4.45)	39536.7 (4.59)	58076.4 (4.76)
	L3	71614.3 (4.86)	1690.4 (3.23)	12133.9 (4.08)	38018.9 (4.58)	55335.0 (4.74)
Mean		58076.4 (4.76)	95940.1 (4.98)	45396.2 (4.66)	39719.2 (4.59)	56363.8 (4.75)
Overall mean		63386.9 (4.802)	84333.5 (4.93)	30619.6 (4.49)	34514.4 (4.54)	48752.9 (4.69)

Level	Mean	
1	33728.7(4.53)	C.D (P) N.S
2	66988.5(4.83)	C.D (L) N.S
3	51286.1(4.71)	C.D (M) N.S

The data in the parenthesis are log-transformed values

Table 25. Effects of amendments and levels of phosphorus on ^{32}P counts in Fe- P ($cpmg^{-1}$) at 30 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	679.2 (2.832)	344.4 (2.54)	10423.2 (4.02)	1124.6 (3.05)	1285.3 (3.11)
	L2	14521.1 (4.162)	3732.5 (3.57)	13.0 (1.12)	42657.9 4.63	2344.2 (3.37)
	L3	377572.2 (5.577)	7277.8 (3.86)	1 (0)	23173.9 (4.37)	2824.9 (3.45)
Mean		15488.2 (4.19)	2103.78 (3.32)	51.4 (1.71)	10351.4 (4.02)	2041.7 (3.31)
M2	L1	810.9 (2.91)	3191.5 (3.50)	6324.1 (3.80)	31915.4 (4.50)	4786.3 (3.68)
	L2	12589.3 (4.10)	6606.9 (3.82)	1 (0)	29444.2 (4.47)	1250.3 (3.09)
	L3	22646.4 (4.36)	18967.1 (4.28)	1 (0.0)	32136.6 (4.51)	1927.5 (3.29)
Mean		6137.6 (3.79)	7362.1 (3.87)	18.5 (1.27)	31117.2 (4.49)	2259.4 (3.35)
Overall mean		9794.9 (3.99)	3935.5 (3.59)	30.8 (1.49)	17947.3 (4.25)	2147.8 (3.33)

C.D (P) 0.75

C.D (L) N.S

C.D (M) N.S

The data in the parenthesis are log-transformed values

4.4.5. Occluded P fraction

4.4.5.1. Occluded P fraction just before sowing 15 days after incubation

The occluded P fraction in the initial soil sample was 76 mg kg^{-1}. Application of amendments significantly reduced the occluded P fraction compared to the initial soil sample (Table 28). Lime had a significant effect in reducing the sesquioxide occluded P fraction (65 mg kg^{-1}), when compared with the other two amendments. However, application of *Pongamia* and *Cleistanthus* had a significantly better effect in reducing the occluded P fraction (73 mg kg^{-1} and 71 mg kg^{-1}) in comparison with the treatment without any amendments where the occluded fraction of phosphorus increased from the initial status.

4.4.5.2. Occluded P fraction, 15 days after sowing

The data in table 26 indicate that application of amendments significantly reduced the occluded P fraction 15 days after sowing. Lime is the most effective amendment (51.1 mg P) in reducing the sesquioxide occluded P fraction, which is followed by *Pongamia* and *Cleistanthus* (55.5 and 59.5 mg P kg^{-1} respectively). The treatment without amendment gave the highest amount of occluded P fraction (74.0 mg P kg^{-1}).

The occluded P fraction increased with increase in the rate of phosphorus applied. The P fraction increased from 44.4 to 75.1 mg kg^{-1} when the P level increased from 15 to 45 kg ha^{-1}.

Band placement of phosphorus recorded reduction in quantity in occluded P fraction (58.3 mg kg^{-1}) when compared with the thorough mixing of phosphorus with soil (61.7 mg kg^{-1}).

4.4.5.3. ^{32}P counts in the occluded P fraction, 15 days after sowing

Application of lime recorded a significantly less ^{32}P counts (1088.9 cpm g^{-1}) than the treatment without any amendment (10139.1 cpm g^{-1}) (Table 28).

Table26. Effects of amendments and levels of P on Occluded P (mg kg^{-1}) at 15days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	32.1	39.9	34.5	58.5	43.7
	L2	41.1	43.9	51.6	69.6	58.4
	L3	61.2	84.1	63.2	92.2	72.9
Mean		44.8	58.7	49.8	73.4	58.3
M2	L1	40.1	42.6	36.8	60.6	45.0
	L2	62.1	63.5	55.6	70.9	63.0
	L3	76.2	75.2	65.2	92.6	77.3
Mean		59.5	60.4	52.5	74.7	61.7
Overall mean		55.5	59.5	51.1	74.0	60.0

Absolute control – 71.5 mg kg^{-1}

Level	Mean	
1	44.4	C.D (P) 1.12
2	60.7	C.D (L) 1.10
3	75.1	C.D (M) 1.08

Table 27. Effects of amendments and levels of P on Occluded P (mg kg^{-1}) at 30days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	22.4	38.3	37.2	80.9	40.1
	L2	42.8	39.8	43.6	65.8	47.0
	L3	57.5	90.4	101.6	99.3	85.1
Mean		38.1	51.6	54.8	80.9	54.3
M2	L1	42.9	40.9	55.5	69.8	51.1
	L2	55.9	53.8	62.5	66.7	59.4
	L3	42.3	89.7	70.2	63.8	64.3
Mean		46.6	58.4	62.4	66.7	57.9
Overall mean		42.2	54.8	58.5	73.5	56.1

Absolute control – 75.1 mg kg^{-1}

Level	Mean	
1	45.3	C.D (P) 1.087
2	52.8	C.D (L) 1.132
3	73.9	C.D (M) 1.106

The levels of phosphorus had no significant influence in the ^{32}P counts at this stage. The method of application had no significant influence in the ^{32}P counts at this stage.

4.4.5.4. Occluded P fraction 30 days after sowing

Application of the amendments had a significant effect in reducing the occluded P fraction at this stage (Table 27). The quantity of occluded P in *Pongamia* incorporated soil was 42 mg kg^{-1} which is significantly lower than that obtained in *Cleistanthus* incorporated soils, followed by the occluded P content in lime treated soils(58.5 mg kg^{-1}). The Fe-P fraction in all the above-amended soils was significantly less than that obtained in non-amended soil.

The occluded P fraction increased with increase in the amount of P applied. The fraction of occluded P increased from 45.3 to 73.9 mg kg^{-1} when the amount of P applied increased from 15 to 45 kg ha^{-1}.

Band placement of phosphorus recorded 54.3 mg kg^{-1} of occluded P which is significantly less than that of Fe-P in the treatment where mixing of phosphorus (57.9 mg kg^{-1}) was done.

4.4.5.5. ^{32}P counts in the occluded P fraction, 30 days after sowing

The treatments, levels and methods of application had no influence on the ^{32}P counts in the occluded P fraction at 30 days after sowing.

4.4.6. Ca-P fraction

4.4.6.1. Ca-P fraction, just before sowing 15 days after incubation.

Ca-P fraction of the initial soil sample was 34.2 mg kg^{-1}. The data given in table 32 reveals that application of lime significantly increased the Ca-P fraction (39.6 mg P kg^{-1}) just before sowing at 15 days after incubation in comparison with the other treatments. Application of *Cleistanthus* did not give any significant effect on the Ca-P fraction when compared to the treatment without any amendment. The other two treatments namely lime and *Pongamia*

Table 28. Effects of amendments and levels of phosphorus on ^{32}P counts in the occluded P (cpm g^{-1}) 15days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	360.6 (2.56)	5741.2 (3.76)	568.9 (2.76)	5888.4 (3.77)	1621.8 (3.21)
	L2	10789.5 (4.03)	26485.0 (4.42)	143.6 (2.16)	7046.9 (3.85)	4120.9 (3.62)
	L3	28575.9 (4.46)	159.6 (2.20)	17139.6 (4.23)	11885.0 (4.08)	5520.8 (3.74)
Mean		4808.4 (3.68)	2897.3 (3.46)	1119.4 (3.05)	7906.8 (3.89)	3334.3 (3.52)
M2	L1	14.7 (1.17)	13899.5 (4.14)	4365.2 (3.64)	21183.6 (4.33)	2084.5 (3.32)
	L2	10000 (4.0)	10375.3 (4.02)	280.54 (2.45)	20323.6 (4.31)	4931.7 (3.69)
	L3	20323.6 (4.31)	13867.6 (4.14)	968.27 (2.99)	5105.1 (3.71)	6109.4 (3.79)
Mean		1442.1 (3.16)	12589.3 (4.10)	1059.3 (3.03)	13001.7 (4.11)	3971.9 (3.59)
Overall mean		2630.3 (3.42)	6039.5 (3.78)	1088.9 (3.04)	10139.1 (4.01)	(3.561)

Level	Mean	
1	1840.8(3.27)	C.D (P) 0.814
2	4508.2(3.65)	C.D (L) 0.705
3	5807.6(3.76)	

The data in the parenthesis are log-transformed values

recorded a significantly higher Ca-P fraction, lime treated soil recording the highest amount.

4.4.6.2. Ca-P fraction, 15 days after sowing

The data in table 29 revealed that application of lime had significantly increased the Ca-P fraction (73.3 mg kg^{-1}) when compared with the other treatments. However, application of *Pongamia* and *Cleistanthus* also showed a significant increase in Ca-P fraction (62.3 and 67.1 mg kg^{-1}) than the treatment without any amendment (51.1 mg kg^{-1}).

The Ca-P fraction increased with increase in the amount of phosphorus also. The Ca-P fraction showed an increase from 57.05 mg kg^{-1} (15 kg ha^{-1}) to 72.15 mg kg^{-1}) (45 kg ha^{-1}). The method of application also had a significant effect on Ca-P fraction. Band placement recorded a Ca-P fraction of 65.3 mg kg^{-1}, which is significantly higher than that obtained in case of thorough mixing of phosphorus (61.6 mg kg^{-1}).

4.4.6.3. ^{32}P counts in Ca-P fraction 15 days after sowing

The treatments, levels and method of application had no significant difference in this stage (Table 31).

4.4.6.4. Ca-P fraction 30 days after sowing

Application of lime resulted in an increase in Ca-P fraction (72.5 mg kg^{-1}), and is significantly superior to the other amendments at this stage (Table 30). Application other two treatments, viz., *Pongamia* and *Cleistanthus* (45.8 and 53.5 mg kg^{-1}) were superior in reducing the Ca-P than the treatment without any amendment (42.9 mg kg^{-1}).

The Ca-P fraction at this stage also increased with the rate of P application. The amount of Ca-P increased from 40.2 mg kg^{-1} (15 kg ha^{-1}) to 64.6 mg kg^{-1} (45 kg P_2O_5 ha^{-1}).

Table 29. Effect of amendments and levels of phosphorus on Ca- P (mg kg^{-1}), at 15 days after sowing.

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	63.54	54.6	55.4	57.2	57.7
	L2	60.26	71.2	65.8	47.4	61.2
	L3	80.5	80.2	97.2	49.6	76.9
Mean		68.1	68.7	72.8	51.4	65.3
M2	L1	39.1	58.8	81.2	46.4	56.4
	L2	53.2	72.2	69.6	49.6	61.2
	L3	77.2	65.6	70.4	56.4	67.4
Mean		56.5	65.5	73.7	50.8	61.6
Overall mean		62.3	67.1	73.3	51.1	63.6

Absolute control – 36.2 mg kg^{-1}

Level	Mean	
1	57.1	C.D (P) 1.121
2	61.2	C.D (L) 1.179
3	72.2	C.D (M) 1.144

Table 30. Effect of amendments and levels of phosphorus on Ca- P (mg kg^{-1}), at 30days after sowing.

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	39.6	68.6	68.6	28.3	42.9
	L2	48.2	58.8	76.6	48.4	58
	L3	63.8	64.6	81.8	49.4	64.9
Mean		49.0	54.3	75.7	42.0	55.3
M2	L1	28.9	22.6	59.2	38.9	37.4
	L2	44.5	63.8	67.0	43.2	54.6
	L3	54.4	71.8	81.8	49.4	64.4
Mean		42.8	52.7	69.3	43.8	52.1
Overall mean		45.8	53.5	72.5	42.9	53.7

Absolute control – 35.9 mg kg^{-1}

Level	Mean	
1	40.2	C.D (P) 1.164
2	56.3	C.D (L) 1.141
3	64.6	C.D (M) 1.114

Table 31. Effects of amendments and levels of phosphorus on ^{32}P counts in the Ca- P (cpm g^{-1}) at 15 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	26061.5 (4.42)	209.9 (2.32)	8433.4 (3.93)	9571.9 (3.98)	4581.4 (3.66)
	L2	8241.38 (3.92)	8241.4 (3.92)	11748.9 (4.07)	20511.6 (4.31)	11297.9 (4.05)
	L3	21037.8 (4.32)	5432.5 (3.74)	20137.2 (4.30)	15559 (4.19)	13740.42 (4.14)
Mean		16519.6 (4.22)	2108.6 (3.32)	12589.3 (4.10)	14521.1 (4.16)	8933.1 (3.95)
M2	L1	11297.9 (4.05)	12589.3 (4.10)	7888.6 (3.89)	15100.8 (4.18)	11402.5 (4.06)
	L2	13304.5 (4.12)	304.1 (2.48)	189.2 (2.28)	12941.9 (4.11)	1774.2 (3.25)
	L3	13427.7 (4.13)	14757.1 (4.17)	2917.4 (3.47)	11194.4 (4.05)	8974.3 (3.95)
Mean		12647.4 (4.10)	3337.1 (3.58)	1633.1 (3.21)	12971.8 (4.11)	5662.4 (3.75)
Overall mean		14454.4 (4.16)	2844.5 (3.45)	4528.9 (3.66)	13740.4 (4.14)	7112.1 (3.85)

Level	Mean	
1	7227.7 (3.86)	C.D (P) N.S
2	4477.13 (3.65)	C.D (L) N.S
3	11117.3 (4.05)	C.D (M) N.S

The data in the parenthesis are log-transformed values

The Ca-P fraction showed a significant increase when phosphorus was applied as band placement (55.3 kg ha^{-1}) than that incorporated by thorough mining with the soil (52.1 mg kg^{-1}).

4.4.6.5. ^{32}P counts in Ca-P fraction 30 days after sowing

No counts were recorded in samples from Ca-P fraction in the treatments, levels and methods of application at 30 days after sowing stage.

4.4.7. The organic P fraction

4.4.7.1. The organic P fraction just before sowing, 15 days after incubation.

The organic P fraction of the initial soil sample was 98.2 mg kg^{-1}. The amendments had a significant effect in improving the organic P fraction of the soil (Table 13). Incorporation of *Cleistanthus* was the most effective in increasing the organic P fraction (227.2 mg kg^{-1}) which was significantly superior to the other two treatments. Application of *Pongamia* also increased the organic P fraction (188.2 mg kg^{-1}) than that in lime (169.9 mg kg^{-1}) which in turn was significantly superior to the treatment without any amendment (103.0 mg kg^{-1}).

4.4.7.2. Organic P fraction, 30 days after sowing

The data in table 32 revealed that application of *Cleistanthus* significantly increased the organic P fraction (251.4 mg kg^{-1}) of the soil than the other treatments. Application of *Pongamia* recorded an amount of 203.6 mg kg^{-1} organic P. The organic P fraction of *Pongamia* (203.6 mg kg^{-1}) which is on par with that in lime treated soil (204.2 mg kg^{-1}). All these amendments were significantly superior in increasing organic P in comparison with that in soil without any amendment.

The application of phosphorus at 30 kg ha^{-1} recorded maximum organic P fraction (225.3 mg kg^{-1}) than the other two.

Band placement of phosphorus showed significantly higher organic-P fraction (219.4 mg kg^{-1}) than thorough mixing of phosphorus with the soil (209.8 mg kg^{-1}).

Table 32. Effects of amendments and levels of phosphorus on organic P (mg kg^{-1}) at 30 days after sowing.

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	221.3	238.2	177.0	192.3	207.2
	L2	190.5	267.3	226.9	207.9	223.2
	L3	218.3	274.8	216.8	201.8	225.2
Mean		210.0	260.1	206.9	200.7	219.4
M2	L1	192.7	234.9	103.8	185.4	179.4
	L2	220.8	243.8	234.4	210.9	227.4
	L3	177.8	249.5	266.6	196.8	222.6
Mean		197.1	242.7	201.6	197.7	209.8
Overall mean		203.6	251.4	204.2	199.2	214.6

Absolute control – 105.3 mg kg^{-1}

Level	Mean	
1	193.2	C.D (P) 1.041
2	225.3	C.D (L) 1.035
3	223.9	C.D (M) 1.029

Detectable levels of radioactive phosphorus could not be extracted from this fraction.

4.5. P content in plant

4.5.1. P content in the plant 15 days after sowing

Application of *Cleistanthus* increased the plant P content (0.073%) than the other treatments (Table 33). Application of lime recorded the plant P content of 0.068 per cent, which is on par with that in *Pongamia* (0.066%) and showed a significantly more P than that of the treatment without any amendment (0.057%).

The levels of phosphorus did not show any significant difference in the plant P content.

There was no significant difference among the methods of application at this stage.

4.5.2. ^{32}P counts in the plant 15 days after sowing

The data is given in table 35 showed that application of lime increased the plant ^{32}P counts (19498.5cpm g^{-1}) than the other treatments. Other treatments had not shown any significant difference among themselves in the ^{32}P counts.

Application of phosphorus at 30 kg ha^{-1} significantly increased the ^{32}P counts in the plant P (17418.1 cpm g^{-1}) than that at 15 kg P_2O_5 ha^{-1} application.

Methods of application had no significant difference in ^{32}P counts in the plant P at this stage.

4.5.3. P content in the plant 30 days after sowing

The data on table 34 revealed that application of *Pongamia i*ncreased the plant P content in a significant manner (0.092%) than the other treatments. However, application *Cleistanthus* also increased the P content (0.089%) which is on par with that in lime (0.089%) and showed a significantly higher content than that of the treatment with out any amendment.

Table 33. Effects of amendments and levels of phosphorus on P content in the plant (percentage) at 15 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	0.066	0.066	0.060	0.051	0.061
	L2	0.060	0.056	0.062	0.056	0.059
	L3	0.075	0.092	0.064	0.054	0.076
Mean		0.067	0.071	0.062	0.054	0.065
M2	L1	0.066	0.049	0.064	0.054	0.058
	L2	0.061	0.064	0.067	0.062	0.063
	L3	0.067	0.11	0.093	0.063	0.083
Mean		0.065	0.074	0.075	0.060	0.069
Overall mean		0.066	0.073	0.068	0.057	0.067

Absolute control – 0.046%

C.D (P) 0.011 C.D (L) N.S C.D (M) N.S

Table 34. Effects of amendments and levels of phosphorus on P content in the plant (percentage) at 30 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	0.086	0.085	0.083	0.080	0.083
	L2	0.105	0.093	0.093	0.080	0.093
	L3	0.096	0.093	0.100	0.091	0.095
Mean		0.096	0.090	0.092	0.083	0.090
M2	L1	0.084	0.088	0.078	0.075	0.081
	L2	0.091	0.095	0.080	0.085	0.088
	L3	0.088	0.080	0.103	0.084	0.089
Mean		0.088	0.087	0.087	0.082	0.086
Overall mean		0.092	0.089	0.089	0.082	0.088

Absolute control – 0.061%

Level	Mean		
1	0.082	C.D (P)	0.0054
2	0.091	C.D (L)	0.0048
3	0.092	C.D (M)	0.0035

Table 35. Effects of amendments and levels of phosphorus on ^{32}P counts in the plant (cpm g^{-1}) at 15 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	8974.3 (3.95)	656.2 (2.81)	12359.5 (4.09)	8830.8 (3.94)	5035.0 (3.70)
	L2	27039.6 (4.432)	24099.1 (4.38)	52480.8 (4.72)	14256.1 (4.15)	16595.9 (4.22)
	L3	12022.6 (4.08)	27164.4 (4.43)	33189.5 (4.52)	6039.5 (3.78)	15995.6 (4.20)
Mean		14288.9 (4.16)	7533.6 (3.87)	27797.1 (4.44)	9141.1 (3.96)	12852.9 (4.10)
M2	L1	6576.6 (3.81)	21777.1 (4.33)	8810.5 (3.94)	9862.8 (3.94)	10568.2 (4.02)
	L2	7533.6 (3.87)	8375.3 (3.92)	12618.3 (4.10)	21827.3 (4.33)	11481.5 (4.06)
	L3	11091.8 (4.04)	33265.7 (4.52)	22855.9 (4.35)	9862.8 (3.94)	13396.8 (4.21)
Mean		8184.7 (3.91)	18238.9 (4.26)	13645.8 (4.13)	12359.5 (4.09)	12589.3 (4.10)
Overall mean		10814.3 (4.03)	11721.9 (4.06)	19498.5 (4.29)	10616.9 (4.02)	12735.0 (4.10)

Level	Mean		
1	7294.6(3.86)	C.D (P)	0.246
2	17418.1(4.24)	C.D (L)	0.317
3	16255.5(4.21)		

The data in the parenthesis are log-transformed values

Table 36. Effects of amendments and levels of phosphorus on ^{32}P counts in the plant P ($cpmg^{-1}$) at 30 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	17988.7 (4.26)	54075.4 (4.73)	1606.9 (3.21)	23604.8 (4.37)	13867. 6 (4.14)
	L2	18197.1 (4.26)	27039.6 (4.43)	29040.2 (4.46)	30478.9 (4.48)	25703.9 (4.41)
	L3	50933.1 (4.71)	4677.4 (3.67)	11455.1 (4.51)	30269.1 (4.48)	21928.1 (4.34)
Mean		25527.0 (4.41)	18967.1 (4.28)	11455.1 (4.06)	27925.4 (4.45)	19860.9 (4.29)
M2	L1	11194.4 (4.05)	27065.8 (4.44)	42756.3 (4.63)	639.8 (2.80)	9571.9 (3.98)
	L2	21527.8 (4.33)	28313.9 (4.54)	43151.9 (4.64)	206.5 (2.32)	9036.5 (3.96)
	L3	78342.9 (4.89)	436.5 (2.64)	19815.3 (4.29)	55975.8 (4.75)	13961.7 (4.15)
Mean		26607.3 (4.43)	7498.9 (3.88)	33189.5 (4.52)	1945.4 (3.29)	10665.9 (4.03)
Overall mean		26061.54 (4.42)	11912.4 (4.08)	19498.5 (4.29)	7362.1 (3.87)	14554.6 (4.16)

Level	Mean	
1	11534.5(4.06)	C.D (P) 0.073
2	15240.5(4.18)	C.D (L) 0.618
3	17498.5(4.24)	C.D (M) 0.504

The data in the parenthesis are log-transformed values

The levels of phosphorus applied showed that the higher levels at 30 and 45 kg P ha^{-1} significantly increased the P content in comparison with that at P applied at 15 kg ha^{-1}. Band placement of phosphorus recorded a significantly higher plant P content (0.090) than that of thorough mixing of phosphorus with the soil (0.086%).

4.5.4. ^{32}P counts in the plant-P 30 days after sowing

The data on ^{32}P counts in the plant at 30 days after sowing showed that all the amendments were significantly superior to the treatment without amendment in increasing the plant P (Table 36). Among the treatments, lime and *Pongamia* were equally effective in increasing the plant P content followed by *Cleistanthus* application. Levels of applied P had no significant influence of ^{32}P counts in the plant P. Method of application also had no significant effect on plant P at this stage.

4.6. P fractions expressed as percent of total inorganic P

4.6.1. Soluble P

The percentage contributions of different P fractions to total inorganic P, extracted at different stages are presented in tables 37, 38, and 39. The soluble P fraction of the soils applied with *Pongamia* showed an increase from 3.5% at just before sowing stage to 8.5% at 15 days after sowing stage. Then it showed a reduction in soluble P fraction to 5.9% at 30 days after sowing.

In *Cleistanthus* amended soils, the soluble P fraction increased from 4.05% to 7.6% during the period of 15 days after sowing. The soluble P fraction then decreased to 5.7% at 30 days after sowing. The same trend was observed in lime-amended soils also. The soluble P fraction increased from 5.7% (just before sowing stage) to 11.5% (15DAS) and then decreased to 5.5% (30DAS).

4.6.2. Al bound P

The Al-P fraction contributed 43.9% total inorganic P initially. Al-P showed a slight increase from initial stage (43.9%) to just before sowing (45.8%) in case of soils amended with *Pongamia* and *Cleistanthus* (Table 42). The Al-P percentage of lime treated soils had not shown any change from the initial stage. The non-amended soil showed an increase to 44.5% at this stage.

At 15 days after sowing, percentage contribution of Al-P to total inorganic P had shown a decrease from just before sowing stage (Table 43). *Pongamia* applied soils recorded 35.6% Al-P, and *Cleistanthus* amended soils recorded 34.8% Al-P. Lime applied soils recorded 35.7 per cent Al-P at this stage.

At 30 days after sowing, Al-P increased in case of all the treatments. The Al-P fraction contributed 44% at this stage except in *Cleistanthus*. However, *Cleistanthus* also showed an increase from 34.8 %(15 DAS) to 41.6 %(30DAS) (Table 44).

4.6.3. Fe bound P

Percentage contribution of Fe-P in the initial stage was 25.4%. At just before sowing, amendments applied soils showed a decrease in Fe-P. *Pongamia* amended soils gave 21.5%, while *Cleistanthus* and lime applied soils recorded 23.6% and 23.2% Fe-P respectively. The non-amended soil showed 24.9% Fe-P at this stage (Table 42).

At 15 days after sowing stage, the percentage contribution of Fe–P in *Pongamia* and *Cleistanthus* applied soils was 21.9%. The percentage contribution of Fe –P in showed decrease in case of lime applied soils (15.2%) when compared with that in previous stage (Table 43).

The percentage contribution of Fe–P showed a decrease from 21.9% to 20.9% and 20.7% in *Cleistanthus* and *Pongamia* amended soils respectively at 30 days after sowing (Table 44). Lime applied soils recorded 14.03% of Fe-P at this stage and the percentage contribution of Fe–P in the treatment without any amendment was 21.7%.

4.6.4. Occluded P

Percentage contribution of Occluded P in the initial stage was 18.1%. At just before sowing application of *Cleistanthus* and lime reduced occluded P from 18.1% to 15.3 and 13.9% respectively (Table 42).

Table 37. P fractions expressed as percent of total inorganic P at just before sowing, 15 days after incubation

Soil	Sol-P (%)	Al-P (%)	Fe-P (%)	Oc P (%)	Ca-P (%)
P1(*Pongamia*)	3.5	45.8	21.5	17.9	11.0
P2 (*Cleistanthus*)	4.05	45.8	23.6	15.3	11.3
P3 (Lime)	5.7	43.9	23.2	13.9	13.2
P4(No amendment)	2.8	44.5	24.9	18.7	9.1

Table 38. P fractions expressed as percent of total inorganic P at 15 days after sowing.

Soil	Sol-P (%)	Al-P (%)	Fe-P (%)	Oc P (%)	Ca-P (%)
P1(*Pongamia*)	8.5	35.6	21.9	16.03	18.1
P2 (*Cleistanthus*)	7.6	34.8	21.9	16.7	18.9
P3 (Lime)	11.5	35.7	15.2	15.4	22.1
P4(No amendment)	4.4	38.9	21.7	20.7	14.3

Table 39. P fractions expressed as percent of total inorganic P at 30 days after sowing

Soil	Sol-P (%)	Al-P (%)	Fe-P (%)	Oc P (%)	Ca-P (%)
P1(*Pongamia*)	5.9	44	20.7	14.1	15.3
P2 (*Cleistanthus*)	5.7	41.6	20.9	16.1	15.7
P3 (Lime)	5.5	44.1	14.03	16.3	20.2
P4(No amendment)	2.7	43.8	22.4	19.6	11.4

At 15 days after sowing, Pongamia amended soils showed a decrease in occluded P (16.1%) while *Cleistanthus* and lime-applied soils showed an increase in occluded P (16.7% and 15.4% respectively) from the previous stage (Table 43).

At 30 days, after sowing, percentage contribution of occluded P had not shown much change in *Cleistanthus* and lime-applied soils. *Pongamia* amended soils showed decrease from 16.03% to 14.1% at 30 days after sowing. The non-amended soils also did not show much change in occluded P at this stage (Table 44).

4.6.5. Ca bound- P

Percentage contribution of Ca bound-P in the initial stage was 8.1%. Percentage contribution of Ca bound-P increased from 8.1 to 11 in case of *Pongamia* and *Cleistanthus* amended soils at just before sowing stage. Percentage contribution of Ca bound-P increased from 8.1 to 13.2 in case of lime amended soils at this stage.

Percentage contribution of Ca bound-P showed increase in all the treatments at 15 days after sowing. Application of *Pongamia* and *Cleistanthus* increased the percentage contribution of Ca bound-P (18.1% and 18.9% respectively).Lime application increased percentage contribution of Ca bound-P from 13.2 to 22.1% at 15days after sowing stage.

At 30 days, after sowing, percentage contribution of Ca bound-P had shown a reduction in all the treatments. Application of *Pongamia* and *Cleistanthus* decreased percentage contribution of Ca bound-P from that at 15 days after sowing to 30 days after sowing (15.3% and 15.7% from 18.1% and 18.9% respectively).Lime applied soil also showed a decrease in Ca bound-P from 22.1percentage to 20.2% at this stage

4.7.1. pH at 15 days after sowing

In case of lime-amended soils, the soil pH had come in to near neutral state at this stage. Other soils amended with green manures did not show any difference in pH (Table 40).

4.7.2. pH at 30 days after sowing

Application of lime increased the soil pH to near neutral state. Other amendments had not shown any significant effect in changing the soil pH at 30 days after sowing (Table 41). However, there was no appreciable change in pH from that at 15 days after sowing in corresponding treatments.

Table 40. Effects of amendments and levels of phosphorus on pH at 15 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)
M1	L1	5.4	5.5	6.5	5.4
	L2	5.2	5.4	6.6	5.3
	L3	5.3	5.4	6.4	5.3
Mean		5.3	5.4	6.5	5.3
M2	L1	5.3	5.6	6.5	5.3
	L2	5.3	5.5	6.4	5.2
	L3	5.4	5.5	6.3	5.1
Mean		5.3	5.5	6.4	5.2
Overall mean		5.3	5.5	6.5	5.3

Table 41. Effects of amendments and levels of phosphorus on pH at 30 days after Sowing

Method/ Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)
M1	L1	5.2	5.5	6.5	5.2
	L2	5.3	5.2	6.6	5.3
	L3	5.2	5.4	6.5	5.1
Mean		5.2	5.3	6.5	5.2
M2	L1	5.3	5.4	6.5	5.1
	L2	5.3	5.4	6.5	5.0
	L3	5.3	5.5	6.5	5.2
Mean		5.3	5.4	6.5	5.1
Overall mean		5.3	5.4	6.5	5.2

4.8.1. Percentage phosphorus derived fertilizer (pdff) at 15 days after sowing

The data on table 42 shows that application of amendments had a significant effect on influencing the pdff at 15 days after sowing. Application of *Pongamia* improved %Pdff significantly (18.4) which is on par with that in case of *Cleistanthus* (18.3). Application of lime also significantly increased the %Pdff (10.1) than that of the treatment without any amendment (9.3).

The %Pdff at this stage increased significantly with the rate of phosphorus application. The %Pdff increased from 10.5 to 15.8when the rate of P application increased from 15to 45 kg ha^{-1}.

The %Pdff showed a significant increase when the P applied through mixing (14.2) than in case of band placement (13.8).

Table 42. Effects of amendments and levels of phosphorus on Percentage phosphorus derived fertilizer (%Pdff) at 15 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	10.6	14.5	7.9	7.8	10.2
	L2	20.7	18.7	13.1	9.9	15.6
	L3	25.4	21.4	5.6	10.1	15.6
Mean		18.9	18.2	8.9	9.3	13.8
M2	L1	10.9	15.1	9.2	8.2	10.8
	L2	19.1	19.1	10.2	9.3	14.4
	L3	23.5	20.9	8.9	10.5	15.9
Mean		17.8	18.4	11.1	9.3	14.2
Overall mean		18.4	18.3	10.1	9.3	14.0

Level	Mean	
1	10.5	C.D (P) 0.348
2	14.9	C.D (L) 0.301
3	15.8	C.D (M) 0.246

4.8.2. Percentage phosphorus derived fertilizer (Pdff) at 30 days after sowing

Application of amendments had a significant effect on influencing the pdff at 30 days after sowing (Table 43). Addition of *Pongamia* had significantly the best effect in increasing the pdff at 30 days after sowing (20.5%). Incorporation of *Cleistanthus* (15.5%) improved %Pdff significantly, which is on par with that in case of lime (15.4%), than that of the treatment without any amendment (7.9%).

The %Pdff increased from 11.0% to 21.3% when the rate of P application increased from 15 to 45 kg ha^{-1}.

The %Pdff showed a significant increase when the P applied through mixing (15.6%) than in case of band placement (14.1%).

Table 43. Effects of amendments and levels of phosphorus on Percentage phosphorus derived fertilizer (%Pdff) at 30 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	9.2	25.2	11.2	6.2	12.9
	L2	16.8	9.8	9.5	7.6	10.9
	L3	38.7	9.3	16.1	8.9	18.3
Mean		21.6	14.8	12.3	7.6	14.1
M2	L1	9.4	9.8	10.1	7.1	9.1
	L2	15.2	13.1	16.2	8.2	13.2
	L3	33.7	26.6	28.9	9.5	24.4
Mean		19.4	16.2	18.4	8.3	15.6
Overall mean		20.5	15.5	15.4	7.9	14.8

Level	Mean	
1	11.0	C.D (P) 0.705
2	12.1	C.D (L) 0.610
3	21.3	C.D (M) 0.498

4.9.1. A and L value at 15 days after sowing

The data on table 44 revealed that maximum A value was obtained for lime amended treatments (4.1) followed by non-amended soil (3.9), *Cleistanthus* incorporated soil (2.9) and *Pongamia* incorporated soils (2.7) in that order.

Higher levels of labeled P fertilizer gave a constant A value (2.6) in *Pongamia* amended soils. However, other two amendments as well as non-amended soil gave highly fluctuating A values at higher levels of applied P at this stage.

In case of L value, the data revealed that lime treatment could significantly increase the L value (5.1). Incorporation of the other amendments as well as no amendment was significantly inferior to liming.

Table 44. Effects of amendments and levels of phosphorus on A and L value at 15 days after sowing

Method/Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	2.9	1.9	5.4	4.3	3.7
	L2	2.6	3.1	2.0	2.4	2.5
	L3	2.6	3.8	4.9	4.9	4.1
Mean (A value)		2.7	2.9	4.1	3.9	3.4
M2	L1	4.1	4.4	5.4	3.5	4.4
	L2	5.4	5.5	5.2	4.5	5.2
	L3	4.2	2.8	4.7	5.3	4.3
Mean (L value)		4.6	4.2	5.1	4.4	4.6

Level	Mean		
1	4.0	C.D (T)	1.61
2	3.8	C.D (T)	1.40
3	4.2	C.D (T)	1.14

Table 45. Effects of amendments and levels of phosphorus on A and L value at 30 days after sowing

Method / Level		P1 (*Pongamia*)	P2 (*Cleistanthus*)	P3 (Lime)	P4 (No amendment)	Mean
M1	L1	1.1	3.6	8.4	3.5	4.3
	L2	4.3	5.7	2.6	4.9	4.4
	L3	4.2	8.8	4.6	3.4	5.3
Mean (A value)		3.5	6.0	5.2	3.9	4.7
M2	L1	3.2	3.2	4.7	1.8	3.2
	L2	5.1	6.6	4.9	2.2	4.7
	L3	2.0	8.3	3.5	2.9	4.2
Mean (L value)		3.4	6.0	4.3	2.3	4.0

Level	Mean	
1	3.75	C.D (T) 0.097
2	4.6	C.D (L) 0.083
3	4.75	C.D (M) 0.069

5.9.2. A and L value at 30 days after sowing

At 30 days after sowing stage, A and L values were highest in treatment with *Cleistanthus* incorporation (Table 45). In case of lime A values obtained was significantly lower than that in *Cleistanthus* incorporation. In non-amended soil the A value obtained was 3.9 at this stage. In *Pongamia* incorporated soil, A value remained almost constant for the lower levels of fertilizer application, while increased significantly at the highest dose of fertilizer (45 kg ha^{-1}). Highest value for labile pool was obtained at 30 kg ha^{-1}.

Discussion

5. Discussion

The results of the present study presented in Section 4 are discussed critically with supporting evidences as well as the related studies from the literature. Five bench mark soils, all of them coming under Ultisols, have been characterised initially. This was carried out with the objective of understanding the relationship, if any, of the electrochemical properties and phosphorus supplying capacity of these soils.

5.1. Electrochemical properties and available nutrient status

The data on electrochemical properties given in table 3 showed that all the five soils were acidic in reaction with a variation in pH from 4.6 to 5.8. The EC of these soils was very low ranging between 0.05 to 0.1 dSm^{-1}. The organic carbon content indicated that three of the soils namely Kunnamangalam series, Pattambi soil and Thirumittakkodu soil were low and remaining two were medium (Angadippuram series and Vellanikkara series) in organic carbon and hence in nitrogen status. With respect to available K status, Kunnamangalam series, Angadippuram series and Pattambi soil were medium and Vellanikkara soil Thirumittakkodu soil were of high fertility. These soils were very high in available Fe and Mn and high in Cu while only soils Pattambi soil and Thirumittakkodu soil are below the critical level (1 mg kg^{-1}) in case of HCl extractable Zn.

5.2. Exchangeable cations, CEC and AEC

The data on exchangeable cations in table 4 revealed that the most dominant cation on exchange sites in all the five soils was Ca^{2+} contributing nearly 50% or more of the CEC [range 0.76 to 2.89 cmol(p+)kg^{-1}] followed by Na^{+} and K^{+} in that order. Exchangeable Al^{3+}, Mn^{2+}, and Mg^{2+} showed similar ranges in these soils with Al and Mn often exceeding the values of exchangeable Mg^{2+}. The contribution of Cu^{2+}, Fe^{2+} and Zn^{2+} were negligible to the exchange surface.

The CEC of these soils were very low ranging from 3.0 to 4.8 cmol (p+)kg^{-1} . The AEC values were on higher range [10 to 13 cmol (e^{-}) kg^{-1}]. These results are as expected because these soils are dominated by kaolinitic clay.

5.3. Availability indices of Phosphorus

5.3.1. P fixing capacity and available P

The data on P fixing capacity and available P of the above five soils given in table 5 indicated that, the P fixing capacity of these soils was very high ranging from 87 to 92 %. The available P level varied from 3.7 to 20 mg kg^{-1}. The data also revealed that three of the five soils (Kunnamangalam series Angadippuram series, Vellanikkara soil and Pattambi soil) were high in available P status (with > 25 kg ha^{-1}) while Thirumittakkodu soil was medium in P (10-25 kg P ha^{-1}). Only Vellanikkara soil was rated low in P status with 8.2 kg ha^{-1} (< 10 kg ha^{-1}). High P fixing capacity is an indication of low P utilization of applied P as major amount of applied P may get fixed making it unavailable to plants. Similar results were obtained by Seena (2000). High P fixing capacity along with low available P status accentuates the problem of P fertilisation as even under deficiency, there is every possible chance of getting no response to applied P unless and until the applied quantity meets the saturation level of P fixation. It is under these circumstances; the Vellanikkara soil with highest P fixing capacity (91.6%) and with lowest level of available P (3.7 mg kg^{-1}) among the five soils, was selected for pot culture experiment.

5.3.2. Soil P Fractions

The data on inorganic fractions of P *viz.* soluble P, Al-P, Fe-P, sesquioxide occluded P (Reductant Soluble P), and Ca-P which were extracted sequentially, and the organic P, in the above said soils are presented in table 5. The data indicated that among the fractions, Al-P and then Fe-P (except in Pattambi soil where Fe–P supersedes Al-P) were the predominant forms in which phosphorus existed in the soils under study. It seems there existed a dynamic relation between the other three fractions *viz*. soluble P, occluded P and Ca-P. Among these three

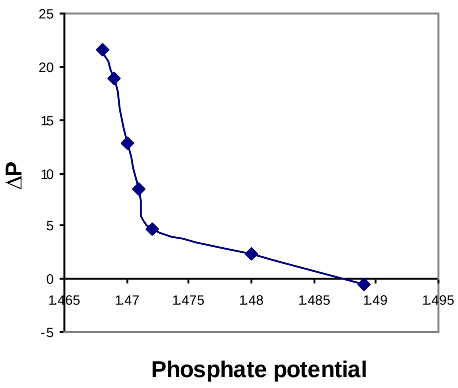


Fig 2a. Kunnamangalam series

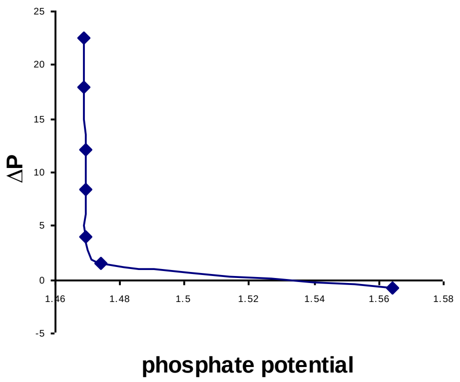


Fig 2b. Angadippuram series

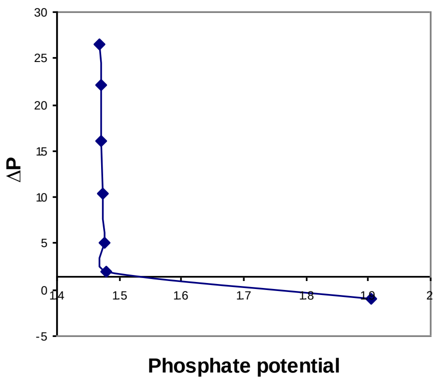


Fig 2c. Vellanikkara series

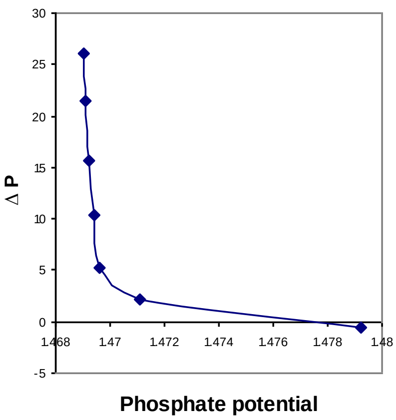


Fig 2d. RARS Pattambi soil

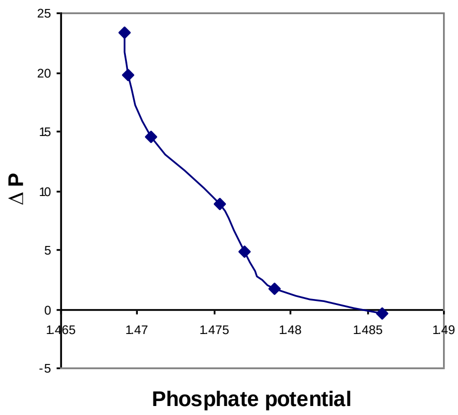


Fig 2e.Thirumittakkodu soil

Fig 2. Quantity - Intensity curves for the selected benchmark soils

fractions, as the soluble P was lowest in Vellanikkara soil (soil taken for pot culture where total P was also the lowest) where occluded P was high while when occluded P was lower as in Pattambi and Thirumittakkodu soils, soluble P was higher. This was further substantiated by the data on percentage contribution of different inorganic P fractions to total inorganic phosphorus (Table 6). For example, Al-P contributed 43.9% followed by Fe-P (25.4%), occluded P (18%) and Ca-P (8.1%) and the least by soluble P (4.6%) in Vellanikkara soil series. It was also observed that, in Pattambi and Thirumittakkodu soils, occluded P contributed only about 2 to 3 percentage, where soluble P contributed 10-13% of the total inorganic P. The organic P was lowest again in Vellanikkara soil (98.3 mg kg^{-1}). So also was the case of total P (605.3 mg kg^{-1}).

5.3.3. Quantity – Intensity Studies

The data generated by incubation experiment on P sorption were used to compute the Q-I parameters. The amount of P adsorbed/desorbed at varying concentrations of added P was expressed as Δ P(mg kg^{-1}) and based on the activities of $H_2PO_4^-$ and Ca^{2+} in solution, phosphate potential (1/2 pCa + pH_2PO_4) was computed and was expressed as relative intensity factor(Δ I).These data are provided in table 4 and the curves are depicted in Fig. 2. Equilibrium phosphate potential (EPP) was obtained from the Q-I curve which is defined as the phosphate potential when there is neither adsorption nor desorption. The phosphate potential is an indication of P supplying power of the soil.

Accordingly, the data in table 6 gives the EPP and buffer power (buffer power was computed as the change in amount of P adsorbed/ desorbed with respect to change in activity of $Ca(H_2PO_4)_2$. The values for EPP were approximately 1.47, practically same for all the five soils. Buffering capacity for Kunnamangalam, Angadippuram and Vellanikkara soils were similar, while that for Pattambi and Thirumittakkodu soils were slightly lower (1.73). This would suggest that the phosphate supplying power of the five soils coming under Ultisol, lateritic in origin, dominated by 1:1 Kaolinitic type of mineral followed almost

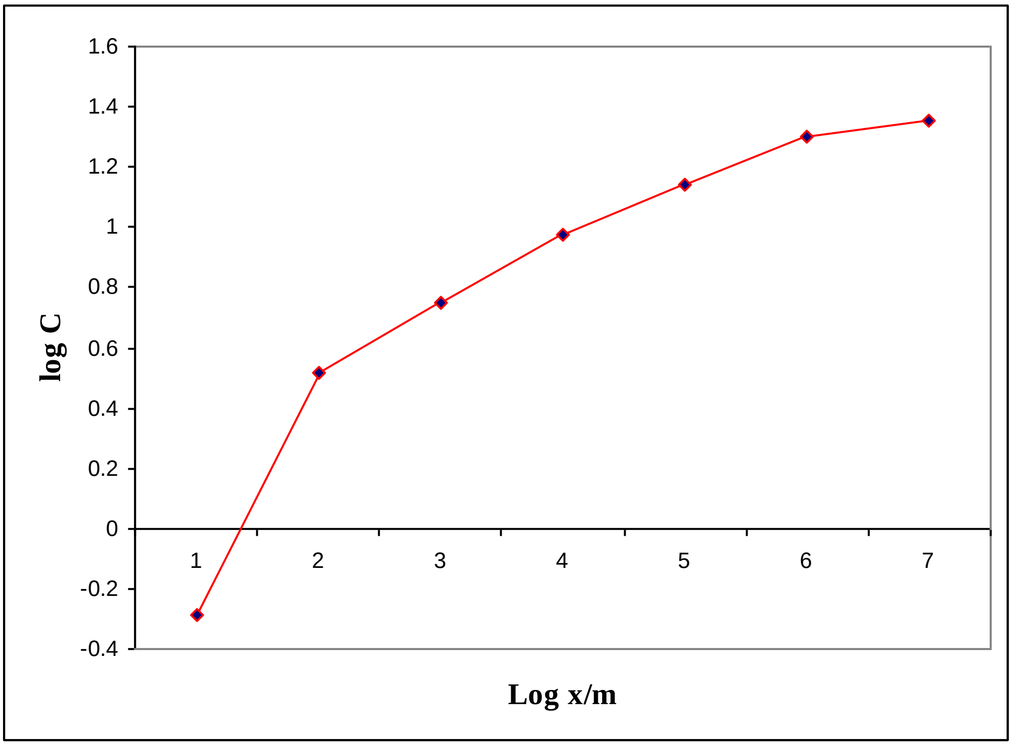


Fig 3. Freundlich isotherm (Kunnamangalam series)

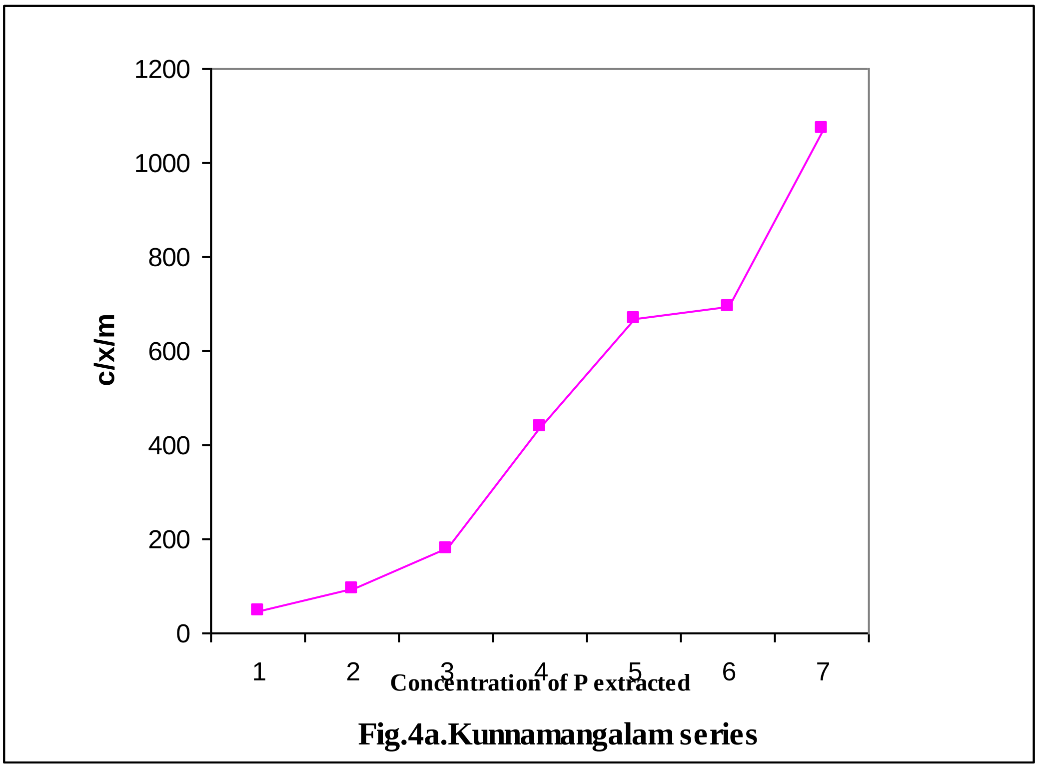


Fig 4. Langmuir isotherms for the selected soils

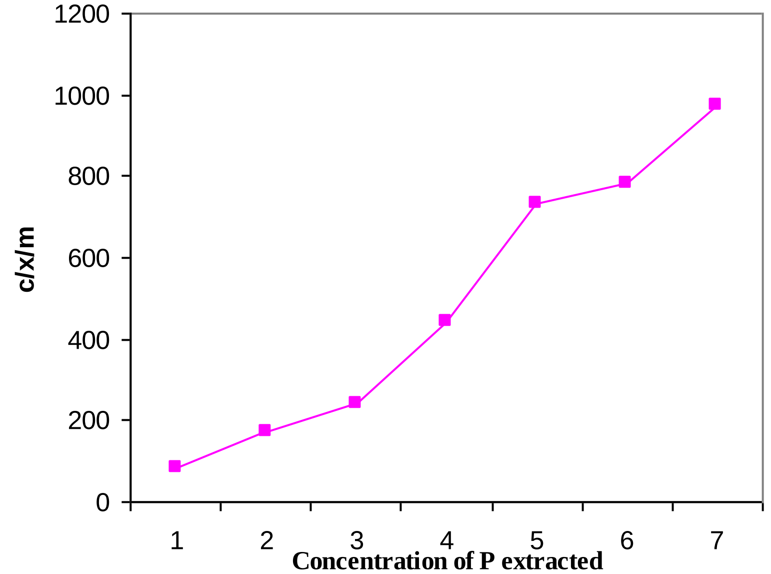


Fig 4b.Angadippuram series

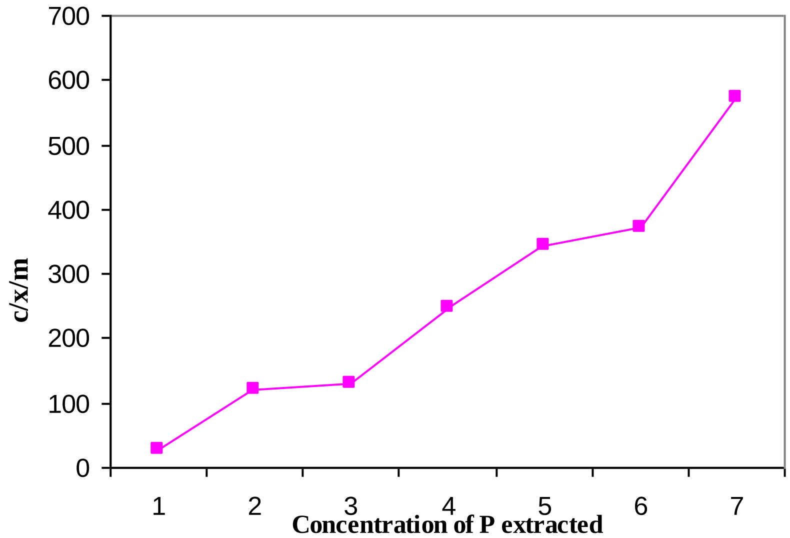


Fig 4c.Vellanikkara series

Fig 4. Langmuir isotherms for the selected soils

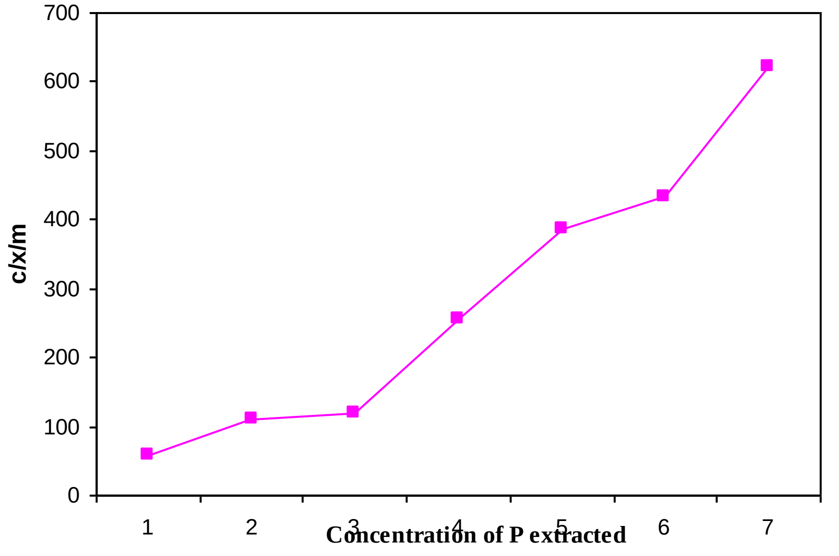


Fig4d.Pattambi soil

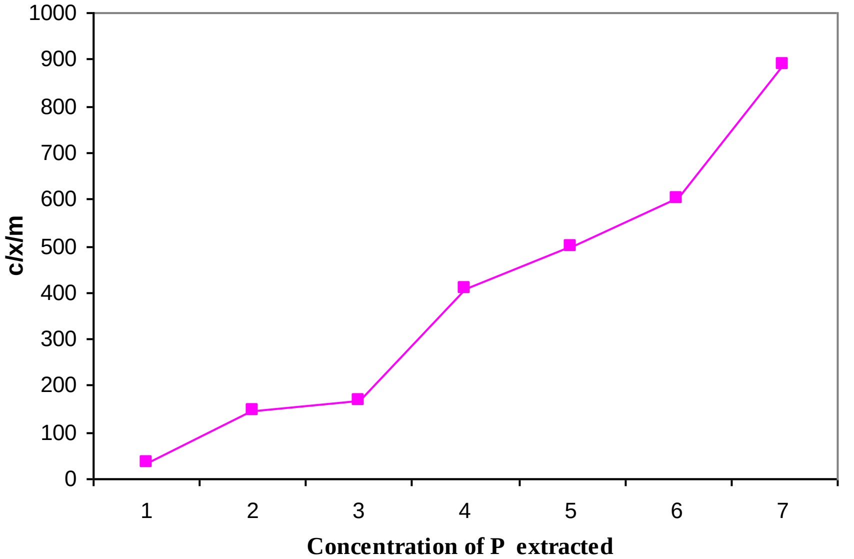


Fig.4e.Thirumittakkodu soil

Fig 4. Langmuir isotherms for the selected soils

similar pattern and was dictated by the amount of P adsorbed as well as the relative intensity factor.

These data on adsorption studies were used to get best fit curves using Langmuir and Freundlich adsorption isotherms. Only one soil (Kunnamangalam soil) (Fig.3.) followed Freundlich adsorption isotherm. Remaining four soils failed to follow Freundlich equation. Freundlich equation, i.e. $x/m=KC^{1/n}$ describes adsorption as a function of concentration alone. It is silent about the maximum possible adsorption by the solid phase of the soil. Thus it is clear that this equation is applicable only at lower concentrations in soil system and hence lesser amounts of P being adsorbed. This might be the reason why majority of the soils did not follow this equation with respect to P adsorption, especially the soils of lateritic origin dominated by kaolinitic clay with high P fixing capacity.

All the five soils gave best fit curves for Langmuir equation i.e. x/m=KMC/1+KC (Table 6 and fig.4.). More than 90% of the variability could be explained in Vellanikkara soil, Pattambi soil and Thirumittakkodu soils, when the data were fit in Langmuir equation. In the remaining two soils – Kunnamangalam and Angadippuram series, only 26 and 50 percentage of the variability could be explained probably be cause of the low adsorption maxima (~11mg kg^{-1}). On the other hand, for soils from Vellanikkara, Pattambi and Thirumittakkodu, the adsorption maxima were 182, 143, 97 mg kg^{-1} respectively. An opposite trend was observed in case of bonding energy coefficient i.e. values were 10 times less (about 003 to 0.04 mL g^{-1})(similar results were obtained by Muralidharan *et a*l. (1999) in Kuttanad soils.) in these three soils compared to Kunnamangalam and Angadippuram series indicating more spontaneity of adsorption reaction in these three soils. Thus it is clear that the adsorption pattern in Vellanikkara, Pattambi and Thirumittakkodu soils were in agreement with monolayer adsorption following Langmuir equation and that most of the adsorption sites in these soils are similar in nature and hence well suited to linear type of Langmuir equation.

5.4. Pot culture experiment

Among the five soils for which availability indices discussed above, the Vellanikkara soil which recorded the lowest available P, soluble P (3.7 and 19.2 mg kg^{-1} respectively), the highest P fixing capacity (91.3%) and maximum adsorption(182 mg kg^{-1}) as per Langmuir equation. Based on the above characteristics this soil was expected to have problem with P nutrition and hence selected for pot culture experiments.

The treatments involving three levels of phosphorous, four sources of amendments, and two methods of application as detailed in Chapter-3 where superimposed before sowing cowpea seeds. The soils with amendments namely, leaves off *Pongamia* (P_1), *Cleistanthus* (P_2), lime (P_3) and the one without any amendment(P_4) were incubated for 15 days after application of the treatments. Soil samples were drawn after the incubation period. The labeled P fertilizer in required quantities as per treatments were then added and the seeds were sown. Sampling - both the soil and plant – was done 15 and 30 days after sowing.

5.4.1. Available P

5.4.1.1. Available P just before sowing, 15 days after sowing

Initially the available P was 3.7 mg kg^{-1} which was improved to 4.2 to 4.6 mg kg^{-1} due to incubation with or without amendment (Table 8). The data indicated that though the available P status was increased due to incubation, significant contribution were not from any of the amendments since the available P between the treatments did not differ significantly. Similar results were obtained by Smitha (2005)

5.4.1.2. Available P at 15 days after sowing

At 15 days after sowing, the amendments improved the available P status substantially while the available P did not change from the initial status in case of treatment without any amendment (Table 9). The maximum increase in available P was in the case of lime incorporated treatments. The green leaves of *Pongamia* and *Cleistanthus* also increased the available P status. In case of lime treated pots the increase in availability of P could be stated as a result of increase in pH (5.4 to 6.5). It is further reminded here that the amount of lime applied (9.1 t ha^{-1}) was to meet the lime requirement to raise the pH to 6.5. Available P level also increased in the case of treatment with green leaf manures where the pH was not changed, indicating that these manures might have either contributed to the available pool by themselves or might have solubilised the insoluble fractions of inorganic P.

Available P increased with respect to increase in applied P. Similar results were also obtained by Viswambharan (1995).

Band placement was found to be significantly superior to thorough mixing of the fertilizer and this might be due to exposing applied P for fixation and reversion. However available P status in both the cases was much higher than the initial level.

5.4.1.3. ^{32}P counts in the available P pool at 15 days after sowing

Since radioactive P (^{32}P) was labeled to the applied KH_2PO_4, the counts of radioactive P expressed as counts per minute (cpm g^{-1}) of soil in the extract containing the available P (Bray No.1 extract) was recorded (Table 11). The highest count 253.5 cpm g^{-1} was obtained in treatment without any amendments. The counts in amended soils were significantly lower with lime recording 55.5 cpm g^{-1}, followed by *Cleistanthus* 21.2 cpm g^{-1} and *Pongamia* 18.5 cpm g^{-1}, the latter two, being comparable. The applied ^{32}P in soluble form might have immediately equilibrated with the labile pool of P which includes both solution P and surface P. In treatment without any amendments the labile P thus contributed to higher counts. But the data on Bray No.1 extractable P at this stage was not in agreement with the counts of ^{32}P. This requires further investigation as certain replication of the amended soil did not record any counts at all.

The amendments when compared among themselves, lime recorded the highest count followed by *Cleistanthus*, and then by *Pongamia* perfectly in agreement with the data on available P at this stage.

As the level of fertilizer was increased, count rate also increased in the same manner as that of available P.

5.4.1.4. Available P at 30 days after sowing

The trend on available P status at this stage was similar to that at 15 days after sowing (Table 10). Application of lime slightly improved the available P to 7.6 mg kg^{-1} when compared with the same at 15 days after sowing (6.9 mg kg^{-1}). Though the pH was not changed due to application of *Cleistanthus* leaves, it did increase the P status to 7.4 mg at 30 days after sowing. Application of *Pongamia* leaves also showed the same trend but was not improving the available P status as that of lime or *Cleistanthus*. In case of treatment without any amendment, there was a slight decrease in available P status from that of the initial soil. Shivanna *et al.* (1996) reported an increase in available P by the incorporation of *Pongamia* leaves.

At this stage also increased level of applied P significantly improved the available P. The increased available P content with increased levels of applied P was obtained by Kumaraswamy (1981), Sadanadan and Hamza (1996), Uppari *et al*. (1995) and Anilkumar, (1999). The methods of application did not differ significantly in changing the available P.

5.4.1.5. ^{32}Pcounts in the available P 30 days after sowing

At this stage also highest count was obtained for treatment without any amendment and the lime amended soil gave the lowest count. This contrasting trend in available P and ^{32}P counts in Bray No.1 extract, points to the possibility of applied P not directly contributing to the Bray extractable fraction (Table 12).

Correlation studies of available P with different inorganic P fractions gave significant negative correlations with inorganic fraction Al-P at 15 days after sowing (*0.214) and Fe-P (*-0.320) at 30 days after sowing. Similar results were recorded by Jenkins (1996) and Jose (1973). This should be viewed in conjunction with the fact that Al-P and Fe-P fractions constituted nearly 60% or more of the total inorganic P. The Bray No.1 extractant partially extracts P from the pools of

Al-P, and Ca-P along with soluble and surface P. At the same time as per isotopic dilution principles (Russel *et al*. 1954) applied ^{32}P with or without carrier directly equilibrates with only surface and solution P. It was also reported that isotopic exchange method is unsuited for soils with high P sorption capabilities and low solution P concentrations. In brief it is clear from the above facts that the ^{32}P counts in Bray extractable P need not give an indication of available P because the available P extracted by Bray No.1 and ^{32}P in this extract are not coming from the same pool.

Neither the levels of P nor the methods of application differ significantly with respect to ^{32}P counts in the available P pool (Table 12).

5.4.2. Fractions of phosphorus in soil

The soil samples drawn at 4 stages were analysed for different inorganic P fractions as well as organic P whereas radio assay was carried out in case of samples drawn at 15 and 30 days after sowing.

5.4.2.1. Soluble P just before sowing, 15 days after incubation with amendments.

In comparison with the initial soil sample, soluble P decreased after the incubation (Table 13). The soluble P fraction in amended soils was significantly higher in quantity than that in the non amended soil. This would mean that amendments, whether it was lime or green leaf manures, had a positive influence over non amended soil in maintaining the soluble P level.

5.4.2.2. Soluble P 15 days after sowing

At 15 days after sowing the increase in soluble P was highest in lime amended soil (38.1 mg kg^{-1}) which was significantly superior to *Pongamia* and *Cleistanthus* (29 and 20.85 respectively). The soils without any amendment was far below (15.7 mg kg^{-1}) when compared to the treatments with the amendments (Table 14).

This increase in soluble P during incubation viewed in conjunction with the decrease in Al-P with a corresponding increase in Ca-P and Organic

P(similar results were obtained by Bapat, *et* al. 1965) suggest that the pathway of P transformation took route from insoluble forms of Al-P and Fe-P gradually through Ca-P and probably through organic P enriching the soluble P. A significant negative correlation of available P with Al-P and a significant positive correlation of soluble P with available P further indicated that it was the solubilisation of Al-P resulting in an increase in soluble P there by increasing the available P.

The effect of improving the solubility of P fraction by lime through increasing pH to near neutrality is clearly established from the data. Increase in rate of application contributed to an increase in soluble P. However method of application had no significant influence.

5.4.2.3.^{32}P counts in soluble P at 15 days after sowing

The data on ^{32}P counts in soluble P fraction (Table 16) revealed that lime treated soils recorded the highest count rate followed by *Cleistanthus* and *Pongamia*. The count rate did not differ significantly at this stage with increase in rate of P application. Methods of application did not differ significantly.

The results on radioactive P counts revealed that *Cleistanthus* applied soils recorded the highest count rate which was on par with that of soils amended with *Pongamia*. The data on soluble P at this stage indicated the effect of *Cleistanthus* in improving the soluble P. This might be due to solubilisation of P by organic acids produced as a result of decomposition. However the soluble P and count rate of radio active P revealed that all the soluble P might have come both from native and applied P. This would further means that lime might have caused more solubilisation of native P in comparison with the other amendments, while green leaves of *Cleistanthus* and *Pongamia* influenced the soluble P levels from applied P.

5.4.2.4. Soluble P 30 days after sowing

The quantity of soluble P decreased considerably from that at 15 days after sowing. But it was higher than the initial values (Table 15). The decrease might be due to either plant uptake or due to reversion to insoluble forms. Here also lime amended soil recorded the highest value which was (19.7) on par with that in *Cleistanthus* amended soil. The soil without amendment recorded the lowest value.

5.4.2.5. ^{32}P counts in the soluble P fraction at 30days after sowing.

Though the soluble P fraction at 30 days decreased from that at 15 days in general (Table 17), it is interesting to note that the count rate substantially increased at 30 days. This would again establish that the contribution to soluble P at this stage was not directly from native P as the native P might have reverted back reducing the concentration of P in solution. Simultaneously there might be transformation of applied P to soluble P via Al-P which in fact increased the count rate.

5.4.3. Al-P fraction

5.4.3.1. Al-P fraction just before sowing, 15 days after incubation

The Al-P fraction initially was 185 mg P kg^{-1}. The amount of P in this fraction decreased considerably during the period of incubation (Table 13). Amending the soil with lime caused significant reduction in the amount of Al-P fraction i.e. 185 to 133 mg kg^{-1}. Similar results were obtained by Ogutoyinibo, (1996.). This was due to precipitation of Al, as its hydroxides as the pH increased from 5.4 to 6.5 as a result of lime application. Further, this resulted in increased concentration of Ca which might have caused the formation of Ca-phosphate as revealed by the data on change in Ca-P from 34 to 39.6 mg kg^{-1}. During this period, major amount of phosphorus in Al-bound pool got immobilized to organic form which is revealed by the substantial increase in organically bound P during the period of incubation. In general there was a substantial decrease in Al bound P during incubation irrespective of the treatments with and without amendments.

5.4.3.2. Al-P fraction 15 days after sowing

The data on Al-bound P 15 days after sowing (Table 18) clearly indicated that lime could further reduce the amount of P in this fraction to about

120 mg kg^{-1}. The other two amendments in terms of green leaves i.e. *Pongamia* and *Cleistanthus* came next in reducing the Al-bound P. The Al-P fraction in non amended soils remained unchanged during this period. During this time, there was a significant increase in Ca bound P and organic P which are also not in soluble form. However, it can be released slowly to the soluble form depending up on the environment.

It was observed that the Al bound P fraction increased with increase in amount of P applied. Similar observations were made by Kumaraswamy (1981). However the rate of increase was significantly lower in lime amended treatments. Both the green leaf manures were on par while in non amended treatment, there was no change in Al bound P.

The placement of KH_2PO_4 near the root zone in band recorded a significant decrease in Al-P fraction in comparison with thorough mixing of P fertilizer.

5.4.3.3. ^{32}P counts in the Al-P fraction at 15 days after sowing

The data on radio active P in Al-bound P fraction (Table 20) revealed the following facts. Lowest count rate was obtained in Pongamia amended samples, whereas the highest was in *Cleistanthus* applied soils followed by lime treated soils. This observation points to the fact that the effect of two green leaf manures i.e. *Pongamia* and *Cleistanthus* were totally different in governing the fate and dynamics of applied P. This may be due to the effect of different decomposition product obtained on degradation of these two green manures. The products formed from *Pongamia* might have complexing on soluble P making it insoluble, but it might be released slowly.

The count rate increased with increase in level of applied activity. The method of application was found to have no influence in deciding the Al-P fraction.

However, it is interesting to note that Al bound P showed a steady decrease with increased levels in *Cleistanthus* incorporated samples when the labeled fertilizer was thoroughly mixed with soil. However, at this stage, radioactive P in the Fe bound fraction was much higher than Al bound P. It shows more affinity of P to Fe than Al, and also due to the excess of Fe as compared to Al in the soil (Table 20).

5.4.3.4. Al-P at 30 days after sowing

At this stage Al-bound P increased considerably when compared to that at 15 days after sowing (Table 19). But the amount was still lower than the initial value. Between the treatments, *Pongamia* incorporation was most effective in reducing the Al-P followed by *Cleistanthus*. Lime application was not effective in reducing the Al-P as it obtained almost the same value as that of treatment with out any amendment. Here also increase in amount of applied fertilizer increased the amount of Al-bound P. Application of lime showed an immediate effect in reducing the Al bound P than that of green manures. Green manure requires more time for decomposition and hence it gives a slow effect.

5.4.3.5.^{32}P counts in the Al-P fraction at 30 days after sowing

The data on ^{32}P counts in the Al-P fraction 30 days after sowing is given in table 21. There was no significant difference among the levels and method of application at this stage with reference to the count rate of ^{32}P in Al-P fraction. However incorporation of lime recorded a significantly higher count rate suggesting that lime induced precipitation of part of applied P as Al-P.

5.4.4. Fe-P fraction

5.4.4.1. Fe-P fraction just before sowing, 15 days after incubation

The fate of Fe-P fraction as evidenced from the data in table 13 showed similar reduction from the initial level as that of Al-bound P at just before sowing due to incubation for 15 days. However it was the application of *Pongamia* which reduced the Fe-bound P effectively than lime and *Cleistanthus*. The reduction in quantity of Fe-bound P was least in the case of treatment without any amendment. The decomposition products of *Pongamia* had more solubilizing effect on Fe-P rather than Al-P which is well evidenced by the data on Al-P in the same period.

5.4.4.2. Fe-P fraction at 15 days after sowing

The data on table 22 revealed that at 15 days after sowing, amending the soil with lime was found to be most effective in reducing the Fe bound P from 68 mg kg^{-1} (at just before sowing) to 50.5 mg kg^{-1} (15 days after sowing) While the amendments with green manures were found to enhance the Fe bound P during the period of 15 days after sowing. Ogutoyinibo, (1996.) reported that application of lime significantly increased soil pH from 4.2 to 4.9 and had significantly decreased concentration of extractable Al, Fe and Mn .. The treatment without any amendment did not show any difference in Fe-P from that at just before sowing. The effect of lime might be caused through increase in pH resulting in precipitation and inactivation of Fe.

The decomposition products have been started reacting with the P fraction associated with Fe bound P. The fraction associated with Fe may be forming a complex with Fe-P and this might have subsequently released the P from complex by locking the Fe. That is well understood by the low level of Fe bound P recorded at 30 days after sowing.

Application of increasing rates of P fertilizers was found to increase the Fe-P. However even this increased level of Fe bound P was much lower than that at the initial stage. Band placement of P recorded significantly higher amount of Fe-bound P in comparison with that of thorough mixing of P fertilizers.

5.4.4.3. ^{32}P counts in Fe-P fraction 15 days after sowing

Even though there was no significant difference between amendments (Table 24), the levels of applied phosphorus as well as the method of application, considerably higher levels of count rate were obtained in the extract of Fe bound P fraction. This would mean that in spite of significant difference among the treatment combinations, conspicuous amounts of applied P were transformed in to Fe-bound forms.

5.4.4.4. Fe-P at 30 days after sowing

The Fe-bound P reduced gradually at 30 days after sowing in all the treatments (Table 23) except in un amended soils, when compared with the amount of this fraction at different stages. Among the amendments, lime was found to be most effective in reducing the Fe-bound P, followed by *Pongamia* and *Cleistanthus* in that order. However, quantity of phosphorus in this fraction increased in un amended soils at this stage. The Fe-bound P content in soil increased significantly with increase in quantity of fertilizer applied.

Band placement recorded significantly higher amount of Fe-P than thorough mixing at 30 days after sowing.

5.4.4.5. ^{32}P counts in the Fe P fraction at 30 days after sowing

It was noteworthy to observe that the lime amended soil recorded the lowest radioactivity in Fe bound P fraction, while the treatment without any amendment recorded the highest count rate (Table 25).

The application of green manures did not significantly reduce the count rate from that in the non amended samples. A perusal of the data on count rate at 15 days after sowing and 30 days after sowing indicated that in lime amended soil the applied P initially reverted to Fe-P and then slowly disappeared from that fraction.

5.4.5. Occluded P fraction

5.4.5.1. Occluded P just before sowing, 15 days after incubation

The data on sesquioxide occluded P (reductant soluble P) in table 13 showed that the addition of amendments reduced the quantity of occluded P while a slight increase was observed in unamended soil, during the period of incubation. Lime was the most effective amendment in reducing the occluded P.

5.4.5.2. Occluded P at 15 days after sowing

At this stage also, application of lime and green leaf manures was found to reduce the occluded P content than that at just before sowing. The treatment without amendment showed only a slight decrease. Here again, lime was the most effective treatment in reducing occluded P fraction (Table 26).

The amount of occluded P increased with increased rate of application. Band placement recorded lesser amount occluded P than that in thorough mixing.

5.4.5.3. ^{32}P counts in the Occluded P at 15 days after sowing

All the amendments were on par with respect to the counts of radio active phosphorus. However lime was found to be superior to the treatment without any amendment (Table 28) in reducing the count rate.

5.4.5.4. Occluded P at 30 days after sowing

The occluded P fraction was lowest in Pongamia amended soils, which recorded a reduction in this fraction when compared with that at 15 days after sowing (Table 27). *Cleistanthus* came next with similar effects though to a lesser extend. Lime treated soils, showed an increase in occluded P (58.5) when compared with the data at 15 days after sowing. However, this amount was much lower than that at just before sowing. The treatment without any amendment did not show any change in occluded P from that at 15 days after sowing.

5.4.5.5. ^{32}P counts in the occluded P fraction, 30 days after sowing

The treatments, levels and methods of application had no influence on the ^{32}P counts in the occluded P fraction at 30 days after sowing.

5.4.6. Ca-P fraction

5.4.6.1. Ca-P just before sowing 15 days after incubation

Phosphorus content in Ca-P in initial sample was 34.2 mg kg^{-1}. 15 days of incubation with amendments in the form of green leaves did not show any significant change in the quantity of this fraction (Table 13). Lime amended soils showed a significant increase, whereas the treatment without amendment resulted in a decrease in this fraction when compared with the corresponding value of the initial soil sample.

5.4.6.2. Ca-P at 15 days after sowing

All the treatment combinations of amendments, P levels, as well as method of application increased the Ca-bound P 15 days after sowing (Table 29). This could be viewed in conjunction with a decrease in quantity of Al bound P and Fe bound P which clearly indicated that during this period both Al-P and Fe-P fractions got transformed into Ca-bound P. This fact is more pronounced in the case of lime treated soils, were the increase in Ca-bound fraction was highest when compared to other treatments. Both *Pongamia* and *Cleistanthus* application also hastened the process of transformation of Al-P and Fe-P when compared with the treatment without any amendment.

The level of applied P increased the Ca bound P content. Band placement enhanced the quantity of Ca-bound P when compared with mixing of fertilizer with soil at this stage.

5.4.6.3. ^{32}P counts in the Ca-P at 15 days after sowing

Though there was no significant difference between the log transformed values of counts of radioactive P, noticeable counts were obtained in Ca-bound pool of phosphorus which means that, a significant amount of applied P was converted to Ca-P (Table 31). These results are in similar lines with the ^{32}P counts in Fe-P fraction. The lowest counts were obtained in case of *Cleistanthus* treated soils followed by lime application.

5.4.6.4. Ca-P at 30 days after sowing

In general, phosphorus in Ca bound fraction decreased in comparison with that at 15 days after sowing (Table 30). The decrease was highest in unamended soils (42.9 mg kg^{-1}) followed by that in *Pongamia* amended soils (45.8 mg kg^{-1}) and *Cleisanthus* 58.5 in that order. In the case of liming no change in Ca bound P was observed from that at 15 days after sowing. Increased levels of

Ca in lime amended soils might have caused the higher levels of Ca bound P in these soils.

At this stage none of the samples recorded any count in this fraction, probably because of very low levels of decayed radio active phosphorus. The increase in ^{32}P counts in soluble P fraction from 15 days to 30 days after sowing, with a corresponding decrease in radio active P in Ca-bound P to non detectable limits could be probably an indication of solubilisation of Ca-P coming from the applied fertilizer.

Ca-bound P increased with increased rate of application and the quantity was more in treatment where P fertilizer was placed in bands.

5.4.6.5. ^{32}P counts in the Ca-P at 30 days after sowing

The treatments, levels and methods of application had no influence on the ^{32}P counts in the Ca- P fraction at 30 days after sowing

5.4.7. Organic P fraction

5.4.7.1. Organic P just before sowing 15 days after incubation

Cleistanthus incorporation caused a substantial increase in organic P followed by soils with Pongamia and lime in that order (Table 13 and Fig.6.). The treatment without amendment showed a slight increase in organic P. This increase could be viewed as a result of corresponding reduction in soluble P, Al bound P, and Fe bound P, as well as occluded P.

Among the amendments *Cleistanthus* was most effective in increasing quantity of this fraction followed by *Pongamia* and lime. These results indicate that green leaf manures enhanced the organic forms of P content probably due to the increase in organic matter content.

5.4.7.2. Organic P fraction at 30 days after sowing

Organic P fraction further increased from the levels at just before sowing to 30 days after sowing substantially during the plant growth as revealed by the data at 30 days after sowing. Here also *Cleistanthus* applied soils recorded

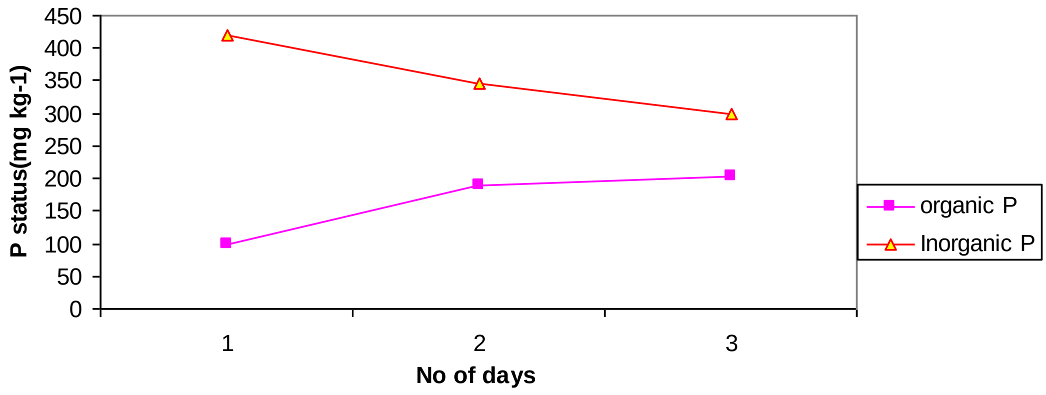


Fig 5a. ***Pongamia***

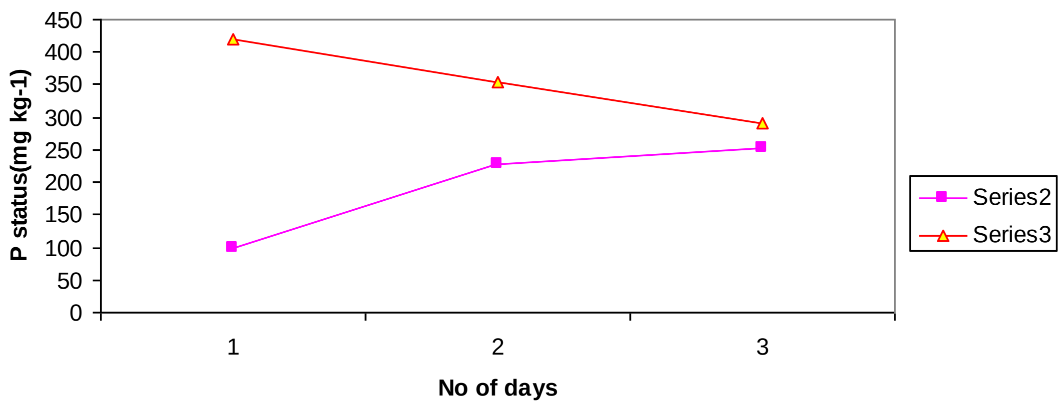


Fig 5b. Cleistanthus

Fig 5. Effect of amendments on changes in organic and inorganic P

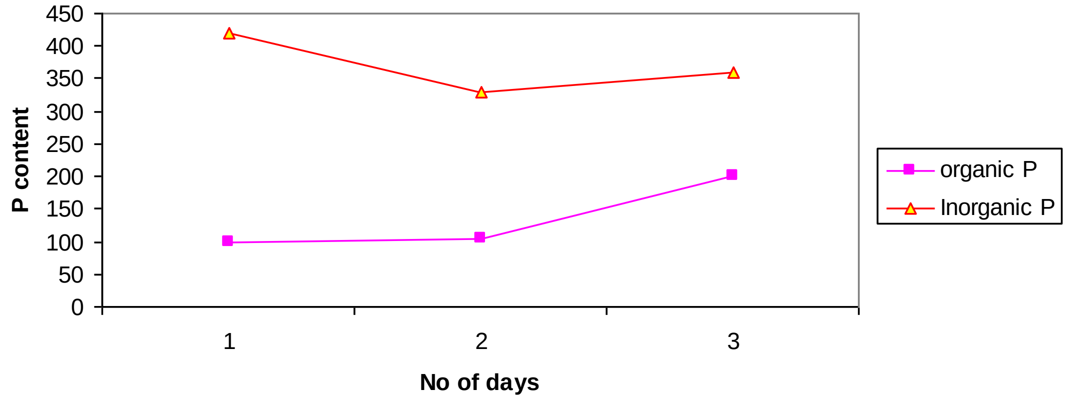


Fig 5c. Lime

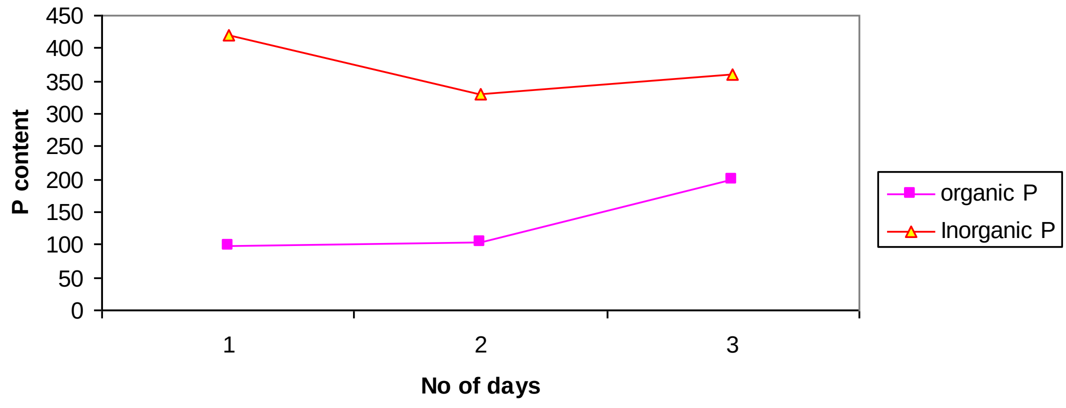


Fig 5d. No amendment

Fig 5. Effect of amendments on changes in organic and inorganic P the highest value followed by lime and *Pongamia.* The treatment without any amendment recorded the lowest value. Even in this treatment the organic P increased substantially from that at just before sowing (Table 32 and Fig.6.) indicating some degree of immobilisation.

5.4.7.3. ^{32}P counts in organic P fraction

Radio active phosphorus could not be detected in organic P fraction indicating that there was not any transformation of applied P to organic P. This is further supported by the data on organic P content with respect to increased levels of applied P, which showed that increase in organic phosphorus fraction was not in direct proportion with rate of application. This would further point to the fact that applied phosphorus was not transformed into organic forms within the period of 30 days.

5.5. Phosphorus content in the plant

5.5.1. Plant P 15 days after sowing

In general phosphorus content was very low at 15 days after sowing. All the amendments were found to increase the plant P content when compared with the treatment without any amendment. *Cleistanthus* application was most effective in increasing the P content followed by lime and then Pongamia. Lupwayi *et al*. (1999) observed an increase in the P content in the leaf, stem and kernel of groundnut due to the application of organic manures into the soil. It was observed that amendments significantly improved the available P status of the soils which in turn resulted in increased P uptake by plants grown in these amended soils. But there was no increase in P content with increased rate of P application. On the other hand banded application of P fertilizer resulted in increased available P status which in turn caused higher P absorption (Table 33).

5.5.2.^{32}P counts in plants 15 days after sowing

The data in table 35 showed that lime amended treatment recorded the highest ^{32}P counts in plants which must have been derived from applied P which in turn was due to increase in pH. Counts were highest at P applied at 30 kg ha^{-1}, which was on par with P applied at 45 kg ha^{-1} and are superior in enhancing radio active P in plants in comparison with P applied 15 kg ha^{-1}.

5.5.3. Plant P 30 days after sowing

All the treatments increased the P content in plants significantly in comparison with the treatment without any amendment (Table 39). Similar results were obtained by Smitha, 2005). This again could be due to increase in available P content in soils by application of amendments. The levels of phosphorus showed no significant difference at this stage also, though the available P content increased with increase in rate of application. Band placement was superior in improving the ‘P’ content in plants. This was due to increase in available P in banded application of fertiliser P (Table 34)

5.5.4. ^{32}P counts in plant P at 30 days after sowing

All the amendments were found to improve ^{32}P counts in plant indicating the effect of these amendments in increasing the availability of applied P which in turn might have caused increased ^{32}P absorption (Table 36).

5.6. Percentage contribution of P fractions to total inorganic P

5.6.1. Soluble P

A perusal of the data on percentage contribution of different P fractions to total inorganic P points to the following facts: soluble P increased from 4.6 at initial stage to 5.7 % 15 days after incubation with lime. In all other treatments, especially in that without any amendment, it showed a decreasing trend during the period (Table 37). This might be due to the increase in pH during this period of incubation due liming.

At 15 days after sowing, soluble P showed a phenomenal increase in all amended soils, while in non amended soils, it was almost same as that of the initial soil sample. At 30 days after sowing, the soluble P fraction showed a decreasing trend from that at 15 days after sowing and recorded the lowest value (2.7) for the treatment without any amendment, and it was lower than the initial

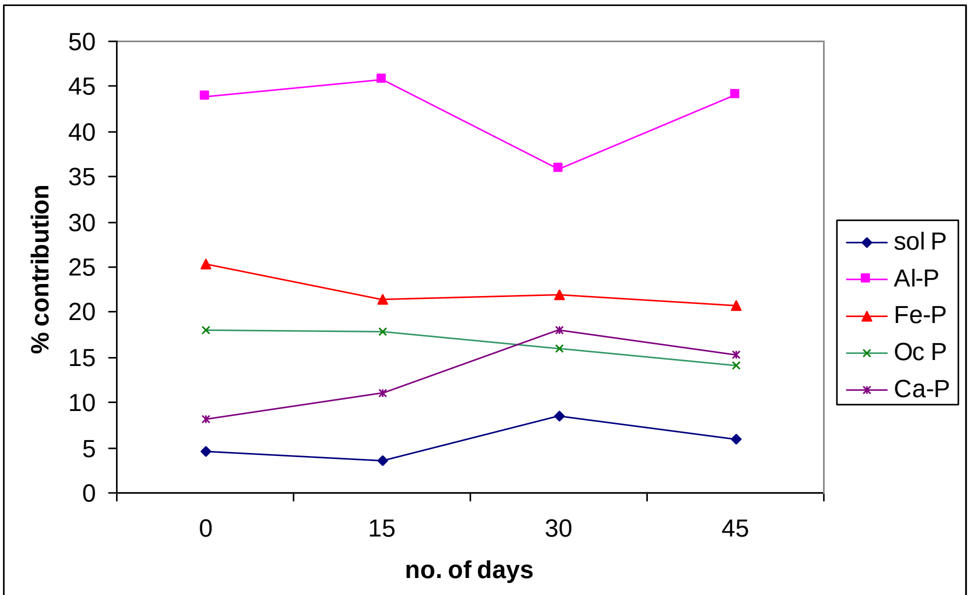


Fig 6a. Pongamia

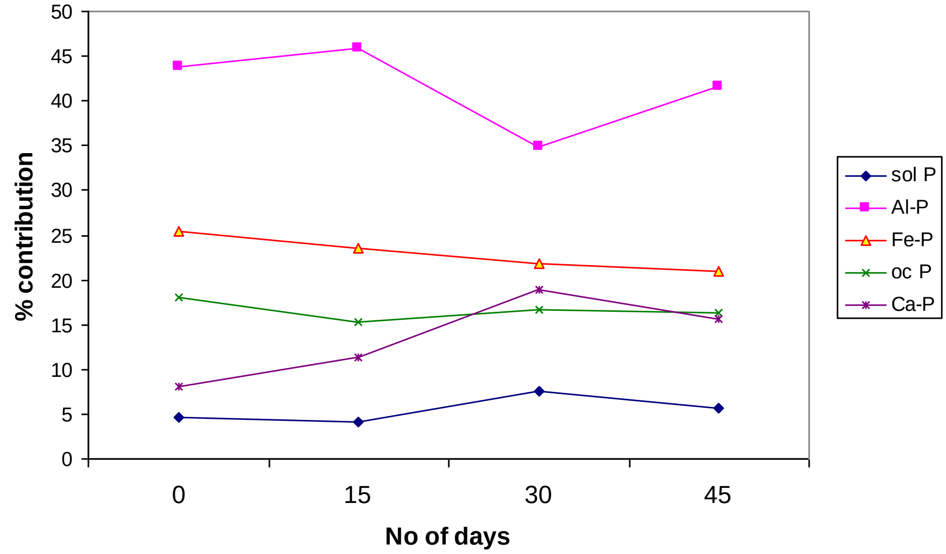


Fig 6b. *Cleistanthus*

Fig 6. Effect of different amendments on percentage contribution of phosphorus to total inorganic P

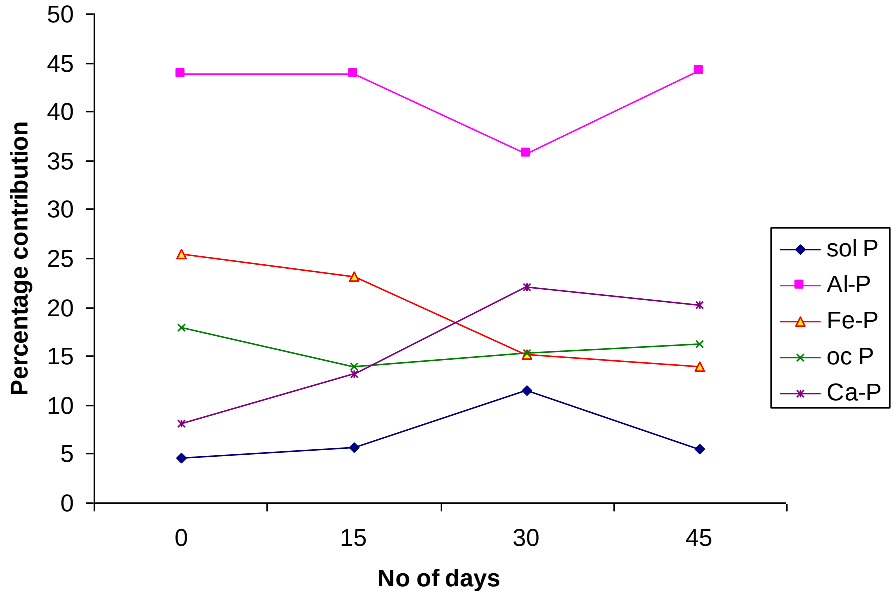


Fig 6c. Lime

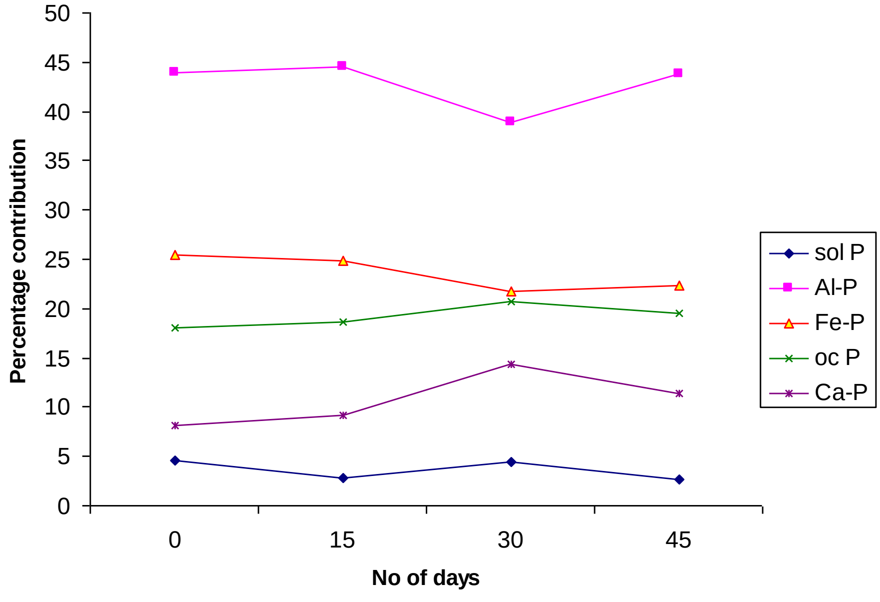


Fig6d. No amendment

Fig 6. Effect of different amendments on percentage contribution of phosphorus to total inorganic P value (Table 38 and 39) which might be due to either plant uptake or due to reversion of P in labile pool.

5.6.2. Al bound P

In case of Al-P, it remained unchanged in lime amended soils due to 15 days of incubation while in all other soils, this fraction recorded a slight increase. At 15 days after sowing, Al bound P recorded the lowest value in all the treatments with and without amendments. At 30 days after sowing, it increased to values nearing to the initial status (Table 37, 38 and 39 and fig.5.).

5.6.3. Fe bound P

The data in tables 37, 38 and 39 and as depicted in fig.5. revealed that Fe bound P showed a declining trend in all the treatments, during the period of days of incubation. At 15 days after sowing, a decrease in Fe bound P was noted, which was substantial in lime amended soils. Similar trend was maintained in case of Fe-P at 30 days after sowing also.

5.6.4. Occluded P

Occluded P declined from the initial value during the period of incubation in case of treatments with lime and Cleistanthus. Occluded P showed a slight increasing trend at 15 days after sowing and almost stabilized at 30 days after sowing (Table 37, 38 and 39 and fig.5).

5.6.5. Ca bound P

Ca bound P increased due to incubation with and without amendment and this increase was highest in lime amended soils. It showed a further increase in 15 days after sowing and followed a declining trend (Table 37, 38and 39).

It is clear from the above facts that an increase in soluble P and Ca-P resulted with a corresponding decrease in Al-P. In contrast, an increase in Al-P caused corresponding decrease in soluble P and Ca-P. It is also evident from the data that increase in Ca-P could be due to a corresponding decrease in Fe–P.

5.7.1. %Pdff 15 days after sowing

Percentage P derived from fertilizer by the plants clearly indicate the efficiency of applied fertilizer. The data in table 42 and fig.7 showed that application of *Pongamia* leaves resulted in 18.4 per cent of applied P absorbed by cowpea plants. This was on par with the other green manure *Cleistanthus* which caused to derive 18.3 per cent of applied P. Sudhir *et al*. (1996) reported that application of green manure with P fertilizers considerably increased P utilization from fertilizer and hence increased the percentage P derived from fertilizers and percentage phosphorus utilization by rice crop. Lime application resulted in a %Pdff of 10.1 which was significantly better than that obtained in non amended treatment (9.3). This shows that the amendment lime actually releases the native P, in the initial stages of plant growth. This is well reflected by the P content in plant, which is almost on par with the other amendments. The %Pdff was found to increase with increase in rate of P application. The data establishes the effect of amendments in improving %Pdff values.

5.7.2. %Pdff 30 days after sowing

The data on %Pdff 30 days after sowing also showed the very similar trends as that obtained at 15 days after sowing (Table 43 and Fig.7.). *Pongamia* amended treatments recorded the highest %Pdff of 20.5(similar results were obtained by Ponnaiyan, 2003 in rice.) per cent while application of *Cleistanthus* and lime resulted in a %Pdff values of 15.5 per cent and 15.4 per cent respectively. The treatment without amendment recorded lowest value of 7.9 per cent. These results would indicate that *Pongamia* leaves incorporation 15 days prior to fertilizer application caused a substantial increase in percentage P derived from fertilizer thereby resulting higher fertilizer use efficiency at 30 days after sowing.

The %Pdff at 30 DAS was in perfect agreement with the plant P content at this stage with respect to the effect of amendments.

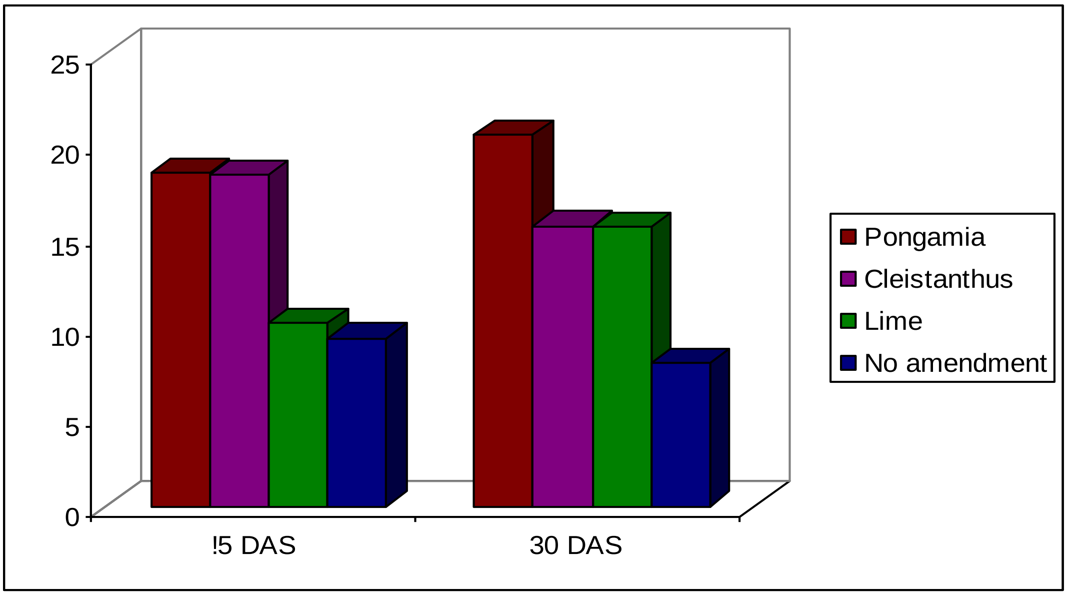


Fig 7. Effect of different amendments on percentage phosphorus derived fertilizer (Pdff)

5.8. A and L value

The A value serves as an availability index for a nutrient either from fertilizer or from soil. For obtaining an accurate A value, the reaction between fertilizer and soil P should be minimum for which the labeled carrier fertilizer must be banded. This in turn minimizes the isotopic exchange and fertilizer P fixation. Thus A values are direct function of P fertility levels of the soil. But if an integrated measurement of fertilizer P reaction and soil fertility level are to be obtained, mixed placement of fertilizer P should be done so as to have maximum isotopic dilution. Thus in the present study depending on the method of fertilizer application, A values and L values were obtained, i.e. when the fertilizer was placed A values were obtained, whereas when it was thoroughly mixed with soil, L values were drawn.

5.8.1. A and L value 15 days after sowing

A critical analysis of the A values at 15 days after sowing (i.e. when the labeled fertilizer was placed in bands) indicated that maximum A value was obtained for lime amended treatments (4.1mg kg^{-1}) followed by non-amended soil (3.9 mg kg^{-1}), *Cleistanthus* incorporated soil (2.9 mg kg^{-1}) and *Pongamia* incorporated soils (2.7 mg kg^{-1}) in that order(Table 44).

Higher levels of labeled P fertilizer gave a constant A value (2.6 mg kg^{-1}) in *Pongamia* amended soils at this stage suggesting that incorporation of *Pongamia* did not influence the A value at this stage. However, other two amendments as well as non-amended soil gave highly fluctuating A values at higher levels of applied P at this stage.

When fertilizer was thoroughly mixed with soil, isotopic dilution was favoured which resulted in obtaining the isotopically exchangeable P. Accordingly when the L values obtained were critically analysed, the data revealed that lime treatment could significantly increase the L value (5.1 mg kg^{-1}). Incorporation of the other amendments as well as no amendment was significantly inferior to liming.

The levels of applied fertilizer gave fluctuated L values. L value increased from 4.5 to 5.2 when the amount of P applied increased from 15 to 30 kg ha^{-1}. Further it reduced to 4.3 at 45 kg ha^{-1} of applied P.

5.8.2. A and L value 30 days after sowing

At 30 days after sowing, A and L values were highest in treatment with *Cleistanthus* application, and this value was almost double than the value at15 days after sowing, which indicate that incorporation of *Cleistanthus* could solublize unavailable forms to labile fraction during an interval of 45 days(Table 45). In case of lime, A values obtained was significantly lower than that in *Cleistanthus* incorporation. This A value for lime treated pools similar to that obtained at 15 days after sowing. In non amended soil, A value was same as that at 15 days after sowing. But, the L value got reduced.

In *Pongamia* incorporated treatment, A value increased where as the L value declined. A value remained almost constant for the lower levels of fertilizer application while increased significantly at the highest dose of 45 kg ha^{-1}. Highest value for labile P (4.7 mg kg^{-1}) was obtained at 30 kg P ha^{-1}.

The different trend shown in case of A and L values at 15 and 30 days after sowing showed that the effect of green manures in increasing these values took time probably due to the time taken for complete decomposition. At the same time effect of lime was manifested at 15 days itself which remained constant at 30 days also.

5.9. Phosphorus transformation in soil plant system

A lateritic soil (Vellanikkara series) with low available P (3.7mg kg^{-1}) and very high P fixing capacity (91.6%) following, linear form of Langmuir adsorption isotherm (with bonding energy coefficient 0.0296 mL $g^{-1}$and adsorption maximum 182.59mg kg $^{-1}$) was used for the present study. Initially this soil was incubated for 15 days with *Pongamia* and *Cleistanthus* (20 t ha^{-1} each) and lime (to meet the lime requirement of 9.1 t ha^{-1} to raise the pH to 6.5) and also without any amendment. During this period available P showed a slight increase with Pongamia incorporated samples recording the highest value.

Fractionation of Phosphorus after the period of incubation showed that lime treatment increased the soluble and Ca-P and decreased the occluded P, indicating the effect of lime in solubilising the occluded P fraction which was transformed to soluble P and Ca-P. This effect might be due to effect of lime in increasing the pH from the initial 5.4 to 6.5.

These treated soils after a period of 15 days incubation were used for a pot culture study with 3 levels of phosphorus at the rates of 15, 30 and 45 kg ha (0.3, 0.6, 0.9 mg kg^{-1}) which was applied through ^{32}P labeled KH_2PO_4 (1 mci/g). The fertilizer was applied through band placement as well as through thorough mixing with the soil. Cowpea seeds were sown in these soils. The available P, P fraction, ^{32}P counts in available P and in fractions, phosphorus content in plants, ^{32}P counts in plants, percentage P derived from fertilizer, and A/L values were computed at 15 days and 30 days after sowing.

Available P was increased at both 15 and 30 days after sowing due to application of amendments while it decreased in non amended soil. Lime was the most effective in increasing the P availability, probably due to its effects in increasing the pH. Though there was no change in pH, both the green leaf manures also could increase the P availability which might be due to solubilisation of insoluble fraction by organic acids released during decomposition. The quantity of P in available pool seems to be derived from solubilisation of native phosphorus as evidenced by the data on ^{32}P counts in available pool. These data showing highest count in unamended soil suggest maximum fertilizer P was coming to available pool in unamended soil at both 15 and 30 DAS. At both stages higher levels of P application increased the available P content probably through shifting the equilibrium of inorganic P fractions. This is evidenced from the increase in phosphorus content in soluble P, Al-P, Fe- P, occluded P, as well as the Ca-P. This would mean that applied P might have first transformed in to either of these fraction through various reactions and finally contributing to the available pool. This might be the reason why thorough mixing of phosphatic fertilizer contributed more to the available pool than in the case of band placement.

Amendments influenced significantly in increasing the soluble P, with lime being the most effective one during the entire period of plant growth, when the pH was maintained at 6.5. Increase in level of phosphorous caused an increase in soluble P. Similar trends were shown by ^{32}P counts in soluble P at 15 days after sowing. Application of lime reduced the Al-P fraction at both stages.

The positive significant correlation of solution P to available P and significant negative correlation of Al-P with available P, indicated that the effect of amendments especially lime in increasing the available P might be through solubilisation of Al-P. The effect of amendments in solubilising the Al-P and Fe-P might be due to increase in pH as a result of lime application or due to solubilization of this insoluble fraction by organic acids during the decomposition of green leaf manures.

Increase in levels of phosphorus contributed to increase in Al and Fe-bound fractions.

Occluded P was also reduced during this period of plant growth due to application of amendments, lime being the most effective at 15 days after sowing and green manure at 30 days after sowing. This sesquioxide occluded phosphorus was also found to be enhanced by increasing the rate of P application. The data on ^{32}P counts in occluded P fraction supported the argument that applied fertilizer directly contributed to this fraction in non amended soil as the application of amendments resulted a significantly higher ^{32}P counts in this fraction.

Ca-P fraction was significantly increased due to amendments, lime being the most effective and steady in imparting this effect. Though there was no significant difference in ^{32}P counts in Ca-bound pool of phosphorus. Notably higher counts were obtained in all the treatment combinations indicating conversion of a major portion of applied P into Ca-P at 15 days after sowing.

Failure of obtaining any detectable counts in Ca-P fraction at 30 DAS points to the fact that this might be transformed in to the other fractions. A substantial decrease in Ca-P from that at 15 days to 30 days after sowing with a corresponding increase in Al-P supports possibility of this transformation.

An interesting observation on organically bound P was that it steadily increased from the initial level during the period of incubation as well as that of pot culture.

No detectable counts were obtained in case of organic P indicating the possibility of immobilization only from the native pool.

Percentage P derived from fertilizer at 15 and 30 days after sowing depicted the effect of amendments in improving the P absorption by the plant from the fertilizer. However, this effect was conspicuous in case of green manures, while the case of lime, this effect was shown at 30 days after sowing. At 15 days after sowing, lime treated pools recorded the lowest Pdff values, which again clearly indicated applied P was not directly moving to available pool at least in case of lime amended treatments.

Lime was most effective in enhancing A and L values at 15 days after sowing while it was Cleistanthus which recorded the highest value at 30 days after sowing. The effect of green manures in increasing these values took time probably due to the time taken for complete decomposition. At the same time effect of lime was manifested at 15 days itself which remained constant at 30 days also. These results would help in drawing the conclusion that though lime helped in improving the availability of phosphorus it was the green manures which enhanced the fertilizer use efficiency directly.

The phosphorus content in plants at both 15 and 30 days after sowing also showed that the green manures are contributing more in enhancing the plant P content.

Summary

6. SUMMARY

Five benchmark soils of lateritic origin were collected and used for the present study of Q-I relations, dynamics and transformations of P. Samples of these soils were collected from Kunnamangalam (Calicut), Angadippuram (Malappuram), Vellanikkara (Thrissur), Pattambi and Thirumittakkodu (Palakkad) . The soils were characterized with respect to pH, EC, P fixing capacity, CEC and exchangeable cations, AEC , and available nutrient status (Organic carbon, available P, K, Fe, Mn, Cu and Zn) The inorganic P fractions *viz*. soluble P, Al bound P Fe bound P, sesquioxide occluded P, and Ca bound P as well as the organic P were estimated.

Quantity –Intensity relationship of these soils with respect to phosphorus were studied. The equilibrium phosphate potential and buffer power of these soils were estimated from the Q/I curve. The data obtained from phosphate adsorption experiments were fitted into different adsorption isotherms like Freundlich and Langmuir isotherms. The data for all the soils could be described by Langmuir equation. From this, bonding energy coefficients and adsorption maxima values were calculated. Only one soil (Kundamangalam) was following Freundlich isotherm.

Among the five soils, Vellanikkara soil series recorded the lowest available P and soluble P fraction (3.7 and 19.2 mg kg^{-1} respectively), the highest P fixing capacity (91.3%) and highest adsorption maximum as per Langmuir equation (182 mg kg^{-1}). Based on the above characteristics this soil was selected for pot culture experiments.

The pot culture experiment was carried out at Radiotracer laboratory, College of Horticulture using the above said lateritic soil (Ultisol) collected from the main campus of Kerala Agricultural University, Vellanikkara. Bulk samples were collected, processed and was transferred to plastic containers @ 100g soil $container^{-1}$. Amendments viz. *Pongamia* leaves, *Cleistanthus* leaves and lime were added in the respective treatments and kept for two weeks for wetting and

drying cycles so as to ensure thorough mixing of added amendments for possible decomposition and other chemical changes and incorporation throughout the soil system. After the incubation period of 15 days, $KH_2{}^{32}PO_4$ (^{32}P @ 1 mCi g $^{-1}$P) was added as per the treatments. Nitrogen and potassium were applied as per the package of practice recommendations. Seeds of cowpea (variety Kanakamony) were sown @ 3 seeds pot^{-1} Treatments included three levels of P viz. 15, 30 and 45 kg P_2O_5 ha^{-1} and four amendments viz. *Pongamia* leaves @ 20 t ha^{-1}, *Cleistanthus* leaves @ 20 t ha^{-1}, lime @ 9.1 t ha^{-1} and no amendment and an absolute control. The experiment was laid out in CRD with 25 treatments and 6 replications. The salient results of the present study along with the practical implications were summarized below:

- Application of lime increased the soil pH to near neutral stage (6.5)15 days after incubation and this pH was stabilised during the 30 days of crop growth. Other soils amended with green manures as well as non amended soils did not show any difference in pH.

- At all the stages of sampling, viz. just before sowing, 15 days after sowing, and 30 days after sowing, the maximum increase in available P was in the case of lime incorporated treatments probably because of the increase in pH and also due to increased Ca-P fraction which might be directly contributing to labile pool. The green leaves of *Pongamia* and *Cleistanthus* also increased the available P status.

- At both the stages after sowing, application of phosphorus at increasing levels from 15 to 45 kg P_2O_5 ha^{-1} increased the available phosphorus status in a linear fashion in a significant manner.

- The highest count rate of ^{32}P in the available pool was obtained in treatment without any amendments at both 15 days and 30 days after sowing suggesting the possibility of applied P coming to labile pool indirectly via the other fractions. Amendment applied samples gave the lowest counts in both the cases.

- The soluble P fraction decreased after the incubation. At 15 days after sowing the increase in soluble P was highest in lime amended soil which was significantly superior to *Pongamia* and *Cleistanthus.* The quantity of soluble P at 30 DAS decreased considerably from that at 15 days after sowing. But it was higher than the initial values. Lime amended soils recorded highest soluble P status at all the stages of sampling.

- ^{32}P counts in soluble P fraction revealed that lime treated soils recorded the highest count rate followed by *Cleistanthus* and *Pongamia* in both 15 days and 30 days after sowing indicating transformation of applied P to soluble P indirectly through Al-P.

- Application of lime significantly reduced the Al-P fraction when compared to all other amendments at just before sowing, 15 days and 30 days after sowing. However application of the other two amendments also reduced the Al-P fraction when compared with the treatment with out any amendment. In general, Al-P fraction showed a slight increase from 15 days after sowing to 30 days after sowing.

- ^{32}P counts in Al-P fraction at 15 days after sowing, showed that, lowest count rate was obtained in *Pongamia* amended samples, whereas the highest was in *Cleistanthus* applied soils followed by lime treated soils. Incorporation of lime recorded a significantly higher count rate suggesting the lime induced precipitation of part of applied P as Al-P which might be gradually solubilised to soluble P at 30 days after sowing.

- Fe-P fraction showed reduction from the initial level at just before sowing due to incubation for 15 days. Application of *Pongamia* reduced the Fe-bound P more effectively than lime and *Cleistanthus*. The reduction in quantity of Fe-bound P was least in the case of treatment without any amendment.

- Amending the soil with lime was found to be most effective in reducing the Fe bound P at 15 days after sowing. At 30 days after sowing also; lime was found to be most effective in reducing the Fe-bound P, followed by *Pongamia* and *Cleistanthus*. However, quantity of phosphorus in this fraction increased in non amended soils at this stage. The Fe-bound P content in soil increased significantly with increase in quantity of fertilizer applied.

- There was no significant difference between amendments in reducing the Fe-P fraction at 15 days after sowing. Lime amended soil recorded the lowest level of radioactivity in Fe bound P fraction at 30 days after sowing. The application of green manures did not significantly reduce the count rate from that in the non amended samples.

- Lime was the most effective amendment in reducing the sesquioxide occluded P at all the three stages of sampling. The addition of amendments reduced the quantity of occluded P while a slight increase was observed in non amended soil, during the period of incubation and at 30 days after sowing.

- Lime was found to be superior to the treatment without any amendment in reducing the count rate in the occluded P at 15 days after sowing. No count rates were recorded in the occluded P at 30 days after sowing.

- Lime amended soils showed a significant increase in Ca-P fraction in all the stages of sampling, application of *Pongamia* and *Cleistanthus* also showed a significant increase in Ca-P fraction than the treatment without any amendment at 15 and 30 days after sowing.

- The amendments had a significant effect in improving the organic P fraction of the soil. Incorporation of *Cleistanthus* was the most effective in increasing the organic P fraction. Application of *Pongamia* also increased the organic P fraction at a higher rate than that in lime which in turn was significantly superior to the treatment without any amendment.

- At 15 days after sowing, application of *Cleistanthus* increased the plant P content than the other treatments. Application of lime and *Pongamia* also showed a significantly more P than that of the treatment without any amendment at this stage. The levels of phosphorus did not show any significant difference in the plant P content.

- At 30 days after sowing, application of *Pongamia* increased the plant P content in a significantly superior manner than the other treatments. However, application of *Cleistanthus* and lime also increased the P content and showed a significantly higher content than that of the treatment with out any amendment.

- Application of lime increased the plant ^{32}P counts than the other treatments. Other treatments had not shown any significant difference among themselves in the ^{32}P counts at 15 days after sowing.

- Lime and *Pongamia* were equally effective in increasing the count rate in the plant followed by *Cleistanthus* application at 30 days after sowing.

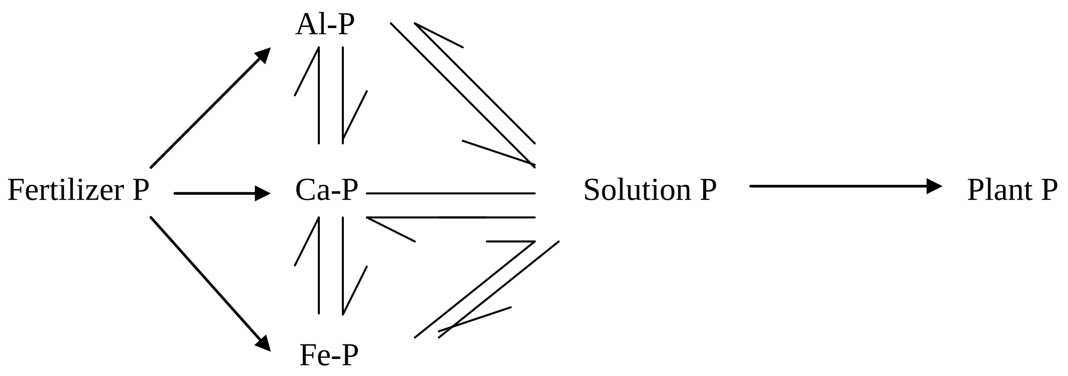
- Application of *Pongamia* improved percentage phosphorus derived fertilizer (%Pdff) significantly which is on par with that in case of *Cleistanthus* at 15 days after sowing. Application of lime also significantly increased the %Pdff than that of the treatment without any amendment. The %Pdff at this stage increased significantly with the rate of phosphorus application.

- Addition of *Pongamia* had the best effect in increasing the %Pdff at 30 days after sowing. Incorporation of *Cleistanthus* improved %Pdff significantly, which was on par with that in case of lime and were significantly superior to that of the treatment without any amendment at this stage.

- Maximum A value at 15 days after sowing was obtained for lime amended treatments followed by non-amended soil, *Cleistanthus* incorporated soil and *Pongamia* incorporated soils in that order. Lime treatment could significantly increase the L value. Incorporation of the other amendments as well as no amendment was significantly inferior to liming.

- At 30 days after sowing stage, A and L values were highest in treatment with *Cleistanthus* incorporation. Lime recorded a significantly lower A value than *Cleistanthus*. In *Pongamia* incorporated soil, A value remained almost constant for the lower levels of fertilizer application. Highest value for labile pool was obtained at 30 kg ha^{-1}.

It can be concluded from the present study that application of different amendments did dictate the transformation of P in soil. The available P, soluble P and %Pdff could be improved significantly. Lime as well as green manures had significantly improved available P estimated by the routine method as well as by tracer techniques. The %Pdff also could be improved by amendments A different trend in radioactive phosphorus activity in available P as well as in A and L values indicated that the applied P though contributing to the available pool in amended soils, this might be routed in the following manner contributing only indirectly to the available pool:



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* Originals not seen

QUANTITY – INTENSITY RELATIONS OF PHOSPHORUS WITH REFERENCE TO ITS BIOAVAILABILITY IN LATERITIC SOILS

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ABSTRACT OF THE THESIS

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Abstract

Five benchmark soils of lateritic origin were collected and used for the present study of Q-I relations, dynamics and transformations of P. Samples of these soils were collected from Kunnamangalam (Calicut), Angadippuram (Malappuram), Vellanikkara (Thrissur), Pattambi and Thirumittakkodu(Palakkad) . The soils were characterized with respect to pH, EC, CEC and exchangeable cations, AEC, available nutrient status (Organic carbon, available P, K, Fe, Mn, Cu and Zn) and P fixing capacity The inorganic P fractions *viz*. soluble P, Al bound P Fe bound P, sesquioxide occluded P, and Ca bound P as well as organic P was estimated. The equilibrium phosphate potential and buffer power of these soils were estimated from the Q/I curve.

Among the five soils, Vellanikkara soil series recorded the lowest available P and soluble P fraction, the highest P fixing capacity and highest adsorption maximum as per Langmuir equation Based on the above characteristics this soil was selected for pot culture experiments to grow cowpea as a test crop using three different amendments (*Pongamia*, *Cleistanthus*, and lime) three levels of labeled phosphatic fertilizer and two methods applications. Available P and fractions of phosphorus in the soil was estimated at three stages. P content as well as ^{32}P counts in the plants were also estimated. A and L values were computed at 15 and 30 days after sowing.

It can be concluded from the present study that application of different amendments dictated the transformation of P in soil. The available P, soluble P and %Pdff could be improved significantly. A different trend in radioactive phosphorus activity in available P as well as in A and L values indicated that the applied P though contributing to the available pool in amended soils, this might be routed through the inorganic fraction Ca-P and not directly coming to the soluble/labile pool.