PHOSPHORUS DYNAMICS IN AN ULTISOL

By

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THESIS

submitted in partial fulfilment of the requirements for the degree of

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Kerala Agricultural University, Thrissur

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COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
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DECLARATION

I, hereby declare that this thesis entitled **"Phosphorus dynamics in an Ultisol"** 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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We, the undersigned members of the Advisory Committee of **Ms. Smitha, M.S.** a candidate for the degree of **Master of Science in Agriculture** with major in **Soil Science and Agricultural Chemistry,** agree that the thesis entitled **"Phosphorus dynamics in an Ultisol"** may be submitted by Ms. Smitha, M.S. in partial fulfilment of the requirements for the degree.

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Smitha, M.S.

Dedicated to

Achan, Amma

and Mahesh

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Introduction

1. INTRODUCTION

Phosphorus is considered to be the most critical and important element among plant nutrients next to nitrogen. Phosphorus has been called "the key of life" because it is directly involved in most of the life giving processes. It is a component of every cell and tends to concentrate in seeds and in growing points of plant. Phosphorus in any biological system is present in organic and inorganic form and is involved in various chemical and biochemical reactions. It is an essential component of ATP and hence often called energy currency of living cell. Adequate P nutrition enhances many aspects of plant physiology, including the fundamental processes of photosynthesis, nitrogen fixation, flowering, fruiting, maturation and root growth etc.

Phosphorus occurs in soil in both organic and inorganic form .The concentration of inorganic forms ($H_2PO_4^-$, HPO_4^{2-}) in soil solution is the most important single factor governing the availability of this element to plants. Uptake of $H_2PO_4^-$ is more rapid than HPO_4^{2-}, with former being most abundant at pH value below 7.2.

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

$$\text{Soil solution P} \longleftrightarrow \text{Labile P} \longleftrightarrow \text{Non labile P}$$

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 exhibit 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.

Phosphorus is one of the major plant nutrients often limiting crop growth in many soils. In the soils of India, the available P is generally medium to low. A knowledge of various forms of P present in soils and conditions under which they become available is a pre-requisite in assessing the P nutrition of plants. Much of the P is in inorganic forms, since different P fractions have different solubility and the amount of each depends on various soil characteristics. The availability of soil P should largely depend on total P present and soil characteristics (Singh *et al.*, 2004).

Laterite soils cover nearly 60 percent of the total area of the Kerala state occupying the mid lands and mid upland regions coming under the order Ultisol. The laterite soils are confronted with the problems due to the excess aluminum, iron and manganese with low CEC and exchangeable bases. These soils are reported to have high phosphorus fixing capacity to the tune of about 80 percent or more (Seena, 2000).

According to Sanchez *et al.* (1982) phosphorus deficiency is the most widespread constraint in an Ultisol. So these soils require a large initial dose of P fertilizer to obtain acceptable crop yields .The high rate of P fixation under acidic lateritic environment causes lack of response to P even for sensitive crop like cowpea. Hence, the application of amendments *viz.*, Pongamia leaves, sodium silicate and lime increase the P availability.

Keeping these facts in mind and the practical problems with respect to phosphorus nutrition, the present study has been undertaken with the following objectives:

1) To trace the fate of fertilizer phosphorus applied to the soil .

2) To study the changes if any, in the dynamics of phosphorus due to the addition of different amendments like Pongamia leaves, sodium silicate and lime.

3) To find out the use efficiency of applied phosphorus under acidic lateritic environment .

Review of Literature

2. REVIEW OF LITERATURE

The dynamics of phosphorus in soil arises from a variety and complexity of soil processes associated with its transformation. However, salient research findings related to phosphorus dynamics in Ultisol have been reviewed here under.

2.1 PHOSPHORUS AVAILABILITY IN LATERITE SOIL

Phosphorus applied to the tropical acid soils is readily rendered unavailable to plants because of high P fixing power of these soils. 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. Deepa (1995) and Krishnakumar (1991) reported the low available P status in laterite soil, in spite of the continuous application of fertilizer P.

Phosphorus deficiency is the most widespread constraint in an Ultisol (Sreekala, 1996). The deficiency problem is compounded by the wide spread P fixation capacity. These soil possess low cation exchange capacity and require a large initial dose of P fertilizer to obtain acceptable high yields (Sanchez *et al.*, 1982).

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 19.6$\mu g\ g^{-1}$. High phosphorus fixing capacity to the tune of 80 per cent or more was found in this soil.

2.2 EFFECT OF LEVELS OF APPLIED PHOSPHORUS ON PHOSPHORUS AVAILABILITY

Upperi *et al.* (1995) reported that significant increase in the P content of the soil was recorded with increased level of of P_2O_5 (50 kg P_2O_5 ha^{-1}). Higher level of P registered significant increase in pod yield of groundnut over the control in red soils.

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. Anilkumar *et al.* (1999) found that available P content in an acid soil increased with increase in level of applied P.

Dhillon *et al.* (2004) reported that the amount of P desorbed from 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, 100, 150 and 200 mg P kg^{-1} soil. The amount of P desorbed increased with increasing levels of P.

Laltlanmawia *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 (12.4 kg ha^{-1}).

2.3 EFFECT OF AMENDMENTS ON P AVAILABILITY

2.3.1 Green manure

Several studies have shown that the availability of P can be increased through the incorporation of green manures to the soil under laboratory (Blair and Boland, 1978; Hundal *et al.*, 1987; Yadvinder- Singh *et al.*, 1988) and field conditions (Chatterjee *et al.*, 1979; Yadav and Singh, 1986). 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 (318.5 kg ha^{-1}) which was higher than inorganic fertilizer as ammonium phosphate alone (40.5 kg ha^{-1}). Easterwood and Sartain (1990) reported that in soils with high P fixing capacities, organic acid released during the decomposition of the crop residue, may increase phosphorus availability by blocking the phosphorus adsorption sites.

Sanyal and De Datta (1991) reported a positive correlation between the organic matter content of soils and phosphorus sorption. The role of organic matter in increasing the ability of the soil to sorb P had been attributed to its association with cations such as Fe, Al and Ca. Juang (1994) reported that plant available P in a corn field doubled from 22 to 55 mg kg^{-1} due to organic amendment.

Paulraj and Velayudham (1996) found that combination of rock phosphate enriched farmyard manure with daincha, could have released more available phosphorus, possibly due to the production of organic acids during the decomposition of green manure.

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 farmyard 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 its decomposition.

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) reported that application of green manure along with P fertilizers increased the grain yield as well as crop P uptake substantially by rice.

Anilkumar *et al.* (1999) reported that an increase in inorganic phosphorus was more in green manure amended soil than in soil incubated without green manure.

Sureshkumar (1999) reported that incorporation of ung (*Pongamia glabra*) and silica was found to be beneficial in reducing Fe and Mn toxicity and in increasing phosphorus availability in low land lateritic soil.

Krishna (2002) found that the decomposition of green manure releases P in available forms into the soil. Cavigelli and Thien (2003) found that during cover crop decomposition, Bray-I P increased by about 4 mg kg^{-1} in the soil cropped to pea, vetch and wheat which was greater than increase in Bray-I P of 1.6 mg kg^{-1} observed in control soil.

Ponniyan (2003) reported that laterite soil (Ultisol) treated with Pongamia leaves registered higher concentration of available P in soil than the control.

2.3.2 Silicates

Noda and Saio (1952) reported that SiO_2 had greater effect on the fixation of P than SiO_3.

Mariakulandai (1954) in his study on the effects of sodium silicates, super phosphate and silicophosphate with and without lime or green manure on lateritic soils of Nilgris found that silicophosphate treated soils showed nearly double the available phosphate when compared to those treated with super phosphate.

Hosoda and Takata (1957) found that in a soil with low SiO_2 / Al_2O_3 ratio, the availability of phosphorus in the soil and in plants were higher in calcium silicate plot than in calcium carbonate applied plot.

Reeve and Sumner (1970) observed that response to calcium silicate in Oxisols of Natal was due to the elimination of Al toxicity and consequent improvement in P uptake by plants rather than to any improvement in the rate of P supply to soils. Binh *et al.* (1974) reported that application of silicate raised the pH and had marked increase in P availability.

Smyth and Sanchez (1980) reported that silicates and P applications decreased P fixation and improved cation retention properties. Domning and Amberger (1988) reported that the availability of soluble phosphate was increased by silicate application. Kundu *et al.* (1988) reported the presence of silicates, and fluoride anions resulted in increased recovery of phosphorus and that the effect of silicates and fluoride ions in reducing P fixation was found to decrease with time.

Subramaniam and Gopalaswamy (1991) studied P availability in four rice soils of Tamil Nadu and reported the enhancement of phosphorus availability consequent to silicate application. They attributed this to ligand exchange reaction, which involve competition between phosphates and silicates for adsorption.

Vig *et al.* (1994) reported the effect of various anions including silicates on phosphorus desorption.

Sreekala (1996) reported that application of sodium silicate @ 800 $\mu g\ g^{-1}$ showed significant effect on the release of P in Oxisols and Ultisols.

2.3.3 Lime

Kothandaraman *et al.* (1969) obtained favourable results from high availability of phosphorus in super phosphate 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).

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 (Mathan and Raj, 1975).

Freisen *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. Similar observation was made by Haynes (1983) also. Smyth and Sanchez (1980) found that the effect of applied phosphate to an Oxisol was greater when soils were simultaneously limed.

Marykutty (1986) found an increase in available P content by graded levels of lime in lateritic alluvial soils. Lime application also increased the uptake of P by rice straw. Han *et al.* (1989), Maria *et al.* (1985), Holford (1985), and Wang and Yuan (1989) reported that available P content was increased by the addition of lime. Hartikainen and Mohemmedi (1991) reported that isotopically exchangeable P was affected by calcium carbonate.

Viswambharan (1995) reported that available phosphorus content of soil increased from sowing to 30 DAS and then decreased at the time of harvest in cowpea, when lime was added alone @ 400 kg ha^{-1} or in combination with phosphorus. Rattan *et al.* (2001) reported that liming of acid soils resulted in enhanced 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.

2.4 FRACTIONATION OF SOIL PHOSPHORUS

Fractionation of inorganic soil phosphorus has been essential in developing principles and knowledge of the nature and behaviour of phosphorus in soil. The purpose of these methods has been used to characterize the pools of phosphorus and their contribution to P availability in the soil system. Dyer (1894) was probably the first to effect a fractionation of soil phosphorus by extracting available phosphorus with one per cent citric acid.

Russel and Russel (1932) have indicated that soil phosphorus compounds can be classified into three broad groups as follows.

i) Inorganic phosphorus in neutral and alkaline soils probably as calcium phosphate hydroxy apatite.

ii) Inorganic phosphorus in acid soils likely to be in combination with iron and aluminium oxides.

iii) Organic phosphorus compounds.

Williams (1937) using NaOH fractionated soil P into (a) an alkali soluble fraction to include organic P, exchangeable P and the more soluble inorganic P and (b) alkali insoluble fraction consisting of the apatites.

Dean (1938) showed that the P compounds of the soil could be divided into (a) organic compound soluble in NaOH (b) inorganic compounds dissolved with NaOH followed by an acid and (c) insoluble compounds.

Ghani (1943a) divided the soil P into five groups (i) acetic acid soluble (mono, di and tri calcium phosphate), (ii) alkali soluble inorganic P (Fe and Al-P), (iii) alkali soluble organic P; (iv) H_2SO_4 soluble (phosphate of apatite type) and (v)insoluble (an integral part of the clay complex). Ghani (1943b) further modified this procedure by the addition of 8-hydroxy-quinoline to acetic acid during the extraction of P with acetic acid.

Williams (1950) fractionated P in Australian soils into three fractions (i) fraction soluble in 2.5 per cent acetic acid plus 8-hydroxy-quinoline (water soluble P, hydroxyl and carbonate apatites); (ii) fraction soluble in 0.1 N NaOH (adsorbed P, basic Fe and Al-P and organic P), (iii) fraction insoluble in extractants (i) and (ii) - (chloro and fluorapatite, crystal lattice P and resistant P minerals). Turner and Rice (1954) found that Neutral N NH_4F could dissolve Al-P but not Fe-P. It was concluded that the P extracted by the above extractant which was used by Bray and Kurtz (1945) must be largely Al-P.

Chang and Jackson (1957) developed a fractionation procedure of soil P and P fractions include

1) Al-P extracted by Neutral 0.5 N NH_4F
2) Fe-P extracted by 0.1 N NaOH
3) Ca-P extracted by 0.5 N H_2SO_4 acid
4) Reductant soluble Fe-phosphate (iron oxide occluded) extracted by $Na_2S_2O_4$-citrate
5) Occluded Al-phosphate extracted by Neutral 0.5 N NH_4F
6) Occluded Al-Fe-Phosphate extracted by 0.1 N NaOH

Peterson and Corey (1966) modified the soil P fractionation procedure of Chang and Jackson, resulted in a number of studies whose objective were to critically examine sources of P solubilised by the extractants commonly employed in soil testing. Based on selective solubility of P in various extractants the various P fractions identified were

i) Saloid bound phosphate extracted by 1M NH4Cl

ii) Aluminium phosphate extracted by 0.5 M NH4F

iii) Iron phosphate extracted by 0.1M NaOH

iv) Reductant soluble phosphate

v) Occluded phosphate

vi) Calcium phosphate extracted in 0.25 M H_2SO_4 acid

Frink (1969) reported that the method of Chang and Jackson was adequate for fractionation of Al and Fe-P, but modifications were needed for the determination of reductant soluble P and Ca-P. Olsen and Sommers (1982) outlined a fractionation procedure for soil phosphorus to extract (i) non occluded Al and Fe bound P using 0.1N NaOH (ii) P sorbed by carbonates using 1M NaCl and citrate-bicarbonate (iii) P occluded with in Fe-oxides using citrate-dithionate to remove P occluded within Fe-oxides and hydrous oxides and (iv) 1N HCl to remove Ca bound P.

Hedley *et al.* (1982) fractionated the soil P into the following fractions.

1) H_2O - P extracted using 30 ml deionised water

2) $NaHCO_3$ - inorganic P extracted using 30 ml of 0.5 M $NaHCO_3$

3) $NaHCO_3$ - organic P extracted by digesting the above fraction with ammonium persulphate

4) NaOH - inorganic P extracted with 0.2 M NaOH

5) NaOH - organic P extracted by digesting the above fraction with ammonium persulphate

6) HCl - P extracted by using 0.1 M HCl

7) Residual P extracted using sulphuric acid and water

Ivanov (1989) suggested an improved method of fractionation of soil-P. The fractions determined are

1) Soil solution phosphate extracted with 0.01M $CaCl_2$

2) Isotope exchangeable phosphate by adding ^{32}P to 0.01M $CaCl_2$

3) Plant available phosphates - anion exchange resin extraction

4) Aluminium and iron phosphate extracted by 0.5 N NaOH and 0.1 N KCl (1 hr)

5) Aluminium and iron phosphate not available to plants extracted by 0.5 N NaOH and 0.1 N KCl

6) Calcium phosphate extracted with 1 N HCl

7) Residual insoluble phosphate extracted with Conc. HCl

8) Organic phosphate as difference between total and 4th, 5th, 6th and 7th extracts

A modified version of Hedley *et al.* (1982) procedure was described by Tiessen and Moir (1993) was used to sequentially fractionate soil P. In this, soil sample was subjected to a series of extractions

1) Resin extractable P (at soil pH=5.5)

2) Bicarbonate (0.5M $NaHCO_3$ at pH=8.5) extractable inorganic and organic P

3) Hydroxide (0.1N NaOH at pH=13) extractable inorganic and organic P

4) IM HCl extract Ca-P

5) Sulphuric acid and hydrogen peroxide which removes residual P

2.5 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.

Metzger (1940) have reported the conversion of soluble form of phosphorus into sparingly soluble compounds by reaction with the cations like iron, aluminium and calcium.

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 accounts for 55 to 98 per cent of the added amount. Approximately 45 per cent of added P might be 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.

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. Yadavanshi *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 an 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 water logging. Increase in Al-P was due to the conversion of reductant soluble-P, occluded-P and Ca-P into Al-P.

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 in organic matter untreated soils. Transformation of added P into saloid, Al and Fe-P increased, whereas Ca-P decreased with increasing solubility of the fertilizer.

2.6 P FORMS AND THEIR RELATIONSHIP WITH P AVAILABILITY

Studies carried out by Chai Moocho and Cladwell (1959) observed that (i) the 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 (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. He directly measured the quantity of phosphorus absorbed from each chemical form of inorganic phosphate. 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 well drained soils. However, they undergo reduction to more soluble ferrous forms in water logged soils, so 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 urd, 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. The phosphorus uptake by plants was highly correlated with the amount of iron phosphate but not with the amount of other fractions (Singh and Brahman, 1976).

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

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 the multiple correlation and regression, Singhania and Goswami (1978b) studied the relationship between inorganic phosphate fractions and available phosphorus in four major soils viz., alluvial, black, red and laterite. Al-P was found to be the main source of Olsen and Bray extractable P.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 upto 12.7 to 25.8 per cent of total P. The third abundant fraction was Ca-P 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. Ca-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. 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 more important fraction contributing towards the availability of phosphorus in soils followed by Red-P and saloid-P.

Tiwari (2002) reported that inorganic P constituted a dominant part of total P, it being 40 to 55 percent 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.Various pools were inter related and contributed to plant available P.

Materials and Methods

3. MATERIALS AND METHODS

In order to achieve the objectives of the present investigation, an experiment was conducted at Radiotracer laboratory, College of Horticulture, Vellanikkara during 2004-2005. The materials used and methods adopted during the course of the study are as detailed below.

3.4 COLLECTION OF SOIL

The bulk surface soil sample (0-20 cm) was collected from the main campus of Kerala Agricultural University near Radiotracer Laboratory, Vellanikkara. The area came under the Vellanikkara I soil series (Soil Survey Staff, 1976) and belonging to the order Ultisol.

3.4 PROCESSING OF THE SOIL

The soil was allowed to air dry under shade, by spreading on a polyethylene sheet, powdered with a wooden mallet and passed through two-millimeter sieve.

3.3 POT CULTURE EXPERIMENT

A pot culture experiment was carried out at the glass house of the Radiotracer Laboratory, College of Horticulture, using the above soil. Earthen pots with uniform size (10" x 12") were used for the study. The pots were filled with 5 kg of processed soil.

The treatments were,

1. Three levels of P
    - a) 15 kg P_2O_5 ha^{-1}
    - b) 30 kg P_2O_5 ha^{-1}
    - c) 45 kg P_2O_5 ha^{-1}
2. Three sources of amendments
    - a) Pongamia leaves @ 5 tons ha^{-1}

b) Sodium silicate @ 500 kg SiO_2 ha^{-1}

c) Lime @ 250 kg ha^{-1}

d) No amendment

Treatment combinations: 3x4=12+1 (absolute control)

Treatment combinations were

T_1 - 15 kg P_2O_5 ha^{-1} (P1) + Pongamia leaves (A1) @ 5 t ha^{-1}
T_2 - 15 kg P_2O_5 ha^{-1} (P1) + Sodium silicate (A2) @ 500 kg SiO_2 ha^{-1}
T_3 - 15 kg P_2O_5 ha^{-1} (P1) + Lime (A3) @ 250 kg ha^{-1}
T_4 - 15 kg P_2O_5 ha^{-1} (P1) alone
T_5 - 30 kg P_2O_5 ha^{-1} (P2) + Pongamia leaves (A1) @ 5 t ha^{-1}
T_6 - 30 kg P_2O_5 ha^{-1} (P2) + Sodium silicate(A2) @ 500 kg SiO_2 ha^{-1}
T_7 - 30 kg P_2O_5 ha^{-1} (P2) + Lime (A3) @ 250 kg ha^{-1}
T_8 - 30 kg P_2O_5 ha^{-1} (P2) alone
T_9 - 45 kg P_2O_5 ha^{-1} (P3) + Pongamia leaves (A1) @ 5 t ha^{-1}
T_{10} - 45 kg P_2O_5 ha^{-1} (P3) + Sodium silicate (A2) @ 500 kg SiO_2 ha^{-1}
T_{11} - 45 kg P_2O_5 ha^{-1} (P3) + Lime (A3) @ 250 kg ha^{-1}
T_{12} - 45 kg P_2O_5 ha^{-1} (P3) alone
T_{13} - Absolute control

The experiment was laid out in a completely randomized block design with 13 treatments and 4 replications, of which one replication was used for destructive sampling for nutrient analysis.

Amendments viz. Pongamia leaves, sodium silicate and lime were added in respective treatments. Soil was then subjected to wetting and drying cycles for two weeks so as to ensure thorough mixing of added amendments with possible decomposition and other chemical changes and incorporation through out the soil system.

Soil samples were collected for chemical analysis before the application of the treatments. The fertilizer for the supply of P as basal dose through ^{32}P labelled KH_2PO_4 (^{32}P @ 0.4 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, 2002). The seeds of cowpea variety Kanakamony were sown @ 3 seeds pot^{-1} and two plants were maintained per pot.

3.4 BIOMETRIC OBSERVATIONS

The following biometric observations were taken.

3.4.1 Germination percentage

Germination percentage was found out by placing 25 seeds over a petridish containing filter paper. Water was sprinkled and number of seeds germinated to the number of seeds kept was expressed in percentage.

3.4.2 Plant height

The height of the plant was taken from the base of the plant to the terminal point at two weeks interval.

3.4.3 Number of branches per plant

The number of branches per plant was taken at two weeks interval.

3.4.4 Date of flowering

The date of flowering was noted for each plant.

3.4.5. Dry weight

Dry weight of the haulms and pods were taken after harvesting.

3.5 SOIL ANALYSIS

Processed initial soil samples before the application of treatments was characterised with respect to pH, EC, organic carbon, available P, available K, exchangeable cations and cation exchange capacity, different phosphorus fractions and P fixing capacity. These data are presented in Table 1. Soil samples were collected

Table 1. Chemical characteristics of the processed soil

Characteristics	Value
pH	4.78
EC	0.05 dSm^{-1}
Organic carbon	0.89%
Available phosphorus	6.4 mg kg^{-1}
Available potassium	120 mg kg^{-1}
Exchangeable calcium	480 mg kg^{-1}
Exchangeable magnesium	96 mg kg^{-1}
Exchangeable iron	4 mg kg^{-1}
Exchangeable manganese	20.3 mg kg^{-1}
Exchangeable potassium	180 mg kg^{-1}
Exchangeable sodium	220 mg kg^{-1}
Exchangeable aluminium	14.7 mg kg^{-1}
Cation exchange capacity	4.86 cmol (+) kg^{-1}
Non occluded Al and Fe bound P	68 mg kg^{-1}
P sorbed by carbonates	2.25 mg kg^{-1}
P occluded within Fe oxides and hydrous oxides	7.6 mg kg^{-1}
Ca bound P	12.4 mg kg^{-1}
Phosphorus fixing capacity	86.2%

from all the treatments before sowing, at flowering and at harvest, and were analysed for available P, different phosphorus fractions and radioactive phosphorus.

3.5.1 Soil pH

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

3.5.2 Electrical conductivity

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

3.5.3 Organic carbon

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

3.5.4 Available phosphorus

Available phosphorus in the soil samples was extracted using Bray No.1 reagent (Bray and Kurtz, 1945) and estimated colorimetrically by reduced molybdate ascorbic acid blue colour method using spectrophotometer (Watanabe and Olsen, 1965).

3.5.5 Available potassium

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

3.5.6 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 exchangeable cations (Ca, Mg, Na, K, Al, Fe and Mn) 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 sample were taken in a centrifuge tube and 40 ml of 0.1 M $BaCl_2$ was added. It was shaken for two hours and filtered through Whatman No.42 filter paper. Filterate was used for aspiration to a Perkin Etmer atomic absorption spectrophotometer for the determination of exchangeable iron and manganese. Exchangeable sodium and potassium was estimated with the help of flame photometer. Exchangeable calcium and magnesium were estimated by versanate titration method (Lanyon and Herald, 1982). Exchangeable aluminium was estimated colorimetrically using aluminon (Hsu, 1963; Jayman and Sivasubramaniam, 1974). The sum of exchangeable cations expressed in c mol(p^+) kg^{-1} recorded as the CEC of the soil.

3.5.7 Fractionation of soil phosphorus

Fractionation of soil P was carried out by the method proposed by (Olsen and Sommers, 1982). The extraction procedure involves sequential extraction with

(i) 0.1N NaOH to remove non occluded Al and Fe bound P

(ii) 1M NaCl and citrate-bicarbonate (CB) to remove P sorbed by carbonate during preceeding NaOH extraction.

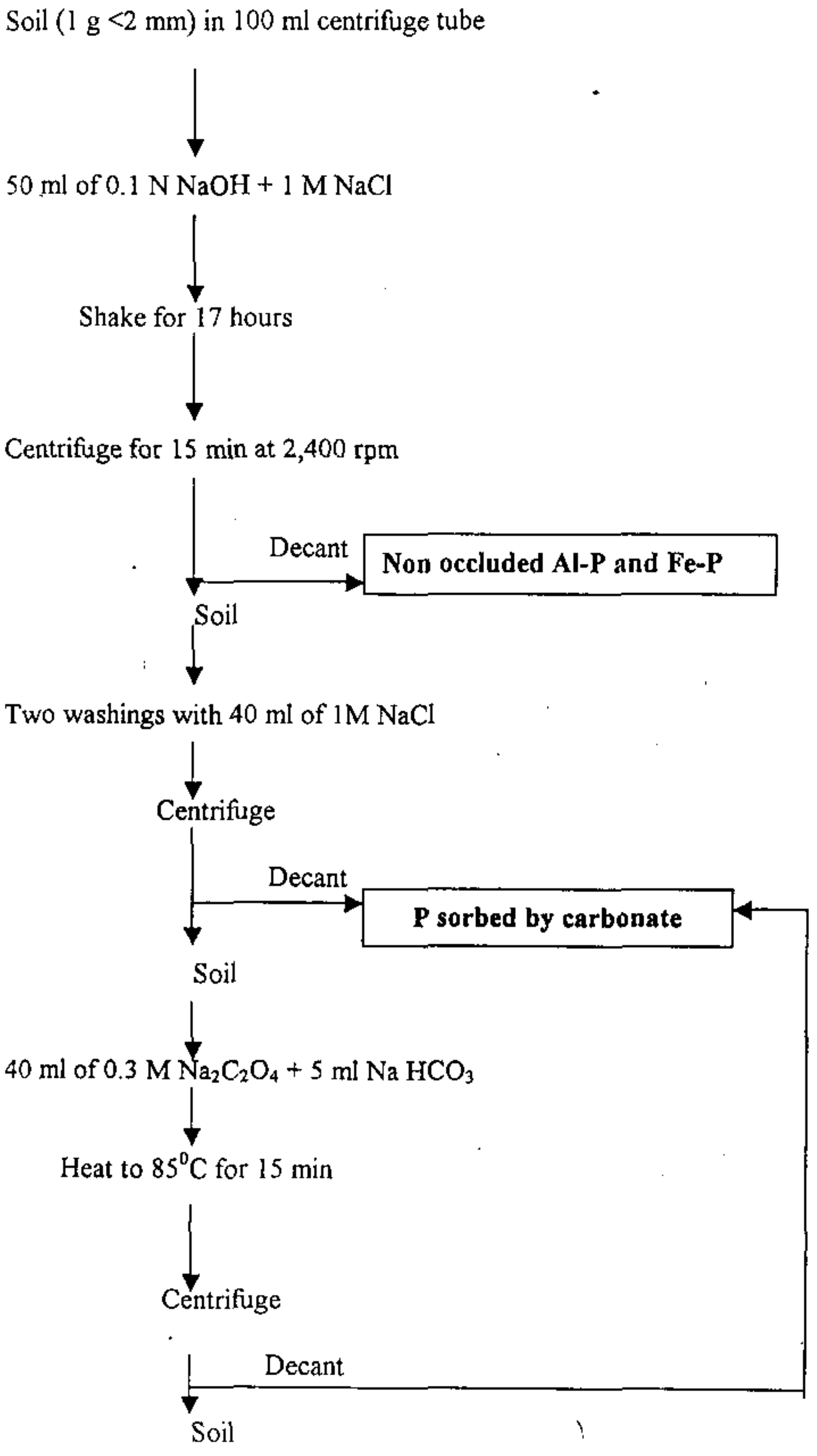
(iii) Citrate-dithionate-bicarbonate-to remove P occluded within Fe oxides and hydrous oxides.

(iv) 1N HCl to remove Ca-bound P.

3.5.7.1 Extraction of P fractions

Fig 1. represents the flow chart for the fractionation of soil P. One gram (less than two milli meters) soil was taken in a 100 ml centrifuge tube. To this 50 ml of 0.1 N NaOH-1M NaCl solution was added and shaken for 17 hours. The tubes with

Fig.1 Flow chart of fractionation of soil phosphorus



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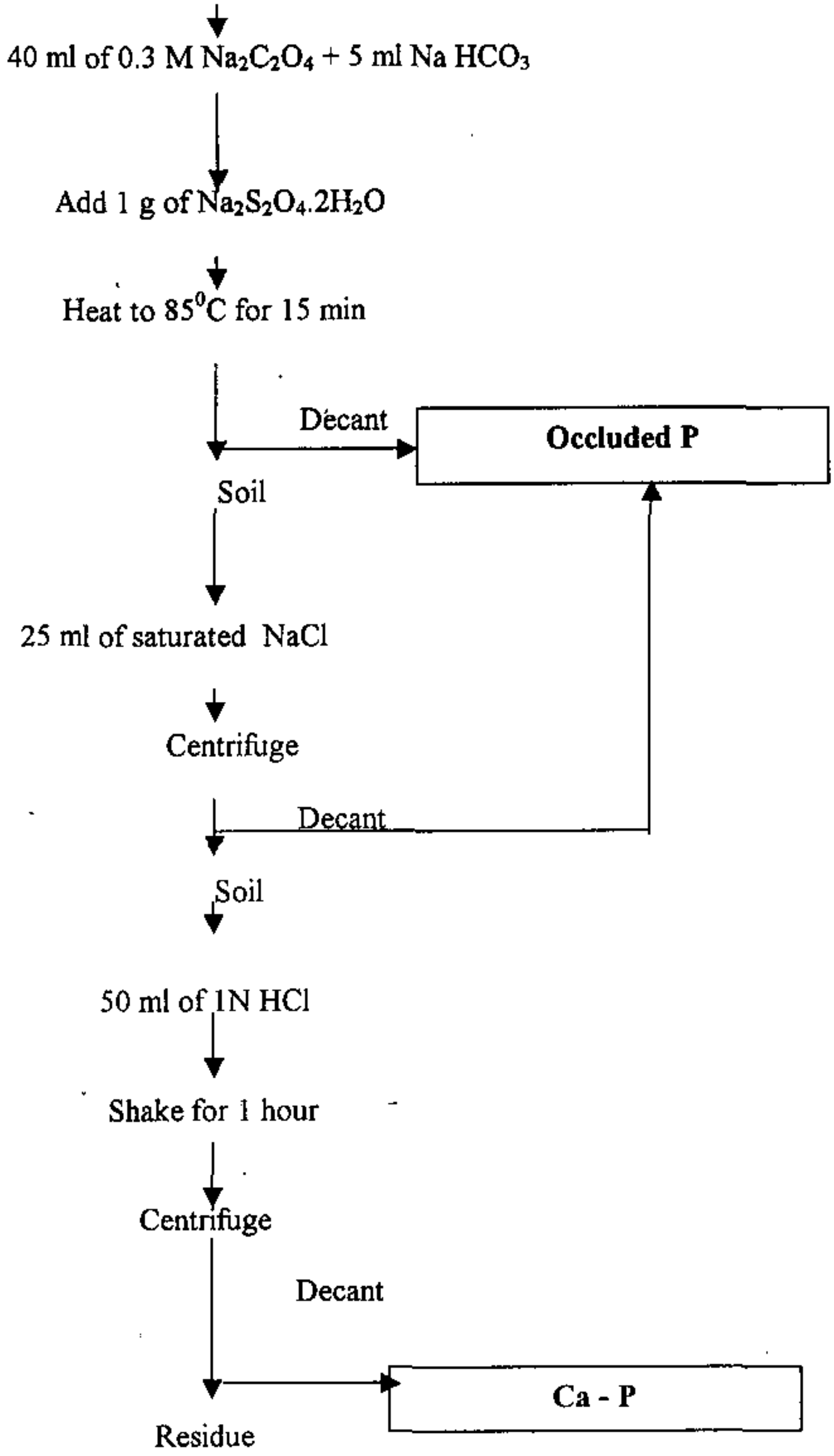
40 ml of 0.3 M $Na_2C_2O_4$ + 5 ml Na HCO_3
Add 1 g of $Na_2S_2O_4.2H_2O$
Heat to 85^{0}C for 15 min
Decant
Occluded P
Soil
25 ml of saturated NaCl
Centrifuge
Decant
Soil
50 ml of 1N HCl
Shake for 1 hour
Centrifuge
Decant
Ca - P
Residue

the extract were then centrifuged for 15 min at 2,400 rpm. The solution was decanted into another tube (non occluded Al and Fe bound P).

The soil residue in the centrifuge tube was washed twice with 40 ml portions of 1M NaCl by stirring and centrifuging. These two extracts were combined with subsequent CB extract. To the soil residue in tube 40 ml of 0.3 M citrate solution and five millilitres of 1 M $NaHCO_3$ solution was added and heated in a water bath for 15 min at 85°C. The suspension were decanted into another flask (P sorbed by carbonates).

To the soil residue 40 ml of 0.3M citrate solution and five millilitres of 1M $NaHCO_3$ solution were added and heated in a water bath to 85°C. To this 1 g of $Na_2S_2O_4.2H_2O$ was added with rapid stirring and the heating was continued to 85°C for 15 minutes. The solution was decanted into another flask (P occluded with in Fe oxides and hydrous oxides). The soil residue was washed with 25 ml of saturated NaCl. This was centrifuged and decanted the supernatant solution to the above flask.

50 ml of 1N HCl was added to the soil residue and shaken for one hour on a shaker. The solution was centrifuged and decanted to another flask (Ca bound P).

3.5.7.2 Estimation of P fractions

3.5.7.2.1 Concentration of P as non occluded Al-P and Fe-P and Ca-P fractions

Fixed quantities of the extract (five millilitres) were pipetted out into a 50 ml volumetric flask. To this distilled water was added to increase the volume to 20 ml.Four millilitres of reagent B (ascorbic acid in ammonium molybdate and potassium antimony tartarate with 5N H_2SO_4 acid) was added. The volume was made up and the concentration of P was read from the blue colour intensity in a spectronic-20 spectrophotometer at 882 nm.

3.5.7.2.2 Concentration of P as P sorbed by carbonates and occluded P with in Fe oxides and hydrous oxides

Fixed quantities of the aliquot was pipetted into 125 ml separatory funnel. To this five millilitres molybdate solution was added and distilled water to 20 ml mark. To this ten millilitres isobutyl alcohol was added. After five minutes the aqueous layer was dicarded. The isobutyl alcohol mixture was washed by shaking for one minute with 10 ml of 2N H_2SO_4 acid and discarded the aqueous layer. To this 10 ml of ascorbic acid was added, shaken for 1 hour and discarded the aqueous layer. The blue isobutyl alcohol layer was transferred to 50 ml volumetric flask and made up to 50 ml with ethyl alcohol. Maximum colour intensity was developed in 10 minutes. The concentration of P in the extract was found using a spectrophotometer at 882 nm.

3.5.8 P fixing capacity of soil

P fixing capacity was determined by incubating two g each of soil samples for 96 hours with various concentrations of phosphorus solutions prepared out of KH_2PO_4. Various 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}, 250 mg l^{-1}, 375 mg $l^{-1}$and 500 mg l^{-1}. One millilitre of P solution was added to 2 g of soil and kept for incubation. After incubation labile P was extracted using Bray No.1 and estimated the P concentration by molybdic ascorbic acid blue colour method (Ghosh *et al.*, 1983).

3.6 PLANT ANALYSIS

Plant samples were collected from different treatments 15 days after sowing (15 DAS), at flowering and at harvest and oven dried to a constant weight and ground for analysis.

3.6.1 Total phosphorus in plant sample

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 (Koenig and Johnson, 1942) and readings were taken in a spectrophotometer.

3.7 RADIO ASSAY

Radio assay of the extracts of available P, P fractions and plant P was carried out using a microprocessor controlled liquid scintillation system. The count rates per minute (cpm) for all samples were corrected for background and decay.

3.8 PERCENTAGE OF AVAILABLE P DERIVED FROM FERTILIZER

Percentage of available P derived from fertilizer was found by taking the ratio of specific activity of available P(cpmg^{-1}) to specific activity of applied fertilizer P (cpm g^{-1}) expressed as percentage.

3.9 STATISTICAL ANALYSIS

Statistical analysis of the data was carried out using MSTAT-C package.

Results

4. RESULTS

The data generated from the study as detailed in materials and methods are presented in this Chapter.

4.1 GROWTH CHARACTERS

Growth characters included in this study were germination percentage, height of the plant, number of branches per plant and date of flowering.

4.1.1 Germination percentage

The germination of seeds was found to be 100 per cent.

4.1.2 Height of the plant

4.1.2.1 15 DAS

The data on plant height at 15 DAS are presented in Table 2. As P level increased from 15 to 30 kg P_2O_5 ha^{-1}, the height of the plant increased from 17.37cm to 19.35cm. There after, it decreased to 17.62cm when the P level was at 45 kg P_2O_5 ha^{-1}. There was no significant difference in plant height at 15 kg P_2O_5 $ha^{-1}$and 45 kg P_2O_5 ha^{-1}.

Application of Pongamia leaves (19.79cm) was found to improve the plant height when compared to no amendment (17.07 cm). It was on par with sodium silicate (18.00cm) and lime (17.62 cm).

The interaction effects of levels of P and amendment was found to be non significant. The height ranged from 16.43cm (15 kg P_2O_5 ha^{-1} + lime) to 21.97cm (30 kg P_2O_5 ha^{-1} + Pongamia leaves)

4.1.2.2 30 DAS

Table 3, indicates the plant height at 30 DAS. Eventhough P levels, amendments and their interaction effects were non significant at this stage the maximum height was recorded by 45.kg P_2O_5 ha^{-1} (22.50cm). Application of 45.kg

Table 2. Effect of levels of P and amendments on height of plant (cm) at15 DAS

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	18.28	21.97	19.12	19.79
Sodium silicate (A2)	18.06	18.10	17.83	18.00
Lime (A3)	16.43	19.52	16.90	17.62
No amendment (A4)	16.70	17.83	16.67	17.07
Mean	17.37	19.35	17.62	

Control = 12.5 cm

CD(A) = 1.61 CD(P)=1.39 CD(PxA) = N.S.

Table 3. Effect of levels of P and amendments on height of plant (cm) at 30 DAS

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	20.67	22.53	24.17	22.45
Sodium silicate (A2)	22.33	19.83	23.33	21.83
Lime (A3)	20.67	20.27	22.00	20.98
No amendment (A4)	18.83	18.67	20.50	19.33
Mean	20.63	20.32	22.50	

Control = 16.5 cm

CD(A) = N.S CD(P)=N.S CD(PxA) = N.S.

P_2O_5 ha^{-1} with Pongamia leaves (24.17 cm) recorded the maximum height for the interaction.

4.1.2.3 45 DAS

Plant height at 45 DAS are presented in Table 4.As the P levels increased from 15 to 30 kg P_2O_5 ha^{-1}, height of the plant increased from 25.98 cm to 26.90 cm and then it decreased to 24.63 cm as the P level increased to 45 kg P_2O_5 ha^{-1}.

None of the amendment was found to significantly influence the plant height at this stage. The height ranged from amendment treatment with no amendment (25.27 cm) to Pongamia leaves (28.14 cm).

The interaction effect was found to be significant.

4.1.2.4 60 DAS

Table 5, represents the plant height at 60 DAS. At this stage, application of P at 15 to 30 kg P_2O_5 ha^{-1} was found to improve the plant height from 26.83 cm to 28.91 cm and then it decreased to 28.66 cm as the P level increased to 45 kg P_2O_5 ha^{-1}.

The application of amendment viz. Pongamia leaves (29.43cm) significantly improved the plant height when compared to no amendment (27.11cm). However, there was no significant difference in height between the amendment applications.

The interaction effect was found to be non significant.

4.1.3 Number of branches

The P levels and amendment treatments had no significant influence on number of branches per plant at 15 DAS, 30 DAS, 45 DAS and 60 DAS (Table 6).

4.1.4 Date of flowering

The data on the date of flowering are presented in Table 7. Treatment 45 kg P_2O_5 ha^{-1} + Pongamia leaves recorded early flowering.

Table 4. Effect of levels of P and amendments on height of plant (cm) at 45 DAS

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	27.33	28.30	28.80	28.14
Sodium silicate (A2)	25.27	27.23	27.12	26.54
Lime (A3)	26.60	24.30	25.30	25.40
No amendment (A4)	24.73	27.77	23.30	25.27
Mean	25.98	26.90	24.63	

Control = 22.17 cm

CD(A) = NS CD(P)=1.94 CD(PxA) = 3.36

Table 5. Effect of levels of P and amendments on height of plant (cm) at 60 DAS

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	28.97	29.50	29.83	29.43
Sodium silicate (A2)	26.50	27.63	29.97	28.03
Lime (A3)	26.83	29.67	27.33	27.94
No amendment (A4)	25.00	28.83	27.50	27.11
Mean	26.83	28.91	28.66	

Control = 23 cm

CD(A) = 1.47 CD(P)=0.99 CD(PxA) = N.S.

Table 6. Effect of P levels and amendments on number of branches of cowpea

Treatments	Number of branches per plant			
	15 DAS	30 DAS	45 DAS	60 DAS
Pongamia leaves + P_1	1	2	2.33	4.66
Sodium silicate + P_1	1	2	2.00	4.00
Lime + P_1	1	2	2.33	4.33
P_1alone	1	2	2.00	4.00
Pongamia leaves + P_2	1	2	2.00	4.33
Sodium silicate + P_2	1	2	1.66	4.00
Lime + P_2	1	2	2.33	4.00
P_2alone	1	2	2.00	4.00
Pongamia leaves + P_3	1	2	3.00	5.00
Sodium silicate + P_3	1	2	3.00	5.00
Lime + P_3	1	2	2.66	4.66
P_3 alone	1	2	2.66	4.66
Control	1	2	2.00	4.00

Table 7. Effect of P levels and amendments on date of flowering

Treatments	Date of flowering
Pongamia leaves + P_1	10.2.05
Sodium silicate + P_1	15.2.05
Lime + P_1	13.2.05
P_1alone	14.2.05
Pongamia leaves + P_2	13.2.05
Sodium silicate + P_2	14.2.05
Lime + P_2	13.2.05
P_2alone	12.2.05
Pongamia leaves + P_3	8.2.05
Sodium silicate + P_3	10.2.05
Lime + P_3	11.2.05
P_3alone	11.2.05
Control	11.2.05

4.2 AVAILABLE P

Available P in soil was estimated at three stages i.e. just before sowing, flowering and harvesting.

4.2.1 Available P just before sowing

Table 8, gives the data on available P in soil, just before sowing. At this stage application of P was found to improve the available P from the initial status of 6.4 mg kg^{-1} (Table1). The different levels of P were found to be significantly different. It was observed that as P level increased from 15 to 45 kg P_2O_5 ha^{-1}, the available P status improved from 7.94 to 14.21 mg kg^{-1}.

At this stage, none of the amendments were found to be significantly influencing the available P. The available P ranged from treatment with no amendment (10.77 mg kg^{-1}) to Pongamia leaves (11.70 mg kg^{-1}).

The interaction effect was found to be non significant. The available P status varied from 7.60 (15 kg P_2O_5 ha^{-1} + no amendment) to 15.13 mg kg^{-1} (45 kg P_2O_5 ha^{-1} + Pongamia leaves).

4.2.2 Available P at flowering

The data on available P in soil, at flowering are presented in Table 9. At flowering, available P content of the soil, increased significantly from 8.33 to 13.96 mg kg^{-1} as the applied P level was enhanced from 15 to 45 kg P_2O_5 ha^{-1}.

The amendments had a significant influence on the available P. The Pongamia leaf incorporation (12.06 mg kg^{-1}) was found to enhance the available P, which was superior to other two amendments *viz;* sodium silicate (11.27 mg kg^{-1}) and lime (11.42 mg kg^{-1}). However, sodium silicate and lime application had a significantly better influence on improving the available P in comparison with P levels without amendments (10.45 mg kg^{-1}).

Table 8. Effect of levels of P and amendments on available P (mg kg^{-1}) in soil just before sowing

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	8.17	11.80	15.13	11.70
Sodium silicate (A2)	7.83	11.03	14.60	11.16
Lime (A3)	8.17	11.37	12.83	10.79
No amendment (A4)	7.60	10.47	14.26	10.77
Mean	7.94	11.17	14.21	

Control = 6.63 mg kg^{-1}

CD(A) = N.S. CD(P) = 0.80 CD(PxA) = N.S.

Table 9. Effect of levels of P and amendments on available P (mg kg^{-1}) in soil at flowering

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	8.57	12.33	15.27	12.06
Sodium silicate (A2)	8.24	11.50	14.07	11.27
Lime (A3)	8.47	12.09	13.70	11.42
No amendment (A4)	8.02	10.53	12.80	10.45
Mean	8.33	11.61	13.96	

Control = 7.23 mg kg^{-1}

CD(A) = 0.41 CD(P) = 0.36 CD(PxA) = 0.72

Table 10. Effect of levels of P and amendments on available P (mg kg^{-1}) in soil at harvest

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	7.93	10.30	12.47	10.23
Sodium silicate (A2)	7.67	9.93	12.00	9.87
Lime (A3)	7.73	10.23	12.27	10.08
No amendment (A4)	7.50	9.53	11.17	9.40
Mean	7.71	10.00	10.98	

Control = 6.57 mg kg^{-1}

CD(A) = 0.26 CD(P) = 0.22 CD(PxA) = N.S.

The interaction effect of P levels and amendments significantly influence the available P status. Further, at higher levels of P (30 and 45 kg P_2O_5 ha^{-1}) with Pongamia leaves was significantly superior in improving the available P status (12.33 and 15.27 mg kg^{-1}) in comparison with other amendments.

4.2.3 Available P at harvest

Table 10 indicates the data on available P in soil at harvest. As in the case of available P at flowering, at harvesting also higher levels of P, significantly improved the available P ie. 7.71, 10.00 and 10.98 mg kg^{-1} of available P at 15, 30 and 45 kg P_2O_5 ha^{-1} of applied P respectively.

Application of Pongamia leaves (10.23 mg kg^{-1}) was found to improve the available P status with significant difference as that of sodium silicate (9.87 mg kg^{-1}). However, the available P content in lime treated pots (10.08 mg kg^{-1}) was on par with that of application of Pongamia leaves.

The interaction effect of P levels and amendments was found to be not significant. The available P ranged from 7.50 mg kg^{-1} (15 kg P_2O_5 ha^{-1} + no amendment) to 12.47 mg kg^{-1} (45 kg P_2O_5 ha^{-1} + Pongamia leaves).

It was found that available P in soil increased from sowing to flowering and then decreased at the time of harvesting.

4.3 FRACTIONS OF PHOSPHORUS IN SOIL

Fractions of Phosphorus in soil viz. non occluded Al –P and Fe-P, P sorbed by carbonates, occluded P and Ca-P were estimated at three stages in soil just before sowing, flowering and harvesting.

4.3.1 Non occluded Al-P and Fe-P fraction

4.3.1.1 Non-occluded Al-P and Fe-P at sowing

Table 11 represents non-occluded Al-P and Fe-P just before sowing. At this stage, higher level of P at 45 kg P_2O_5 ha^{-1} was found to contribute significantly to

Table 11. Effect of levels of P and amendments on non occluded Al-P and Fe-P (mg kg^{-1}) in soil just before sowing

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	105.83	124.54	121.42	117.26
Sodium silicate (A2)	94.47	100.16	111.75	102.12
Lime (A3)	89.67	90.81	106.23	95.57
No amendment (A4)	86.02	88.08	93.30	89.13
Mean	93.99	100.89	108.18	

Control = 70.01 mg kg^{-1}

CD(A) = 7.16 CD(P) = 6.20 CD(PxA) = 12.40

Table 12. Effect of levels of P and amendments on non occluded Al-P and Fe-P (mg kg^{-1}) in soil at flowering

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	65.67	71.67	80.67	72.67
Sodium silicate (A2)	62.00	64.00	71.00	65.67
Lime (A3)	62.67	67.67	74.67	68.33
No amendment (A4)	59.33	65.33	74.25	65.11
Mean	62.42	67.17	74.25	

Control = 38.33 mg kg^{-1}

CD(A) = 1.97 CD(P) = 1.70 CD(PxA) = N.S.

Table 13. Effect of levels of P and amendments on non occluded Al-P and Fe-P (mg kg^{-1}) in soil at harvesting

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	49.17	55.61	68.65	57.81
Sodium silicate (A2)	48.65	54.87	66.63	56.69
Lime (A3)	48.77	54.28	67.56	56.87
No amendment (A4)	47.03	53.73	65.90	55.56
Mean	48.38	54.62	67.19	

Control = 37.49 mg kg^{-1}

CD(A) = 1.34 CD(P) = 1.16 CD(PxA) =N.S.

this fraction (108.18mg kg^{-1}) in comparison to 30 kg P_2O_5 ha^{-1} (100.89 mg kg^{-1}) and 15 kg P_2O_5 ha^{-1} (93.99 mg kg^{-1}).

Non-occluded Al-P and Fe-P was the highest in Pongamia treated pots (117.26 mg kg^{-1}) which differ significantly with lime (95.57 mg kg^{-1}) and sodium silicate (102.12 mg kg^{-1}).

The interaction effect of levels of P and amendments was found to be significant. Treatment 30 kg P_2O_5 ha^{-1}+Pongamia leaves (124.54 mg kg^{-1}) showed the highest contribution to this fraction which was on par with 45kg P_2O_5 ha^{-1} + Pongamia leaves (121.42 mg kg^{-1}). No amendment +15 kg P_2O_5 ha^{-1} (86.02 mg kg^{-1}) showed the lowest value for this fraction. Control pot recorded 70.01 mg kg^{-1} for non-occluded Al-P and Fe-P fraction.

4.3.1.2 Non Occluded Al-P And Fe-P at flowering

Table 12, indicates the non occluded Al-P and Fe-P at flowering. Similar was the trend for this fraction at flowering as just before sowing for the different levels of P. As the level of P increased from 15 to 45 kg ha^{-1} the non occluded Al-P and Fe-P increased from 62.42 to 74.25 mg kg^{-1}.

Application of Pongamia leaves (72.67mg kg^{-1}) was found to increase the non occluded Al-P and Fe-P status with significant difference as that of sodium silicate (65.67mg kg^{-1}) and lime (68.33mg kg^{-1}).

The interaction effect of levels of P and amendments was found to be not significant. This fraction ranged from 80.67 mg kg^{-1} (45 kg $P_2O_5ha^{-1}$ + Pongamia leaves) to 59.33 mg kg^{-1} (15 kg P_2O_5 ha^{-1} + no amendment). This fraction recorded only 38.33 mg kg^{-1} for the control.

4.3.1.3 Non occluded Al-P and Fe-P at harvesting

The data on non-occluded Al-P and Fe-P at harvesting is presented in Table13. At this stage, similar trend as just before sowing and flowering for this fraction for levels of P was noticed. As the levels of P increased, the contribution to this fraction also increased i.e. 48.38 mg kg^{-1}, 54.62 mg kg^{-1} and 67.19 mg kg^{-1} for 15, 30 and 45 kg P_2O_5 ha^{-1}respectively.

Applications of Pongamia leaves (57.81 mg kg-1) significantly differ for this fraction compared to no amendment (55.56 mg kg^{-1}), whereas it was on par with sodium silicate (56.69 mg kg^{-1}), lime (56.87 mg kg^{-1}).

The interaction effect of different levels of P and amendments was found to be not significant. This fraction ranged from 47.03 (15 kg P_2O_5 ha^{-1} + no amendment) to 68.65 mg kg^{-1} (45 kg P_2O_5 ha^{-1} + Pongamia leaves). The lowest value of 37.49 mg kg^{-1} was recorded for the control for non occluded Al-P and Fe-P.

It was found that non occluded Al-P and Fe-P decreased from just before sowing to harvesting.

4.3.2 P sorbed by carbonate fraction in soil

4.3.2.1 P sorbed by carbonate just before sowing

Table 14 represents the data on effect of levels of P and amendments on P sorbed by carbonates in soil just before sowing.

Higher level of P was found to be significantly contributing to this fraction at this stage. The higher level of P, 45 kg P_2O_5 ha^{-1} recorded P sorbed by carbonate of 14.14 mg kg^{-1} compared to 30 and 15 kg P_2O_5 ha^{-1} of 11.16 mg kg^{-1} and 6.28 mg kg^{-1} respectively.

Incorporation of Pongamia leaves (12.74 mg kg^{-1}) was found to contribute to this fraction significantly compared to no amendment (7.52 mg kg^{-1}) and sodium silicate (10.51 mg kg^{-1}) while it was on par with lime (11.33 mg kg^{-1}).

The interaction effect of treatments and amendments was found to be not significant. The value ranged between 4.48 mg kg^{-1} (15 kg P_2O_5 ha^{-1} + No amendment) and 16.47 mg kg^{-1} (45 kg P_2O_5 ha^{-1} + Pongamia leaves). Control recorded only 2.69 mg kg^{-1} for P sorbed by carbonate fraction.

Table 14. Effect of levels of P and amendments on P sorbed by (mg kg^{-1}) in carbonate in soil just before sowing

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	8.93	12.83	16.47	12.74
Sodium silicate (A2)	6.28	11.17	14.10	10.51
Lime (A3)	5.43	13.39	15.17	11.33
No amendment (A4)	4.48	7.24	10.83	7.52
Mean	6.28	11.16	14.14	

Control = 2.69 mg kg^{-1}

CD(A) = 1.90 CD(P) = 1.65 CD(PxA) = N.S.

Table 15. Effect of levels of P and amendments on P sorbed by carbonate (mg kg^{-1}) in soil at flowering

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	7.29	9.90	11.98	9.72
Sodium silicate (A2)	6.77	9.38	10.94	9.03
Lime (A3)	5.73	8.33	10.94	9.33
No amendment (A4)	4.17	7.29	10.42	7.29
Mean	5.99	8.72	11.07	

Control = 2.65 mg kg^{-1}

CD(A) = 1.64 CD(P) = 1.42 CD(PxA) = N.S.

Table 16. Effect of levels of P and amendments on P sorbed by carbonate (mg kg^{-1}) in soil at harvesting

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	6.57	8.57	11.10	8.74
Sodium silicate (A2)	5.00	8.03	10.60	7.88
Lime (A3)	5.00	8.03	10.60	7.88
No amendment (A4)	4.50	6.50	10.10	7.03
Mean	5.27	7.78	10.60	

Control = 2.52 mg kg^{-1}

CD(A) = 1.05 CD(P) = 0.91 CD(PxA) = N.S.

4.3.2.2 P sorbed by carbonate at flowering

The data on the effect of levels of P and amendments on P sorbed by carbonate are presented in Table 15.

Application of P was found to contribute significantly to P sorbed by carbonate fraction at flowering. As the levels of P increased from 15 to 45 kg P_2O_5 ha^{-1}, this fraction improved from 5.99 to 11.07 mg kg^{-1}.

At flowering, the Pongamia leaves (9.72 mg kg^{-1}), sodium silicate (9.03 mg kg^{-1}) and lime (9.33 mg kg^{-1}) had significant contribution to P sorbed by carbonate fraction compared to no amendment (7.29 mg kg^{-1}). The different amendment treatments were on par.

The interaction effect was found to be not significant. This fraction ranged from 15 Kg P_2O_5 ha^{-1} + no amendment (4.17 mg kg^{-1}) to 45 kg P_2O_5 ha^{-1} + Pongamia leaves (11.98 mg kg^{-1}). Only 2.65 mg kg^{-1} was recorded for the treatment control.

4.3.2.3 P sorbed by carbonate at harvesting

Table 16 shows the effect of levels of P and amendments on P sorbed by carbonates in soil at harvesting. Similar was the trend of P sorbed by carbonate in soil at harvesting as that of sowing and flowering. As the level of P increased from 15 to 45 kg P_2O_5 ha^{-1} the contribution to P sorbed by carbonate improved from 5.27 to 10.60 mg kg^{-1}.

Comparing the effect of different amendments at this stage, Pongamia leaf (8.74 mg kg^{-1}) incorporation was found to significantly contribute to this fraction compared to no amendment (7.03 mg kg^{-1}), while sodium silicate (7.88 mg kg^{-1}) and lime (7.88 mg kg^{-1}) was found to be on par.

Interaction effect of levels of P and amendments was found to be not significant. The P sorbed by carbonate fraction ranged from 15 kg P_2O_5 ha^{-1}+ No amendment (4.50 mg kg^{-1}) to 45 kg P_2O_5 ha^{-1} + Pongamia leaves (11.10 mg kg^{-1}). The lowest value of 2.52mg kg^{-1} was recorded in the control for P sorbed by carbonate.

P sorbed by carbonate fraction was also found to decrease from just before sowing to harvesting.

4.3.3 Occluded P fraction

4.3.3.1 Occluded P fraction just before sowing

The data on occluded P fraction in soil just before sowing are presented in Table 17. At this stage, different levels of P were found to significantly contribute to the occluded P fractions in soil. It was observed that as P level increased from 15 to 45kg P_2O_5 ha^{-1}, the occluded P increased from 13.37 to 18.13 mg kg^{-1}.

The amendment application was found to significantly influencing the occluded P fractions. Incorporation of Pongamia leaves (16.54 mg kg^{-1}) was superior to other two amendments viz; sodium silicate (15.98 mg kg^{-1}) and lime (15.60 mgkg^{-1}) in contributing to occluded P. However, sodium silicate and lime application significantly contribute to this fraction when compared to no amendment (14.93 mg kg^{-1}) application.

The interaction effect was found to be not significant. Occluded P fraction ranged from 12.40 (15 kg P_2O_5 ha^{-1} + no amendment) to 18.83 mg kg^{-1} (45 kg P_2O_5 ha^{-1} + Pongamia leaves). Control pot recorded only 7.33 mg kg^{-1} for occluded P fraction.

4.3.3.2 Occluded P fraction at flowering

The data on occluded P fraction in soil at flowering are presented in Table 18. At this stage, levels of P on occluded P had showed same trend as just before sowing. As the levels of P increased, the occluded P also increased significantly. The ascending order of this fraction for different levels of P was 9.35, 13.70 and 16.46 mg kg^{-1} for 15, 30 and 45 kg P_2O_5 ha^{-1} respectively.

The amendments had significant difference on the occluded P fraction in soil at flowering. Incorporation of Pongamia leaves had greatest contribution to

Table 17. Effect of levels of P and amendments on occluded (mg kg^{-1}) in soil just before sowing

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	14.40	16.40	18.83	16.54
Sodium silicate (A2)	13.78	15.97	18.20	15.98
Lime (A3)	12.89	15.97	17.97	15.60
No amendment (A4)	12.40	14.90	17.50	14.93
Mean	13.37	15.81	18.13	

Control = 7.33 mg kg^{-1}

CD(A) = 0.5 CD(P) = 0.47 CD(PxA) = N.S.

Table 18. Effect of levels of P and amendments on occluded P (mg kg^{-1}) in soil at flowering

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	10.65	16.13	17.47	14.75
Sodium silicate (A2)	10.15	14.75	16.60	13.83
Lime (A3)	8.77	13.38	17.03	13.06
No amendment (A4)	7.84	10.55	14.75	11.05
Mean	9.35	13.70	16.46	

Control = 5.65 mg kg^{-1}

CD(A) = 0.75 CD(P) = 0.92 CD(PxA) = N.S.

Table 19. Effect of levels of P and amendments on occluded P (mg kg^{-1}) in soil at harvesting

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	8.37	13.06	15.23	12.22
Sodium silicate (A2)	7.53	11.97	14.17	11.22
Lime (A3)	7.37	12.13	14.20	11.23
No amendment (A4)	6.51	9.73	13.51	9.92
Mean	7.44	11.72	14.28	

Control = 3.43 mg kg^{-1}

CD(A) = 0.69 CD(P) = 0.60 CD(PxA) = N.S.

occluded P of 14.75 mg kg^1 than sodium silicate (13.83 mg kg^1) and lime (13.06 mg kg^1).

The interaction effect of amendments and levels of P was found to be non significant. The value ranged from 7.84 mg kg^{-1} (15 kgP_2O_5 kg^{-1}+ no amendment) to 17.47 $mgkg^{-1}$ (45 kgP_2O_5 ha^{-1}+ Pongamia leaves). Only 5.65 mg kg^{-1} was recorded for the treatment control for occluded P.

4.3.3.3 Occluded P at harvesting.

Table 19 represents the data on occluded P at harvesting. At this stage, same trend was shown by levels of P on occluded P in soil as just before sowing and flowering. As the levels of P increased from 15 to 45 kg P_2O_5 ha^{-1} the occluded P increased from 7.44 to 14.28 mg kg^{-1}.

The amendment application significantly contributed to occluded P compared to no amendment. Pongamia leaves (12.22 mg kg^{-1}) has recorded highest influence in contributing to the occluded P than sodium silicate (11.22 mg kg^{-1}) and lime (11.23 mg kg^{-1}).

The interaction effect of levels of P and amendments was found to be not significant. The value ranged from 6.51 (15 kg P_2O_5 ha^{-1}+ no amendment) to 15.23 mg kg^{-1} (45 kg P_2O_5 ha^{-1}+ Pongamia leaves). The lowest value of 3.43mg kg^{-1} was recorded in the control for occluded P.

The occluded P fraction also decreased from sowing to harvesting.

4.3.4 Calcium-P fraction

4.3.4.1 Calcium-P fraction at sowing

Table 20 presents the data on levels of P and amendments on Ca-P in soil just before sowing. At this stage, application of P was found to contribute significantly

Table 20. Effect of levels of P and amendments on Ca-P (mg kg^{-1}) in soil just before sowing

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	18.67	24.67	25.17	22.83
Sodium silicate (A2)	17.33	22.83	23.67	21.28
Lime (A3)	19.00	24.83	25.67	23.17
No amendment (A4)	17.50	20.50	22.33	20.11
Mean	18.13	23.21	24.21	

Control = 12.00 mg kg^{-1}

CD(A) = 0.77 CD(P) = 0.67 CD(PxA) = N.S.

Table 21. Effect of levels of P and amendments on Ca-P (mg kg^{-1}) in soil at flowering

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	18.67	23.50	25.17	22.44
Sodium silicate (A2)	18.17	22.50	24.33	21.67
Lime (A3)	18.83	23.83	25.33	22.67
No amendment (A4)	17.17	20.17	23.57	20.33
Mean	18.21	22.50	24.63	

Control = 11.67 mg kg^{-1}

CD(A) = 0.41 CD(P) = 0.35 CD(PxA) = 0.70

Table 22. Effect of levels of P and amendments on Ca-P (mg kg^{-1}) in soil at harvesting

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	18.86	23.93	25.33	22.71
Sodium silicate (A2)	18.25	22.81	24.70	21.92
Lime (A3)	19.24	23.87	25.87	22.99
No amendment (A4)	16.95	20.65	23.83	20.48
Mean	18.32	22.82	24.93	

Control = 12.84 mg kg^{-1}

CD(A) = 0.43 CD(P) = 0.37 CD(PxA) = N.S.

to the Ca-P fraction in soil. It was observed that as the level of P increases, contribution to the Ca-P fraction also increases. As the levels of P increased from 15 to 45 kg P_2O_5 ha^{-1} the fraction increased from 18.13 to 24.21 mg kg^{-1}.

Pongamia leaves (22.83 mg kg^{-1}), sodium silicate (21.28 mg kg^{-1}), lime (23.17 mg kg^{-1}) significantly contributed to Ca-P fraction compared to no amendments (20.11 mg kg^{-1}). However, lime made significantly higher contribution compared to sodium silicate, but it was on par with Pongamia leaves.

The interaction effect of levels of P and amendments was found to be not significant. Control recorded only 12.00 mg kg^{-1} for Ca-P fraction.

4.3.4.2 Calcium-P fraction at flowering

The data on the effects of levels of P and amendments on Ca-P in soil at flowering are shown in Table 21. The application of different levels of P made significant contribution to the Ca-P fraction in soil. The same trend, at sowing was observed in Ca-P for different levels of P at this stage. As the P level increased, the Ca-P fraction also increased in the order 18.21, 22.50 and 24.63 mg kg^{-1} for 15, 30 and 45 kg P_2O_5 ha^{-1} respectively.

The amendments significantly contribute to the calcium P. Application of lime (22.67 mg kg^{-1}) was found to contribute the highest to Ca-P, compared to sodium silicate (21.67 mg kg^{-1}) and no amendment (20.33 mgkg^{-1}) and it was on par with Pongamia leaves (22.44 mg kg^{-1}).

The interaction effect of amendments and levels of P was found to be significant. Further at all levels of P i.e., 15, 30 and 45 kg P_2O_5 ha^{-1}, lime application was significantly superior in contributing to the Ca-P fraction of 18.83, 23.83 and 25.33 mg kg^{-1} respectively in comparison to other amendments. Only 11.67 mg kg^{-1} was recorded in the control for Ca-P fraction.

4.3.4.3 Ca-P at harvesting

Table 22 represents the data on effect of levels of P and amendments on Ca-P fraction in soil at harvesting. The same trend as at flowering and just before sowing was observed for Ca-P at harvesting also. As the P levels increased from 15 to 45 kg P_2O_5 ha^{-1}, Ca-P fraction increased from 18.32 to 24.93 mg kg^{-1}.

The amendments lime (22.99 mg kg^{-1}), Pongamia leaves (22.71 mg kg^{-1}), and sodium silicate (21.92 mg kg^{-1}) significantly contributed to Ca-P fraction compared to no amendment (20.48 mg kg^{-1}). Lime significantly contributed to this fraction than sodium silicate, while it was on par with Pongamia leaves.

The interaction effect of levels of P and amendments was found to be not significant. The Ca-P fraction ranged from 16.95 (15 kg P_2O_5 ha^{-1} + no amendment) to 25.87 (45 kg P_2O_5 ha^{-1} + lime). The lowest value of 12.84mg kg^{-1} was recorded in the control for Ca-P.

The Ca-P fraction remained almost same through out the growth period.

4.4 CONTRIBUTION FROM DIFFERENT FRACTIONS OF P TO AVAILABLE P

Correlation coefficients were worked out with available P as dependent variable and fractions of P as independent variable. Since the correlation coefficients (r) were found to be significant in all cases, path analysis was carried out to obtain the direct and indirect effects of various fractions of P on available P.

4.4.1 Just before sowing

Data in Table 23 showed that the path coefficients, indicating both direct and indirect effects of different P fractions on available P just before sowing. Available P was significantly correlated with non occluded Al-P and Fe-P ($r = 0.5815$), P sorbed by carbonate ($r = 0.7809$), occluded P ($r = 0.8642$) and Ca-P ($r = 0.8099$). Non occluded Al-P and Fe-P had no direct significant effect, but influenced only indirectly through occluded P. P sorbed by carbonate had no direct significant effect, but indirectly influenced through occluded P. The effect of occluded P was

Table 23. Path coefficients indicating direct and indirect effect of fractions of P on available P just before sowing

	Non occluded Al-P and Fe-P	P sorbed by carbonate	Occluded P	Ca-P	Correlation coefficient (r)
Non occluded Al-P and Fe-P	**-0.1231**	-0.1474	0.5409*	0.0163	0.5815*
P sorbed by carbonate	-0.0877	**0.2068**	0.6412*	0.2060	0.7809*
Occluded P	-0.0822	0.1757	**0.7548***	0.0219	0.8642*
Ca-P	-0.0841	0.1786	0.6915*	**0.0239**	0.8099*

Direct effects are in main diagonal. Values on horizontal rows are indirect effect. 'r' value represents the simple correlation coefficient of factors listed with available P.

direct and significant. The influence of Ca-P fraction on available P, indirectly through occluded P.

4.4.2 At flowering

The path coefficients of different fractions on available P at flowering are presented in Table 24. The available P was correlated significantly with non occluded Al-P and Fe-P (r = 0.7911), P sorbed by carbonate (r = 0.8338), occluded P (r = 0.9201) and Ca-P (r = 0.9108) at flowering .Non occluded Al-P and Fe-P had no direct significant effect, but indirectly through Ca-P. The direct effect of P sorbed by carbonate was not significant and the only significant indirect effect is through Ca-P fraction. Occluded-P influenced directly and significantly to the available P. The significant indirect effect of occluded P to available P was through Ca-P. The effect of Ca-P was direct and significant.

4.4.3 At harvesting

The path coefficients of different fractions of P on available P at harvesting are presented in Table 25. The available P was significantly correlated with non occluded Al-P and Fe-P (r = 0.9557), P sorbed by carbonate (r = 0.9235), occluded P (r = 0.9521) and Ca-P (r = 0.9394) at harvesting. Non occluded Al-P and Fe-P had direct significant effect on available P. P sorbed by carbonate, occluded P and Ca-P had no direct significant effect. P sorbed by carbonate had indirect positive effect from non occluded Al-P and Fe-P, occluded P and Ca-P, but not significant. The indirect positive effect of occluded P through non occluded Al-P and Fe-P, Ca-P and P sorbed by carbonate was not significant. The Ca-P influenced the available P indirectly and positively through non occluded Al-P and Fe-P, occluded P, P sorbed by carbonates. But the effect was not significant.

Table 24. Path coefficients indicating direct and indirect effect of fractions of P on available P at flowering

	Non occluded Al-P and Fe-P	P sorbed by carbonate	Occluded P	Ca-P	Correlation coefficient (r)
Non occluded Al-P and Fe-P	**-0.2379**	0.0391	0.4089	0.5811*	0.7911*
P sorbed by carbanate	-0.1807	**0.0514**	0.4339	0.5292*	0.8338*
Occluded P	-0.1974	0.0453	**0.4927***	0.5795*	0.9201*
Ca-P	-0.2171	0.0428	0.4484	**0.6367***	0.9108*

Direct effects are in main diagonal. Values on horizontal rows are indirect effect. 'r' value represents the simple correlation coefficient of factors listed with available P.

Table 25. Path coefficients indicating direct and indirect effect of fractions of P on available P at harvesting

	Non occluded Al-P and Fe-P	P sorbed by carbonate	Occluded P	Ca-P	Correlation coefficient (r)
Non occluded Al-P and Fe-P	**0.4572***	0.1183	0.2338	0.1464	0.9557*
P sorbed by carbonate	0.4149	**0.1303**	0.2330	0.1453	0.9235*
Occluded P	0.4251	0.1207	**0.2515**	0.1548	0.9521*
Ca-P	0.4149	0.1183	0.2431	**0.1601**	0.9394*

Direct effects are in main diagonal. Values on horizontal rows are indirect effect. 'r' value represents the simple correlation coefficient of factors listed with available P.

4.5 RADIO ASSAY FOR AVAILABLE P AND P FRACTIONS

4.5.1 Radio assay in available P

Table 26 shows the radioactivity in available P pool (cpm g^{-1}) in soil just before sowing. Only 45 kg P_2O_5 ha^{-1} level of P showed the radioactivity in terms of count for available P at this stage.

At flowering, radioactivity could not be detected in any of the treatments.

At harvesting, 30 and 45 kg $P_2O_5ha^{-1}$ level of P recorded radioactivity for available P (Table 27).

4.5.2 Radio assay in P fractions

4.5.2.1 Radio assay in non occluded Al-P and Fe- P

This fraction did not register any radioactivity at just before sowing, at flowering and harvesting.

4.5.2.2 Radio assay in P sorbed by carbonate fraction

Table 28 shows the radioactivity in P sorbed by carbonate (cpm g^{-1}) in soil just before sowing.

P sorbed by carbonate fraction recorded radioactivity for all the treatments at just before sowing.This fraction recorded highest ^{32}P value of 305.35 cpmg^{-1} for the treatment 45 kg P_2O_5 ha^{-1}. This fraction did not register a radioactivity at flowering and at harvest stages.

4.5.2.3 Radio assay in occluded P fraction

Table 29 shows the radioactivity in occluded P fraction (cpm g^{-1}) in soil just before sowing. Occluded P fraction recorded radioactivity for all the treatments at just before sowing only. Phosphorus level of 30 kg P_2O_5 ha^{-1}recorded highest value of 57.62 cpmg^{-1}, where as for amendments lime recorded highest value of 40.78 cpmg^{-1}. This fraction did not give radioactivity at flowering or at harvest stages.

Table 26. Radio activity in available P (cpm g^{-1}) in soil just before sowing

Treatments	P1	P2	P3
Pongamia leaves (A1)	0	0	27.78
Sodium silicate (A2)	0	0	47.45
Lime (A3)	0	0	38.48
No amendment (A4)	0	0	27.78
Mean	0	0	35.37

Table 27. Radio activity in available P (cpm g^{-1}) in soil at harvesting

Treatments	P1	P2	P3
Pongamia leaves (A1)	0	492.065	333.335
Sodium silicate (A2)	0	584.125	351.125
Lime (A3)	0	158.780	492.065
No amendment (A4)	0	412.160	333.335
Mean	0	411.780	377.465

Table 28. Radio activity of P sorbed by carbonate (cpm g^{-1}) in soil just before sowing

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	99.48	130.11	310.14	179.91
Sodium silicate (A2)	124.20	119.30	307.88	183.79
Lime (A3)	172.97	124.04	294.01	197.00
No amendment (A4)	200.13	160.11	309.38	223.21
Mean	149.19	133.39	305.35	

Table 29. Radio activity of occluded P activity (cpm g^{-1}) in soil just before sowing

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	14.07	42.98	14.09	23.71
Sodium silicate (A2)	17.90	52.70	13.07	27.89
Lime (A3)	18.16	92.59	11.60	40.78
No amendment (A4)	19.62	42.20	13.78	25.20
Mean	17.44	57.62	13.14	

Table 30. Radio activity of Ca-P activity (cpm g^{-1}) in soil just before sowing

Treatments	P1	P2	P3	Mean
Pongamia leaves(A1)	150.11	139.04	910.85	400.00
Sodium silicate (A2)	262.25	540.75	343.67	382.22
Lime (A3)	767.38	1090.50	570.90	809.59
No amendment (A4)	917.69	1140.65	540.30	866.21
Mean	524.36	727.74	591.43	

4.5.2.4 Radio assay in Ca- P fraction

Table 30 shows the radioactivity for Ca-P fraction (cpmg^{-1}) in soil just before sowing. Ca-P fraction gave radioactivity for all the treatments at just before sowing and not at flowering and harvesting. Just before sowing P level of 30 kg P_2O_5 ha^{-1} recorded a highest ^{32}P value of 727.74 cpmg^{-1}.

4.6 PHOSPHORUS CONTENT IN PLANTS

4.6.1 Phosphorus content in plants at 15 DAS

Table 31 shows the effect of levels of P and amendments on the plant P content at 15 DAS. Highest level of P of 45 kg P_2O_5 ha^{-1} (0.254%) was found to significantly influence the plant P at 15 DAS; while 30 kg P_2O_5 ha^{-1} (0.149%) was on par with 15 kg P_2O_5 ha^{-1} (0.141%).

Comparing the effect of amendments, at this stage, Pongamia leaves (0.205%), sodium silicate (0.187%), lime (0.221%) had significant influence on plant P compared to no amendment (0.112%). But between the amendments no significant influence on plant P was noticed.

The interaction effect of levels of P and amendments was found to be significant. Within 45 kg P_2O_5 ha^{-1} lime (0.359%) application was found to have significantly superior effect on plant P compared to Pongamia leaves (0.266%) and sodium silicate (0.265%). While within 30 kg P_2O_5 ha^{-1} Pongamia leaf incorporation (0.184%) was found to significantly influence plant P compared to no amendment (0.113%) and it was on par with sodium silicate (0.149%) and lime (0.149%).The lowest plant P content was recorded in the control(0.0850%).

4.6.2 Phosphorus content in plants at flowering

The data on effect of levels of P and amendments on plant P at flowering are presented in Table 32. The levels of P were found to significantly improve the plant P. As the level of P increased from 15 to 45 kg P_2O_5 ha^{-1}, the plant P increased from 0.251 to 0.279 per cent.

Table 31. Effect of levels of P and amendments on plant P content (%) at 15 DAS

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	0.164	0.184	0.266	0.205
Sodium silicate (A2)	0.146	0.149	0.265	0.187
Lime (A3)	0.158	0.149	0.359	0.221
No amendment (A4)	0.0968	0.113	0.125	0.112
Mean	0.141	0.149	0.254	

Control = 0.0850 %

CD(A) = 0.0387 CD(P) = 0.0335 CD(PxA) = 0.0670

Table 32. Effect of levels of P and amendments on plant P content (%) at flowering

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	0.299	0.304	0.329	0.311
Sodium silicate (A2)	0.250	0.253	0.257	0.253
Lime (A3)	0.237	0.303	0.289	0.277
No amendment (A4)	0.216	0.224	0.241	0.227
Mean	0.251	0.271	0.279	

Control = 0.211 %

CD(A) = 0.0196 CD(P) = 0.0169 CD(PxA) = N.S.

Application of Pongamia leaves (0.311%) was found to be significantly superior in influencing plant P, than lime (0.277%) and sodium silicate (0.253%). However, sodium silicate and lime had significantly better influence compared to no amendment (0.227%).

The interaction effect of amendments and levels of P was found to be non significant. Plant P content at flowering ranged from 0.216% (15 kg P_2O_5 ha^{-1} + no amendment) to 0.329 per cent (45 kg P_2O_5 ha^{-1} + Pongamia leaves). The treatment control recorded lowest value for plant P (0.211%).

4.6.3 Phosphorus content of haulm at harvest

The data on the effect of levels of P and amendments on P content of haulm at harvesting are presented in Table 33. The levels of P significantly influenced the P content in haulm. At higher levels of P, plant P content improved from 0.168 percent at 15 kg P_2O_5 ha^{-1}, 0.217 percent at 30 kg P_2O_5 ha^{-1} and 0.252 percent at 45 kg P_2O_5 ha^{-1}.

Among the different amendments, Pongamia leaves (0.224%) and sodium silicate (0.214%) was found to significantly improve the haulm P when compared to no amendment (0.201%). It was on par with lime (0.211%).

The interaction effect of levels of P and amendments was found to be non significant. The value lies between 0.158(15 kg P_2O_5 ha^{-1}+ no amendment) to 0.263 per cent (45 kg P_2O_5 ha^{-1}+ Pongamia leaves). The P content of haulm was the lowest for the control (0.130%).

4.6.4 Phosphorus content in seed

Table 34, shows the data on P in seed. At this stage, higher level of P at 45 kg P_2O_5 ha^{-1} was found to significantly improve the P in seed (0.314%) in comparison to 30 kg P_2O_5 ha^{-1} (0.263%) and 15 kg P_2O_5 ha^{-1} (0.225%).

At this stage, none of the amendments were found to significantly improve the P content of seeds. The value lies between 0.262 (no amendment) to 0.273percent (sodium silicate).

Table 33. Effect of levels of P and amendments on plant P content (%) in haulm at harvesting

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	0.181	0.228	0.263	0.224
Sodium silicate (A2)	0.168	0.215	0.258	0.214
Lime (A3)	0.167	0.221	0.246	0.211
No amendment (A4)	0.158	0.204	0.242	0.201
Mean	0.168	0.217	0.252	

Control = 0.130%

CD(A) = 0.011 CD(P) = 0.0102 CD(PxA) =N.S.

Table 34. Effect of levels of P and amendments on plant P content (%) in seed at harvesting

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	0.227	0.267	0.300	0.264
Sodium silicate (A2)	0.225	0.266	0.327	0.273
Lime (A3)	0.226	0.259	0.326	0.270
No amendment (A4)	0.221	0.259	0.306	0.262
Mean	0.225	0.263	0.314	

Control = 0.205%

CD(A) = N.S. CD(P) = 0.0110 CD(PxA) =N.S.

Interaction effects of levels of P and amendments were found to be non significant. The value ranged from 0.221 (15 kg P_2O_5 ha^{-1}+ no amendment) to 0.327percent (45 kg P_2O_5 ha^{-1}+ sodium silicate). The treatment control recorded the lowest value for seed P content (0.205%).

4.7 CORRELATION OF AVAILABLE SOIL P AND PLANT P CONTENT

It was observed that correlation coefficients of available P with P contents at flowering, in haulms at harvesting, in seeds at harvest were positive and significant (Table 35).

4.8 CONTRIBUTION OF DIFFERENT FRACTIONS OF P TO PLANT P CONTENT

4.8.1 At flowering

Plant P content at flowering was significantly correlated with non occluded Al-P and Fe-P (r = 0.6434) P sorbed by carbonate (r = 0.5654), occluded P (r = 0.6109) and Ca-P fraction (r = 0.6076) (Table 36). Non-occluded Al-P and Fe-P had direct and significant effect. The direct effect of P sorbed by carbonate was not significant. Occluded-P had no direct significant effect. Ca-P had no direct significant effect, but indirectly through non occluded Al-P and Fe-P.

4.8.2 Haulms at flowering

Data in Table 37, shows the direct and indirect effects of different fractions of P with P content of haulm at harvesting. P content of haulm at flowering was significantly correlated with non occluded Al-P and Fe-P (r = 0.9199), P sorbed by carbonate fraction (r = 0.9012), occluded P (r = 0.9605) and Ca-P (r = 0.9356). Non occluded Al-P and Fe-P had no direct significant effect. The P sorbed by carbonate had no direct significant effect but indirectly through occluded P. Occluded-P had direct significant effect. Ca-P had no direct significant effect but indirectly through occluded P.

Table 35. Correlation coefficient between the plant P content and available P

	Available P
Flowering plant P content	0.5579*
Harvesting haulm P content	0.9556*
Harvesting seed P content	0.9118*

*Significant at 5% level

Table 36. Path coefficients indicating direct and indirect effect of fractions of P on P content in plants at flowering

	Non occluded Al-P and Fe-P	P sorbed by carbonate	Occluded P	Ca-P	Correlation coefficient (r)
Non occluded Al-P and Fe-P	**0.5326***	0.0612	0.2337	-0.1842	0.6434*
P sorbed by carbonate	0.4045	**0.0806**	0.2480	-0.1677	0.5654*
Occluded P	0.4420	0.0710	**0.2816**	-0.1837	0.6109*
Ca-P	0.4860*	0.0670	0.2563	**-0.2018**	0.6076*

Direct effects are in main diagonal. Values on horizontal rows are indirect effect. 'r' value represents the simple correlation coefficient of factors listed with plant P content.

Table 37. Path coefficients indicating direct and indirect effect of fractions of P on P content of haulm at harvesting

	Non occluded Al-P and Fe-P	P sorbed by carbonate	Occluded P	Ca-P	Correlation coefficient (r)
Non occluded Al-P and Fe-P	**0.1860**	0.0135	0.6616*	0.0587	0.9199*
P sorbed by carbonate	0.1688	**0.0149**	0.6591*	0.0584	0.9012*
Occluded P	0.1729	0.0138	**0.7116***	0.0622	0.9605*
Ca-P	0.1700	0.0135	0.6876*	**0.0644**	0.9356*

Direct effects are in main diagonal. Values on horizontal rows are indirect effect. 'r' value represents the simple correlation coefficient of factors listed with plant P content

4.9 RADIO ASSAY FOR PLANT P

Table 38 and 39 show the radioactivity of plant P (cpm g^{-1}) at 15 DAS and flowering respectively. The ^{32}P activity in plants at 15 DAS derived from fertilizer was highest (6847.33 cpm g^{-1}) with highest level of P (45 kg P_2O_5 ha^{-1} Among the amendments, it was sodium silicate (4880.07 cpm g^{-1}) applied pots, gave highest activity in plants followed by no amendment (4620.83 cpm g^{-1}) at 15 DAS.

Where as at flowering the ^{32}P activity in plants was the highest with 30 kg P_2O_5 ha^{-1} (3334.63 cpm g^{-1}) Among the amendments, it was lime (3361.08 cpm g^{-1}) applied pots, recorded the highest activity in plants followed by no amendment (2681.73 cpm g^{-1}). No activity was observed in plants at harvesting stage for any of the treatments.

4.10 PERCENTAGE OF AVAILABLE P DERIVED FROM FERTILIZER

Table 40 represents data on percentage of available P derived from fertilizer. The data on percentage of available P derived from fertilizer at just before sowing showed that only at highest level of applied P (45 kg P_2O_5 ha^{-1}) contributed to the available pool immediately after application and it was the highest in sodium silicate treated pots. This ranged from 12.8 to 41.8 per cent.

4.11 DRY WEIGHT

4.11.1 Dry weight of haulm

Table 41 represents the effect of levels of P and amendments on dry weight of haulm. The levels of P, had significant influence on dry weight of haulm. As the level of P increased from 15 to 45 kg P_2O_5 ha^{-1}, the dry weight of haulm increased from 1.49 to 2.25 g pot^{-1}.

None of the amendments influenced the dry weight of haulm significantly.

The interaction effect of levels of P and amendments was found to be non significant.

Table 38. Radioactivity of plant P activity (cpm g^{-1}) at 15 DAS

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	2687.75	1430.10	9388.10	4501.98
Sodium silicate (A2)	8786.00	4345.00	1509.22	4880.07
Lime (A3)	2546.25	1398.90	7288.00	3744.38
No amendment (A4)	3268.30	1390.20	9204.00	4620.83
Mean	4322.08	2141.05	6847.33	

Table 39. Radioactivity of plant P activity (cpm g^{-1}) at flowering

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	2158.00	3318.50	1814.15	2430.33
Sodium silicate (A2)	1858.50	3672.50	1925.11	2485.37
Lime (A3)	4070.80	3112.43	2900.00	3361.08
No amendment (A4)	2510.10	3235.10	2300.91	2681.73
Mean	2649.35	3334.63	2235.04	

Table 40. Percentage of available P derived from fertilizer at just before sowing

Treatments	P1	P2	P3
Pongamia leaves (A1)	0	0	12.8
Sodium silicate (A2)	0	0	41.8
Lime (A3)	0	0	20.9
No amendment (A4)	0	0	13.6
Mean	0	0	22.3

Table 41. Effect of levels of P and amendments on dry weight (g pot^{-1}) of haulm

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	1.70	2.13	2.29	2.04
Sodium silicate (A2)	1.46	2.04	2.24	1.91
Lime (A3)	1.46	2.04	2.24	1.91
No amendment (A4)	1.32	2.01	2.24	1.86
Mean	1.49	2.06	2.25	

Control = 1.06 g pot^{-1}

CD(A) = N.S. CD(P) = 0.210 CD(PxA) = N.S.

Table 42. Effect of levels of P and amendments on dry weight (g pot^{-1}) of pods

Treatments	P1	P2	P3	Mean
Pongamia leaves (A1)	1.58	1.97	2.11	1.89
Sodium silicate (A2)	1.35	1.57	1.94	1.62
Lime (A3)	1.19	1.54	1.99	1.58
No amendment (A4)	1.13	1.49	1.89	1.50
Mean	1.32	1.64	1.98	

Control=0.79 g pot^{-1}

CD(A) = 0.14 CD(P) = 0.12 CD(PxA) =N.S.

4.11.2 Dry weight of pods

Table 42 shows the effect of levels of P and amendments on dry weight of pods. The higher level of P significantly increased the dry weight of pods. The dry weight of pods obtained were 1.32 g pot^{-1} for 15 kg P_2O_5 ha^{-1}, 1.64 g pot^{-1} for 30 kg P_2O_5 ha^{-1}, 1.98 g pot^{-1} for 45 kg P_2O_5 ha^{-1}.

Among the amendments the incorporation of Pongamia leaves (1.89 g pot^{-1}) had significant influence in improving the dry weight of the pods compared to no amendment (1.50 g pot^{-1}). It was on par with sodium silicate (1.62 g pot^{-1}) and lime (1.58 g pot^{-1}).

The interaction effect of levels of P and amendments was found to be non significant.

4.12 CORRELATION BETWEEN AVAILABLE SOIL P CONTENT AND PLANT P CONTENT WITH DRY WEIGHT

It was observed that correlation coefficients of available P content with dry weight of haulm and pods at harvesting were positive and significant (Table 43). It was observed that the correlation coefficients of plant P content with dry weight of haulm and pods at harvesting were also positive and significant as shown in Table 43.

4.13 pH

Table 44 presents the effect of treatments on pH of soil at different growth stages. It was observed that pH of the soil increased as growth stages advanced. In other words pH of the soil was nearing to neutrality.

Table 43. Correlation coefficient between dry weight with available P in soil and plant P content

	Available P	Plant P content
Dry weight of haulm	0.84451*	0.8594*
Dry weight of pods	0.8739*	0.8733*

*Significant at 5% level

Table 44.Effect of levels of P and amendments on pH of soil at different growth stages

Treatments	pH		
	Just before sowing	Flowering	Harvest
Pongamia leaves + P1	4.86	5.29	5.51
Sodium silicate + P1	5.08	5.29	5.60
Lime + P1	5.02	5.40	5.60
P1alone	4.76	5.44	5.40
Pongamia leaves + P2	4.55	5.43	5.62
Sodium silicate + P2	5.32	5.42	5.63
Lime + P2	5.1	5.58	5.71
P2alone	4.79	5.49	5.60
Pongamia leaves + P3	4.82	5.56	5.70
Sodium silicate + P3	4.87	5.42	5.69
Lime + P3	4.86	5.46	5.70
P3 alone	4.91	5.48	5.80
Control	4.80	4.91	5.11
Mean	4.90	5.40	5.60

Discussion

5. DISCUSSION

The results of the present study are discussed under this chapter with similar or related studies from the literature, wherever possible.

5.1 GROWTH CHARACTERS

5.1.1 Plant height

At 15 DAS, phosphorus level of 30 kg P_2O_5 ha^{-1} recorded the maximum height of 19.35 cm which was significantly superior to other two levels of P i.e. 15 kg P_2O_5 ha^{-1} (17.37 cm) and 45 kg P_2O_5 ha^{-1} (17.62 cm) as shown in Table 2. At 30 DAS, highest level of P, i.e. 45 kg P_2O_5 ha^{-1} produced maximum height (22.5 cm) compared to other two levels of P at 15 kg P_2O_5 ha^{-1} (20.63 cm) and 30 kg P_2O_5 ha^{-1} (20.32 cm) (Table 3). At 45 DAS, the maximum height of 26.90 cm was produced by phosphorus level of 30 kg P_2O_5 ha^{-1} as in Table 4. At 60 DAS, the maximum height was obtained from the treatment of 30 kg P_2O_5 ha^{-1} (28.91 cm) which was on par with plant height at 45 kg P_2O_5 ha^{-1} (28.66 cm) as presented in Table 5. The effect of levels of phosphorus on the height of the plant showed that 30 kg P_2O_5 ha^{-1} was enough to get optimum growth in terms of height. However, 15 kg P_2O_5 ha^{-1} was inferior to the higher level of P (30 kg P_2O_5 ha^{-1}) at all stages of growth.

With respect to amendments, Pongamia leaves (19.79 cm) and sodium silicate (18.00 cm) were found to influence the growth in terms of height especially at 15 DAS compared to lime (17.62 cm) or treatments without amendments as given in Table 2. This shows that at the time of application of phosphorus, fixation of phosphorus is reduced by these amendments.

The interaction effect (Table 2) also confirmed this result that 30 kg P_2O_5 ha^{-1} with Pongamia leaves produced maximum height of 21.97 cm at 15 DAS. Similarly at 45 DAS, 45 kg P_2O_5 ha^{-1} with Pongamia leaves produced maximum height of 28.80cm (Table 4). At 60 DAS, 45 kg P_2O_5 ha^{-1} with Pongamia leaves resulted in maximum height of 29.83 cm (Table 5).

5.1.2 Number of branches

Neither the level of P, nor the amendments was found to have any significant influence on number of branches at any stage (Table 6) Swaroop *et al.* (2002) also reported that increased level of P had no significant effect on number of branches of cowpea.

5.2 AVAILABLE P

Available P before the start of the experiment was 6.4 mg kg^{-1} (Table 1). In all the stages, i.e. just before sowing, flowering and harvesting. Application of phosphorus at increasing levels from 15 to 45 kg P_2O_5 ha^{-1} was found to improve the available P status at a linear rate in a significant manner. Available P status just before sowing improved from 7.94 to 14.21 mg kg^{-1} (Table 8 and Fig. 2) as applied P increased from 15 to 45 kg P_2O_5 ha^{-1}. The increased available P content with increased levels of applied P was earlier obtained by Kumaraswamy (1981), Sadanandan and Hamza (1996), Upperi *et al.* (1995) and Anilkumar *et al.* (1999). Similarly at flowering stage, available P status increased significantly from 8.33 to 13.96 mg kg^{-1} (Table 9 and Fig. 3) and at harvest, it improved from 7.71 to 10.98 mg kg^{-1} (Table 10 and Fig. 4). This would mean that available P status showed a linear response to the application of P at increasing rates.

The effect of addition of different amendments, was to improve the available P significantly at flowering and harvesting stages, while no significant effect was observed just before sowing. At flowering stage, incorporation of Pongamia leaves (12.06 mg kg^{-1}) was found to be superior to other amendments (sodium silicate - 11.27 mg kg^{-1}, lime - 11.42 mg kg^{-1}) which inturn did not differ among themselves significantly. At harvest, application of Pongamia leaves (10.23 mg kg^{-1}) again showed the superiority over sodium silicate (9.87 mg kg^{-1}) application, but was on par with lime (10.08 mg kg^{-1}). The data (Tables 9, 10 and Fig. 3, 4) clearly indicated that all amendments had significantly superior effect in improving the available P status compared to phosphorus application without amendment. In other words, the amendments (Pongamia leaves, sodium silicate, lime) had a role in reducing P fixation

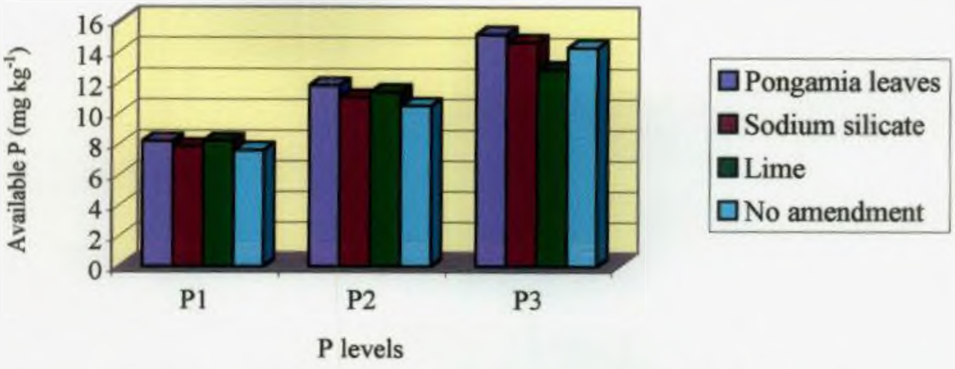

Fig. 2. Effect of P levels and amendments on available P in soil just before sowing

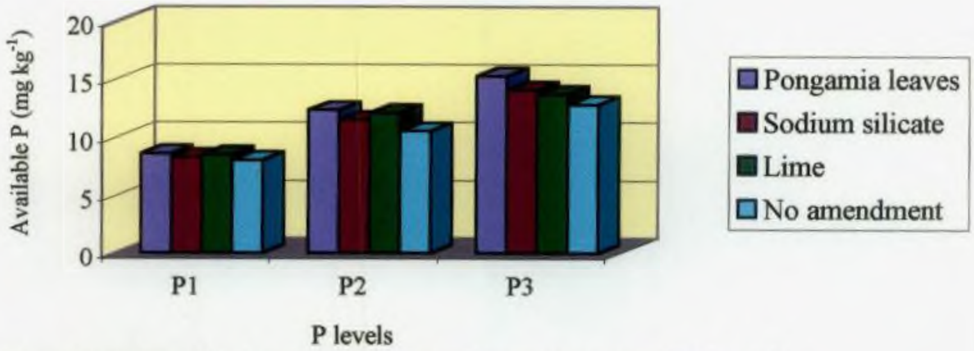

Fig. 3. Effect of P levels and amendments on available P in soil at flowering

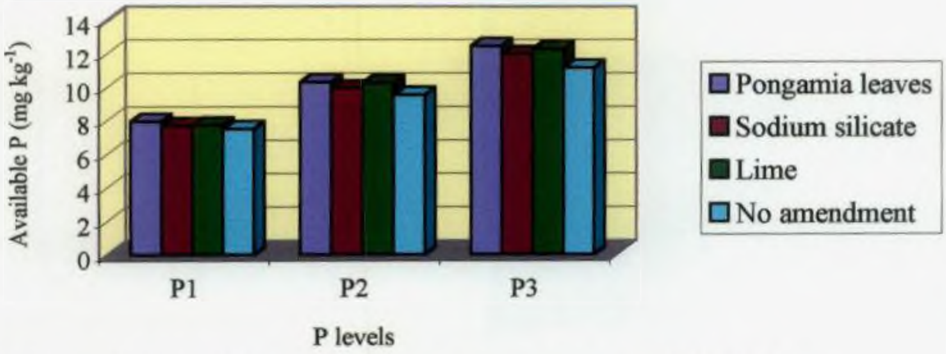

Fig. 4. Effect of P levels and amendments on available P in soil at harvesting

under acidic lateritic environment though the extent of influence varied among themselves. Shivanna *et al.* (1996) reported an increase in available P by the incorporation of green manure ***Pongamia pinnata*** at @ 10 t ha^{-1}. Mishra and Das (2000) reported that the organic amendment gave higher value for available P than lime.

The interaction effects were found to be significant only at flowering stage (Table 9). The highest value of available P were recorded for the highest P level of 45 kg P_2O_5 ha^{-1} with Pongamia leaves (15.27 mg kg^{-1}).

5.3 PHOSPHORUS FRACTIONS IN SOIL

The different phosphorus fractions of P viz. non occluded Al-P and Fe-P, P sorbed by carbonates, occluded P and calcium P were estimated at three stages in soil i.e. just before sowing, flowering and harvesting.

5.3.1 Non occluded Al-P and Fe-P fractions

At all the three stages, it was observed that as the level of applied phosphorus increased from 15 to 45 kg P_2O_5 ha^{-1}, non occluded Al-P and Fe-P fraction was found to be increasing (Tables 11, 12, 13 and Fig. 5, 6, 7). This result was supported by the findings of Kumaraswamy (1981). However, the quantity of this fraction was the highest just before sowing and decreased at flowering and was the lowest at harvesting. This results indicated that applied phosphorus immediately contributed to the non occluded Al-P and Fe-P fraction, which later on might get converted to other forms thereby decreasing this fraction with crop growth and also that these fractions were in dynamic equilibrium.

With respect to the amendments, incorporation of Pongamia leaves, enhanced the contribution significantly to non occluded Al-P and Fe-P fraction at all the three stages (Tables 11, 12, 13 and Fig. 5, 6, 7). Srinivasamurthy *et al.* (1996) reported an increase in Al-P and Fe-P fraction in acid soils by the incorporation of green manure *Glyricidia maculata*. He also reported a decrease in Al-P and Fe-P

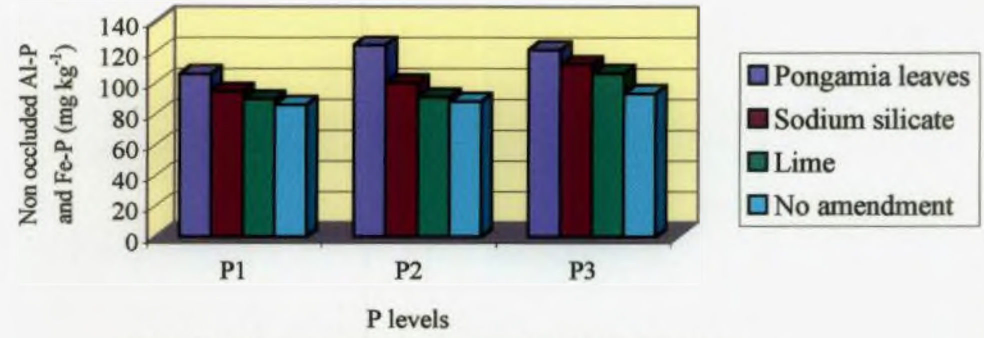

Fig. 5. Effect of levels of P and amendments on non occluded Al-P and Fe-P just before sowing

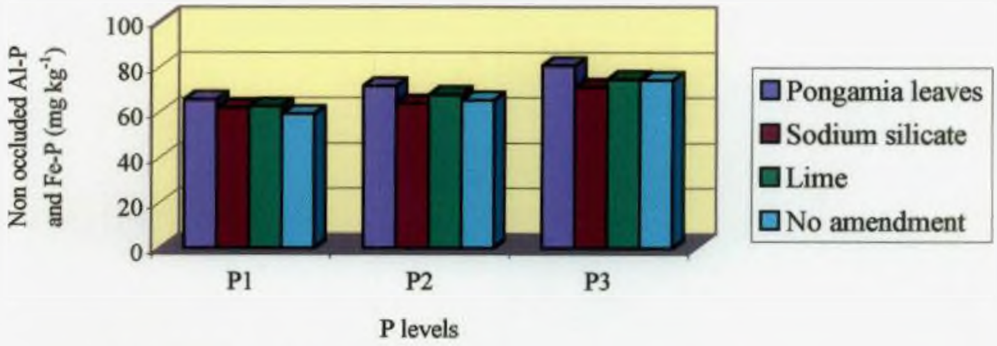

Fig. 6. Effect of levels of P and amendments on non occluded Al-P and Fe-P at flowering

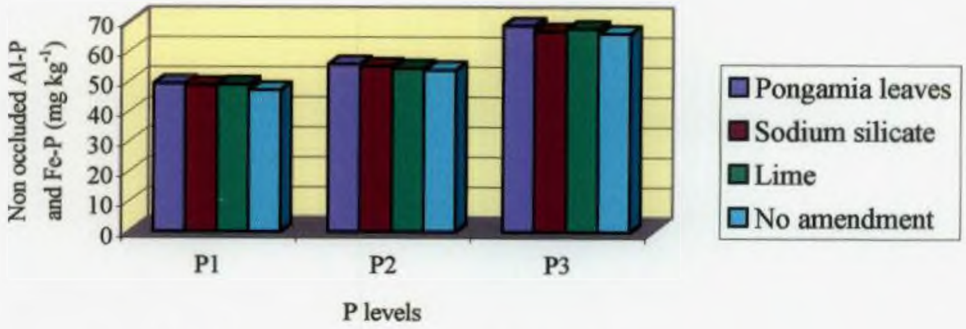

Fig. 7. Effect of levels of P and amendments on non occluded Al-P and Fe-P at harvesting

fraction with increase in period of incubation with treatments of fertilizers with and without green manure.

5.3.2 P sorbed by carbonate fraction

Similar trends as that of non occluded Al-P and Fe-P was observed in the case of P sorbed by carbonate with respect to both, levels of P and amendments.

As the level of P increased, it was found to significantly increase the P sorbed by carbonate at all the three stages, i.e. just before sowing, at flowering and at harvest (Tables 14, 15, 16 and Fig. 8, 9, 10). The quantity of this fraction was found to decrease gradually from just before sowing to harvest.

Pongamia leaves incorporated treatments (just before sowing - 12.74 mg kg^{-1}, flowering - 9.72 mg kg^{-1}, harvesting - 8.74 mg kg^{-1}) had the highest amount of phosphorus with respect to carbonate sorbed pool of P (Tables 14, 15, 16 and Fig. 8, 9, 10). Here also a gradual decrease was observed as the growth stage advanced from sowing to harvesting.

5.3.3 Occluded-P fraction

Occluded-P showed the same trend as the above fractions with respect to levels of P and amendments.

As the P level increased from 15 to 45 kg P_2O_5 ha^{-1}, occluded P fraction increased significantly at all the three stages i.e. just before sowing, at flowering and at harvest (Tables 17, 18, 19 and Fig. 11, 12, 13). This fraction was found to gradually decrease from just before sowing to harvest.

The amendment Pongamia leaf incorporation was found to have better influence in contributing to occluded-P fraction at the three stages (just before sowing - 16.54 mg kg^{-1}, flowering - 14.75 mg kg^{-1} and harvesting - 12.22 mg kg^{-1}) sodium silicate and lime had better influence than no amendment in contributing to this fraction (Tables 17, 18, 19 and Fig. 11, 12, 13). It was observed that as growth stage advanced from sowing to harvesting, this fraction gradually decreased. The same trend

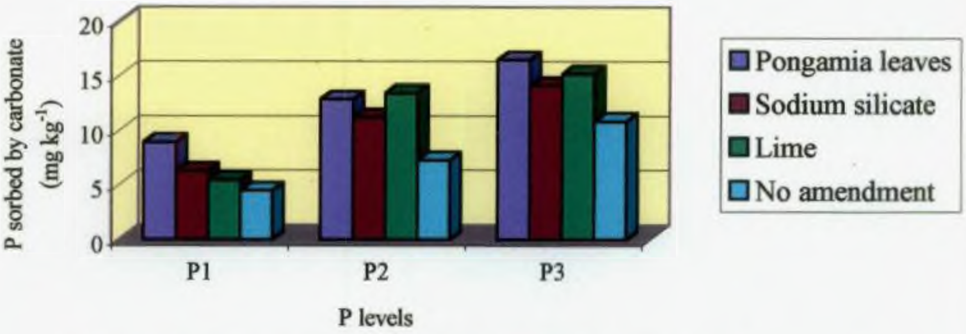

Fig. 8. Effect of levels of P and amendments on P sorbed by carbonate just before sowing

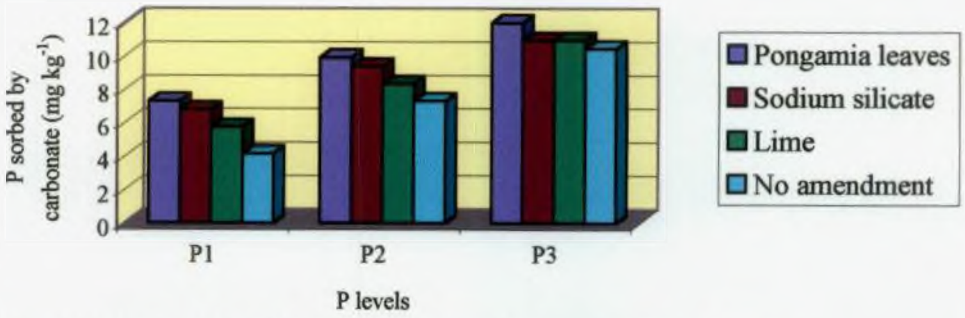

Fig. 9. Effect of levels of P and amendments on P sorbed by carbonate at flowering

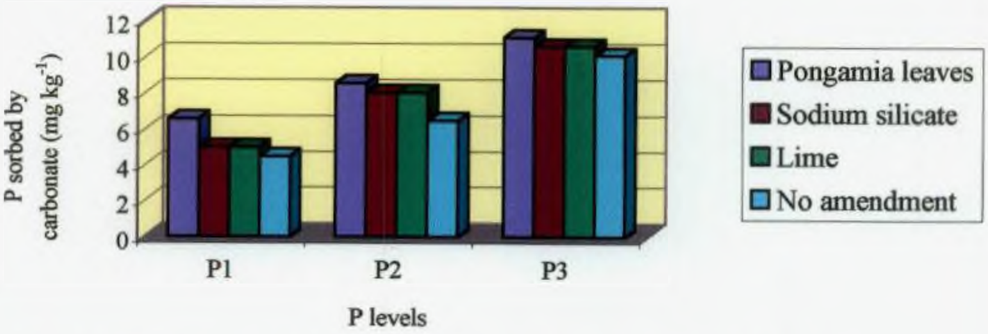

Fig. 10. Effect of levels of P and amendments on P sorbed by carbonate at harvesting

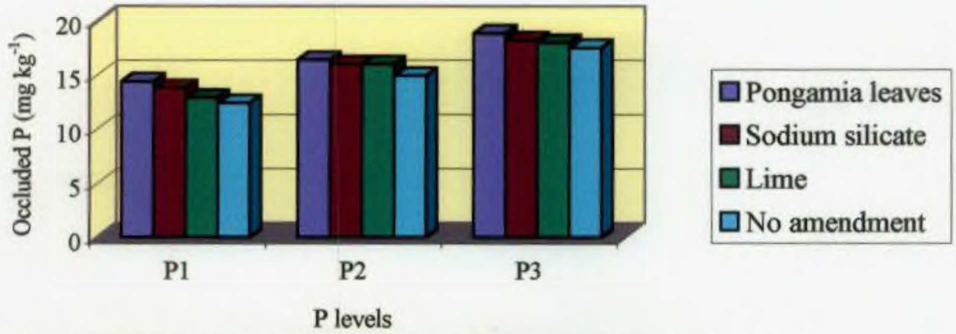

Fig. 11. Effect of levels of P and amendments on occluded P just before sowing

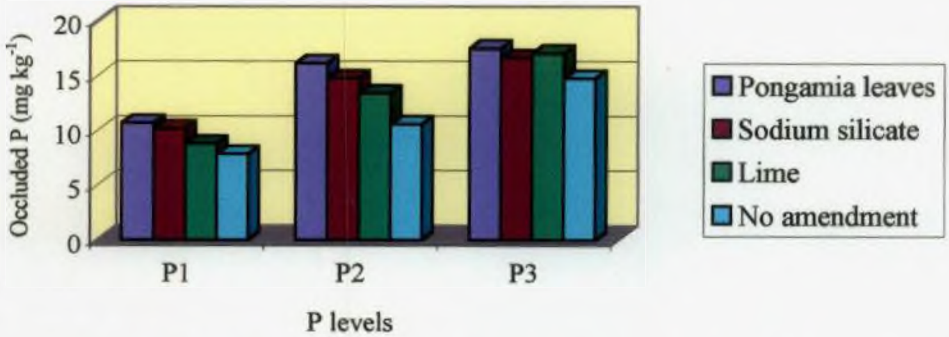

Fig. 12. Effect of levels of P and amendments on occluded P at flowering

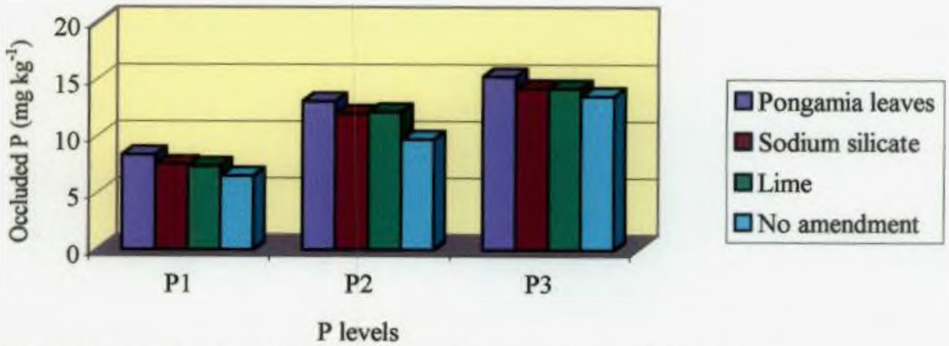

Fig. 13. Effect of levels of P and amendments on occluded P at harvesting

was noticed in an incubation study with *Glyricidia maculata* with and without fertilizer P in an acid soil (Srinivasamurthy *et al.*, 1996) reported that was found to decrease with period of incubation.

5.3.4 Calcium P fraction

At all the three stages i.e. just before sowing, flowering and harvesting, it was observed that as the level of applied P increased from 15 kg P_2O_5 ha^{-1} to 45 kg P_2O_5 ha^{-1}, Ca-P fraction was found to be increasing (Tables 20, 21, 22 and Fig. 14, 15, 16). Ca-P fraction remained almost same throughout the growth stages.

With respect to amendments, incorporation of lime enhanced the contribution significantly to Ca-P fraction at three stages (just before sowing - 23.17 mg kg^{-1}, flowering - 22.67 mg kg^{-1}, harvesting - 22.99 mg kg^{-1}). The amendment Pongamia leaf incorporation was found to be at par (just before sowing 22.8mg kg^{-1}, flowering 22.44 mg kg^{-1} and harvesting - 22.71 mg kg^{-1}) with lime at three stages (Tables 20, 21, 22 and Fig. 14, 15, 16). Ca-P fraction remained same throughout the growth period.

5.3.5 Comparison of different P fractions at different growth stages

Comparison of the different P fractions between themselves, at different growth stages (Table 11 to Table 22) indicated that non-occluded Al-P and Fe-P fraction dominated the other fractions with respect to quantity. It varied from 48.38 mg kg^{-1} (mean value of 15 kg P_2O_5 ha^{-1} at harvest) to 117.26 mg kg^{-1} (mean value of Pongamia treatment just before sowing), which was followed by Ca-P fraction, which ranged from 18.32 mg kg^{-1} (mean value of 15 kg P_2O_5 ha^{-1} at harvest) to 23.17 mg kg^{-1} (mean value of lime treatment just before sowing) and then by occluded P fraction which ranged from 7.44 mg kg^{-1} (mean value of 15 kg P_2O_5 ha^{-1} at harvest) to 16.54 mg kg^{-1} (mean value of Pongamia treatment just before sowing). The lowest value of P was extracted by carbonate sorbed P, which ranged from 5.27 mg kg^{-1} (mean value of 15 kg P_2O_5 ha^{-1} at harvesting) to 12.74 mg kg^{-1} (mean value of Pongamia treatment just before sowing).

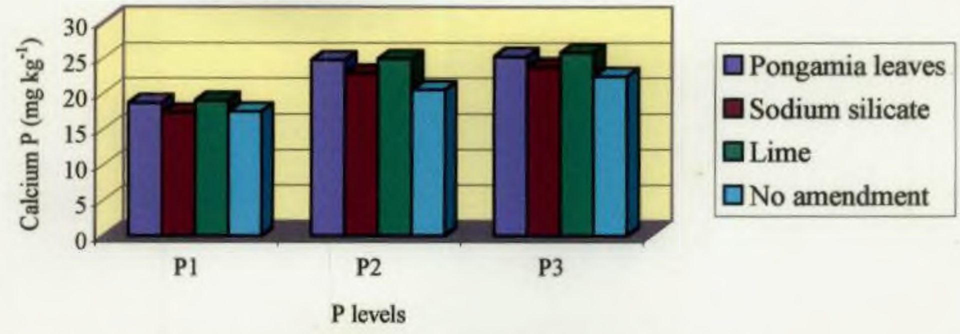

Fig. 14. Effect of levels of P and amendments on calcium P just before sowing

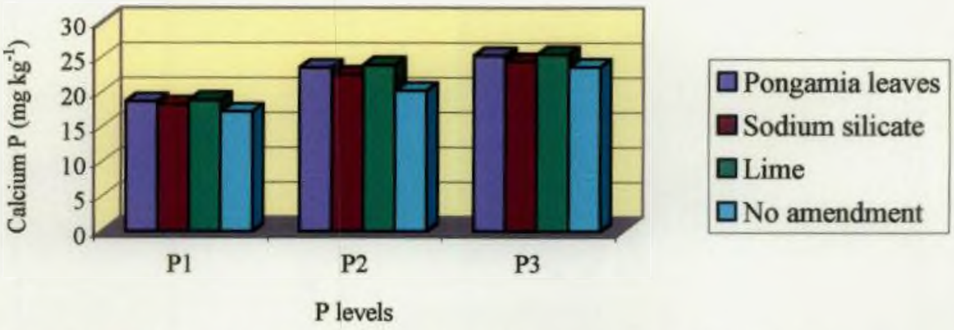

Fig. 15. Effect of levels of P and amendments on calcium P at flowering

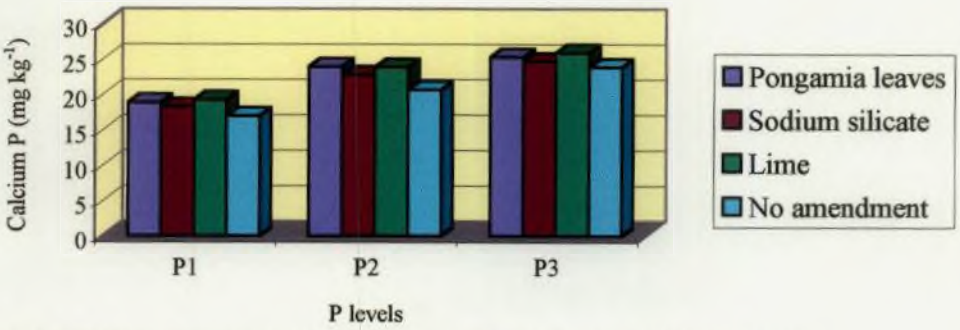

Fig. 16. Effect of levels of P and amendments on calcium P at harvesting

5.4 CONTRIBUTIONS OF DIFFERENT FRACTIONS OF PHOSPHORUS ON AVAILABLE PHOSPHORUS

Available P includes those pools of P, which are in plant available form Naturally this pool will be in equilibrium with the other forms of P in soil .It is in this background, correlation coefficients were computed for available P with different fractions of P i.e. non occluded Al-P and Fe-P , P sorbed by carbonates, occluded P and calcium P. Since the correlation coefficients were found to be significant, partial coefficients which explained the direct and indirect effects of different fractions of P on available P were computed through path coefficient analysis. In other words, these partial coefficients will explain the contribution if any of the different P fractions to the available phosphorus. The different fractions of phosphorus were estimated just before sowing, at flowering and at harvest.

5.4.1 Just before sowing

The path coefficients (Table 23 and Fig. 17) showed that the direct effect of occluded P was significant suggesting that it is from this pool, phosphorus moved to the available pool (0.7548). It was further confirmed by the significance of partial coefficients of indirect effects of non occluded Al-P and Fe-P, P sorbed by carbonates and Ca-P through occluded P. This would mean that these three fractions i.e. non occluded Al-P and Fe-P, P sorbed by carbonates and Ca-P contributing to the available P only through occluded P. Just before sowing, pH of the soil was in and around 4.9 and at this pH, occluded P might be released due to solubilisation of iron and aluminium hydrous oxide coatings.

5.4.2 At flowering

At flowering, occluded P as well as Ca-P were contributing to available P significantly (Table 24 and Fig. 18). Further, non occluded Al-P and Fe-P, P sorbed by carbonates and occluded P contributed to the available P through Ca-P. Thus it was found that, though occluded P was contributing to the available pool of P, more significant contribution was by Ca-P. It was also observed that there was a general increase in pH, in all the amendment applied plots from mean pH of 4.9 to a mean pH

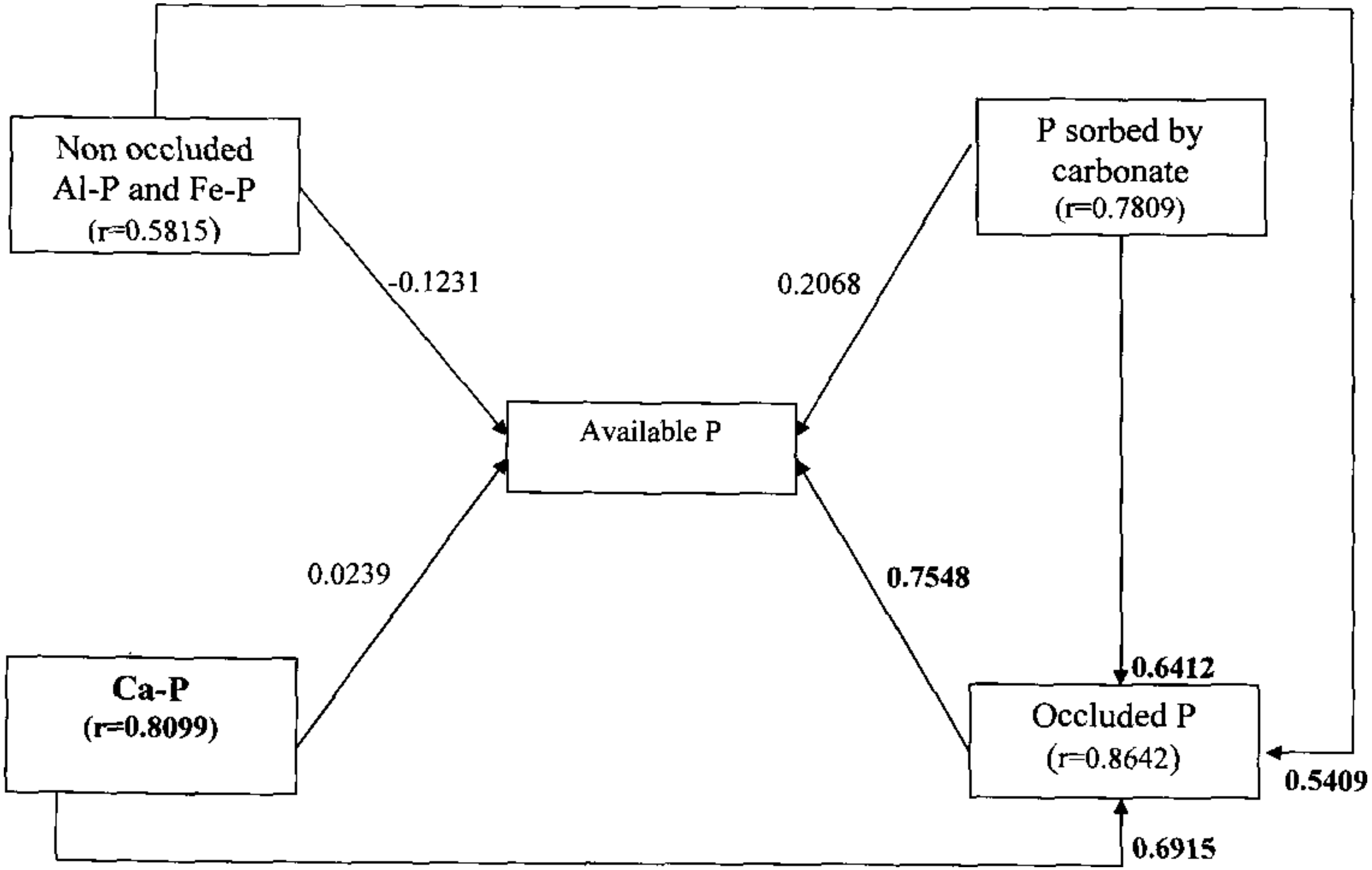

Fig. 17. Schematic diagram representing the contribution of various fractions of P on available P just before sowing

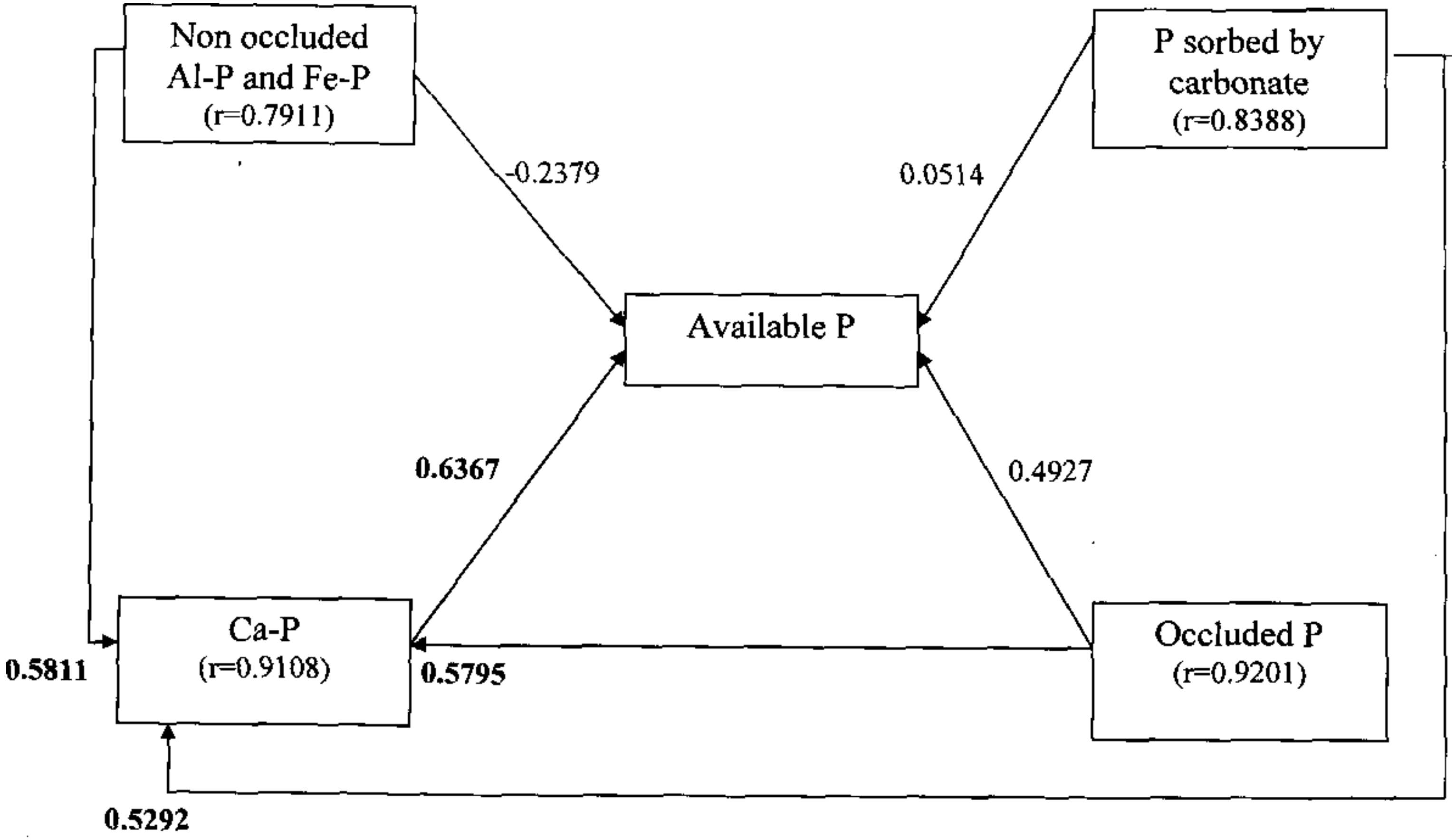

Fig. 18. Schematic diagram representing the contribution of various fractions of P on available P at flowering

value around 5.4 (Table 44). Thus it might be due to the conversion of insoluble Ca-P to phosphorus soluble forms (mono calcium phosphate). Hence, more contribution, could be naturally expected from calcium bound phosphorus in comparison with contribution of occluded P just before sowing.

5.4.3 At harvest

At the time of harvest, only the direct effect of non occluded Al-P and Fe-P were found to be significant (Table 25 and Fig. 19). None of the indirect effect was found to be significant at this stage. The partial coefficients of indirect effect of P sorbed by carbonate, occluded P and Ca-P through non occluded Al-P and Fe-P were nearing to significant level, though not significant. This would mean that as time proceeded, unavailable and insoluble form might become more soluble and available. This is substantiated by the data of different fractions of P at different stages as depicted in Tables 23, 24 and 25. These tables clearly indicated that non occluded Al-P and Fe-P fraction was the dominant one at just before sowing. As time proceeded, it was still the dominant fraction, but the amount of this fraction was reduced substantially to one third of the initial amount suggesting the solubilisation of the fraction. It might be due to the overall effect of P solubilisation depicted its direct influence on available pool.

5.5 RADIO ASSAY

Just before sowing, only at highest level of P (45 kg P_2O_5 ha^{-1}) the ^{32}P activity through fertilizer could be traced out in the available pool indicating that lower levels of applied P (15 and 30 kg P_2O_5 ha^{-1}) ^{32}P could not be traced out in the available fraction (Table 26). In a soil where the P fixing capacity was 86.2 per cent (Table 1) almost all the applied P that too in soluble form was converted to insoluble or unavailable form. Further the data in Table 27 pointed to the fact that applied P at 30 kg P_2O_5 ha^{-1} and 45 kg P_2O_5 ha^{-1}, contributed to the available P. This might be due to the gradual dissolution of the reverted P back to soluble forms.

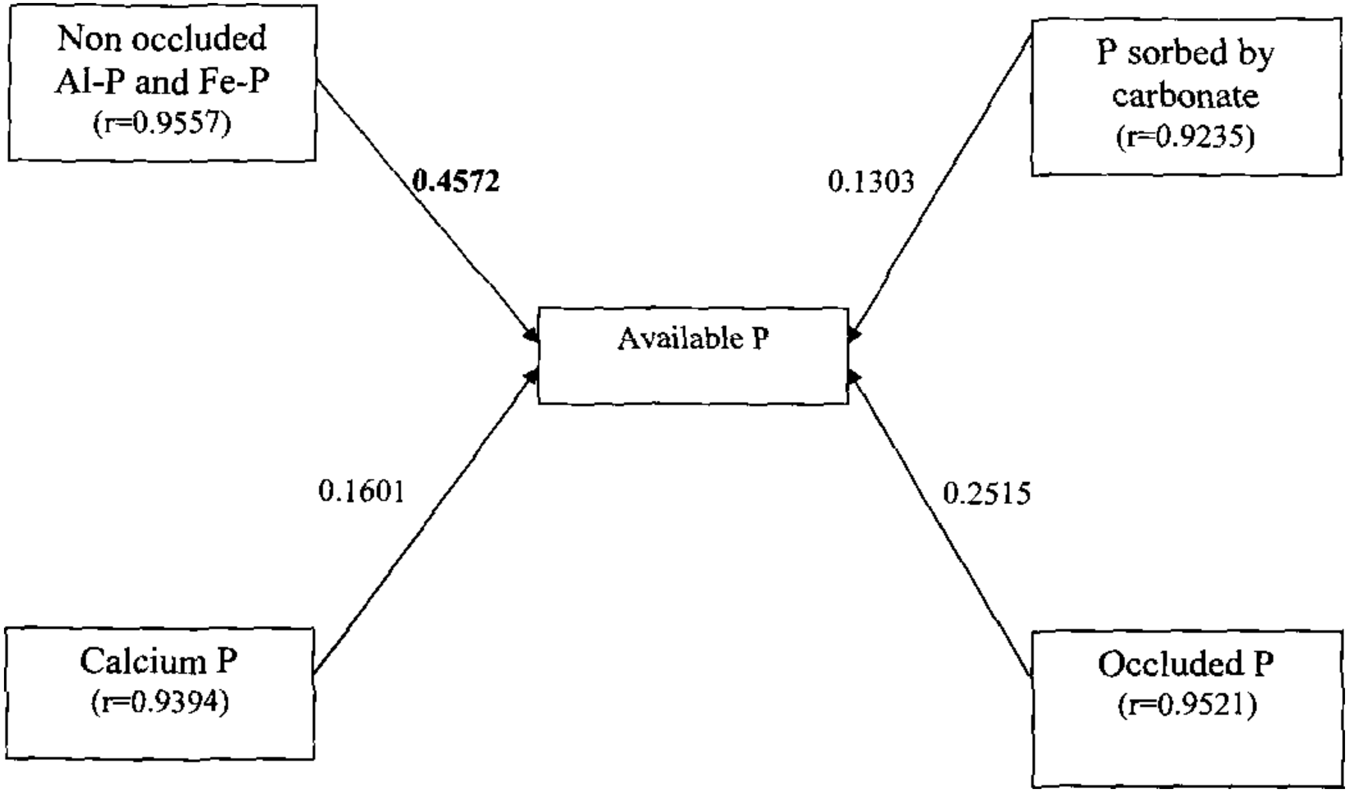

Fig. 19. Schematic diagram representing the contribution of various fractions of P on available P at harvesting

The data on radio assay of different fractions (Tables 28, 29, 30) opened up the following facts.

1) The applied soluble P, moved quantitatively into the fractions Ca-P, P sorbed by carbonates and occluded P in that order in a decreasing manner.

2) In Ca-P fraction, the activity was the lowest at the lowest level of applied P (15 kg P_2O_5 ha^{-1}). Highest activity was observed in the treatment of P applied at 30 kg P_2O_5 ha^{-1} (Table 30)

3) In P sorbed by carbonate fraction, the highest level of applied P recorded the highest radioactivity (Table 28)

4) In occluded P fraction, the highest activity was recorded at 30 kg P_2O_5 ha^{-1} (Table 29).

The activity in occluded P fraction was the lowest, which might be due to the fact that this fraction being dynamic might get converted to other fraction or contributed to the available pool as given in path analysis.

5.6 PHOSPHORUS CONTENT IN PLANTS

5.6.1 At 15 DAS

The data in Table 31 and Fig. 20, clearly indicate a linear response of applied P with respect to plant P content i.e. the concentration of phosphorus was the highest for the highest level of applied P of 45 kg P_2O_5 ha^{-1} at 15 DAS. Application of amendments was also found to enhance the phosphorus concentration in plants compared to that of phosphorus content in plants received treatments without any amendments (Table 31). With respect to the interaction effect, it was observed that lime application was found to increase the phosphorus significantly at 45 kg P_2O_5 ha^{-1}, in comparision with Pongamia leaves and sodium silicate.

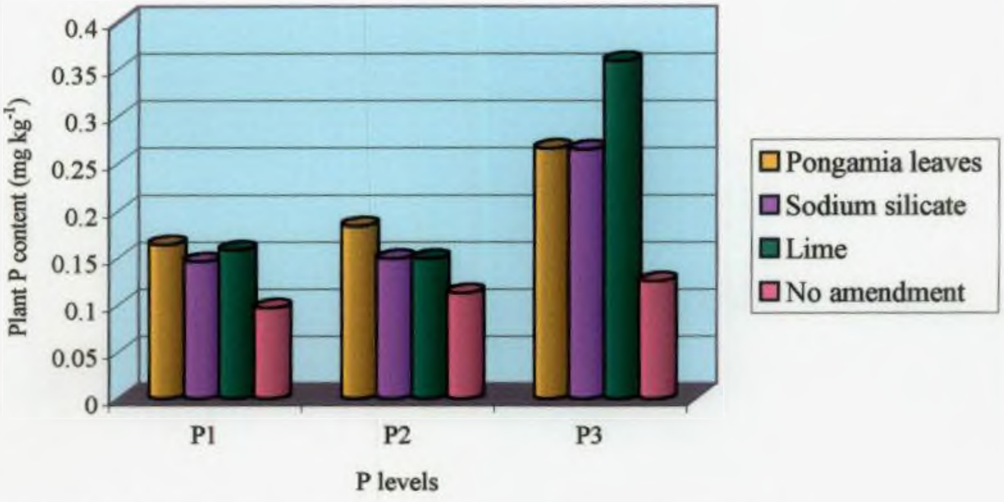

Fig. 20. Effect of levels of P and amendments on plant P content at 15 DAS

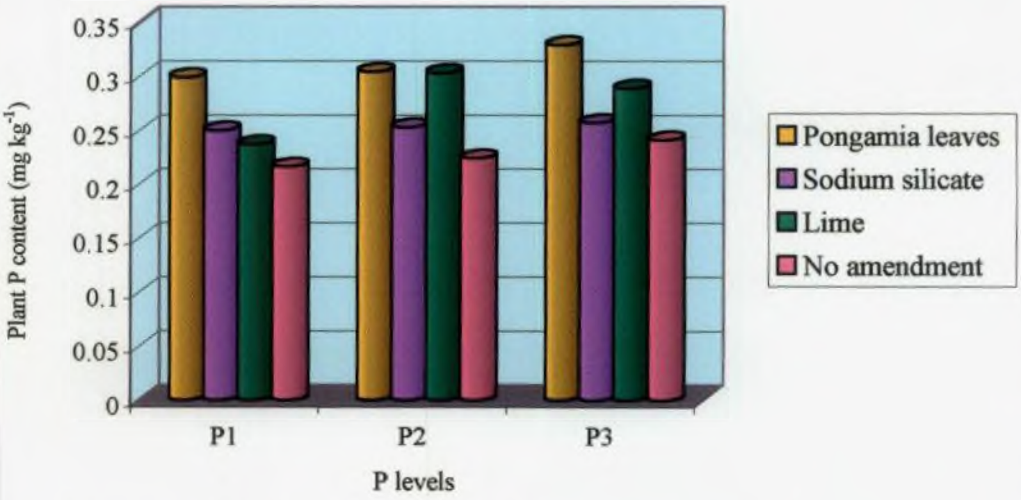

Fig. 21. Effect of levels of P and amendments on plant P content at flowering

5.6.2 At flowering

. At flowering also the response of P application was linear, since phosphorus concentrations in plant increased significantly as the level of applied P increased from 15 to 45 kg P_2O_5 ha^{-1} applied P (Table 32 and Fig. 21). Nagaraj and Siddaramappa (1996) reported an increase in uptake of P by Soyabean with increased level of applied P at flowering. Amendments was also found to improve the phosphorus content with respect to no amendment as shown in Table 32. Incorporation of Pongamia leaves was the best with respect to phosphorus content in plant, when compared to the other amendments (sodium silicate and lime). This would mean that Pongamia leaves helped in solubilising the unavailable forms of phosphorus in a better way than the other amendments at flowering. This is further supported by data on available P (Table 9). Thus highest level of P (45 kg P_2O_5 ha^{-1}) with incorporation of Pongamia leaves at 5 t ha^{-1}, was found to be the best treatment with respect to P content at flowering.

5.6.3 At harvest (haulm)

At harvest, response of haulm P content to higher levels of applied P was linear (Table 33 and Fig. 22). These results are in conformity with the findings of Ravankar and Badhe (1975), Kandaswamy *et al.* (1977), Rather and Chahal (1977) and Sachidanand *et al.* (1980). With the incorporation of Pongamia leaves as explained in the case of P content at flowering stage, was observed at harvesting also (Table 33). The available P content at this stage also indicated that solubilisation of unavailable P to available pool was the highest with the highest level of applied P along with incorporation of Pongamia leaves, thereby increasing the phosphorus content.

5.6.4 At harvest (seed)

The phosphorus content in seeds was the highest with the highest dose of applied P at 45 kg P_2O_5 ha^{-1} (Table 34 and Fig. 23). However, no significant difference was observed between any of the amendments or without any amendment. This might be due to the selective translocation of absorbed phosphorus to the

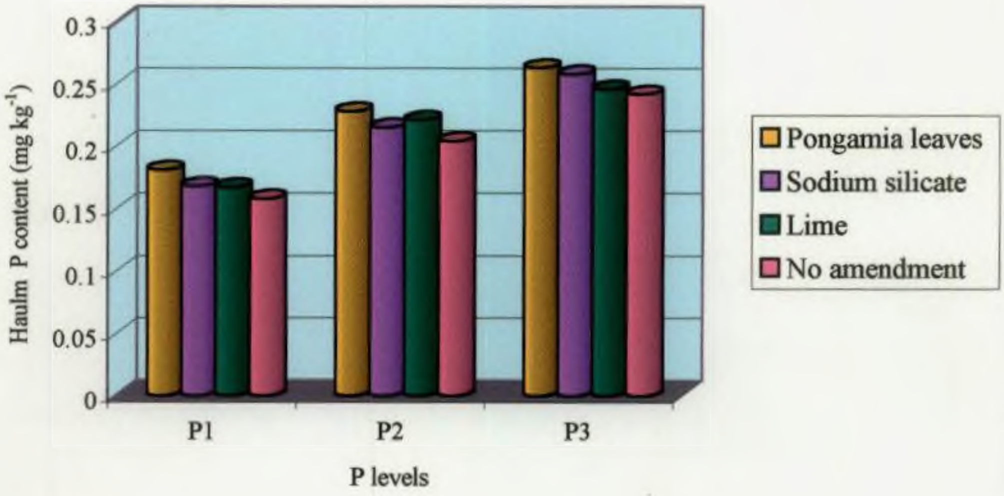

Fig. 22. Effect of levels of P and amendments on haulm P content at harvesting

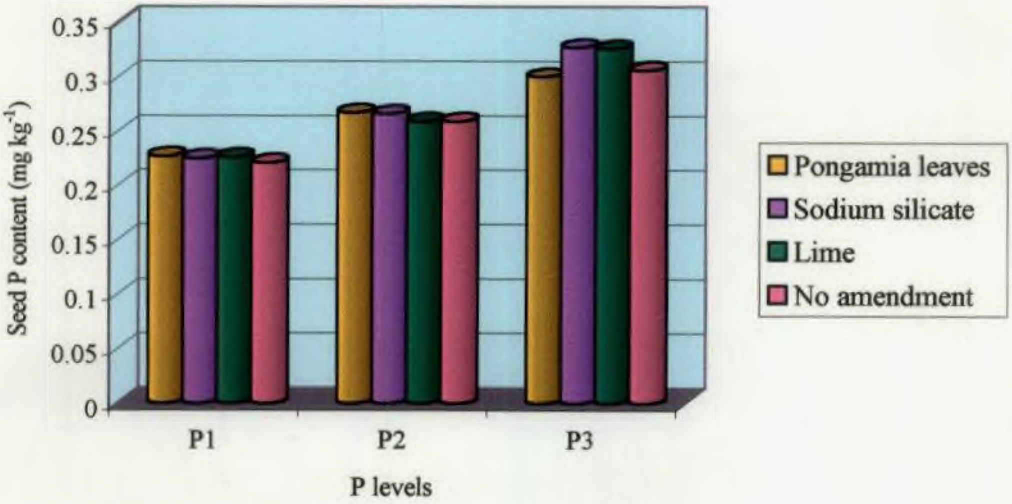

Fig. 23. Effect of levels of P and amendments on seed P content at harvesting

reproductive parts at or after flowering i.e. the concentration of phosphorus in vegetative part, though reflecting the level of applied P, might not be passively translocated to the reproductive part, rather translocation is selective or controlled.

5.7 CORRELATION OF AVAILABLE P TO PLANT P CONTENTS

It was observed that the correlation coefficients of available P with P contents at flowering, in haulms at harvesting, in seeds at harvest were positive and significant (Table 35). Dixit *et al.* (2003) obtained similar correlations in maize and wheat.

5.8 CONTRIBUTIONS OF DIFFERENT FRACTIONS OF P TO PLANT P CONTENT

The path coefficients indicating the direct and indirect effect of different P fractions on plant P content at flowering is given in Table 36. The data revealed that the direct effect of non occluded Al-P and Fe-P, as well as indirect effect of Ca-P through non occluded Al-P and Fe-P was significant.

The data on correlation coefficients (Table 35), path coefficients of different fractions on available P (Table 24), path coefficients of different fractions on plant P at flowering (Table 36 and Fig. 24) indicated that occluded P and Ca-P contributed to the available P pool directly whereas Ca-P was contributing to available P pool directly and indirectly through other fractions. So it can be concluded that Ca-P in soil and that inturn enhances the P content in plants at different stages. These results indicated that it was Ca-P, which is the final product of phosphate reaction in soil, probably Ca $(H_2PO_4)_2$ from which plant absorb P. It was also clear that as pH increased from 4.9 to 5.6 (Table 44) non occluded Al-P and Fe-P might slowly get solubilised to increase the ionic concentration of H_2PO_4 which inturn might be absorbed by plant.

The data on Table 37 and Fig. 25, showed that the fraction contributing to phosphorus content in plant is occluded P. Both direct effect of occluded P as well as indirect effect of other fractions through occluded P were significantly contributing to plant P at harvest. As the time of growth progresses, the Ca-P might get exhausted and it was from occluded P the plant absorbable forms including Ca-P were formed.

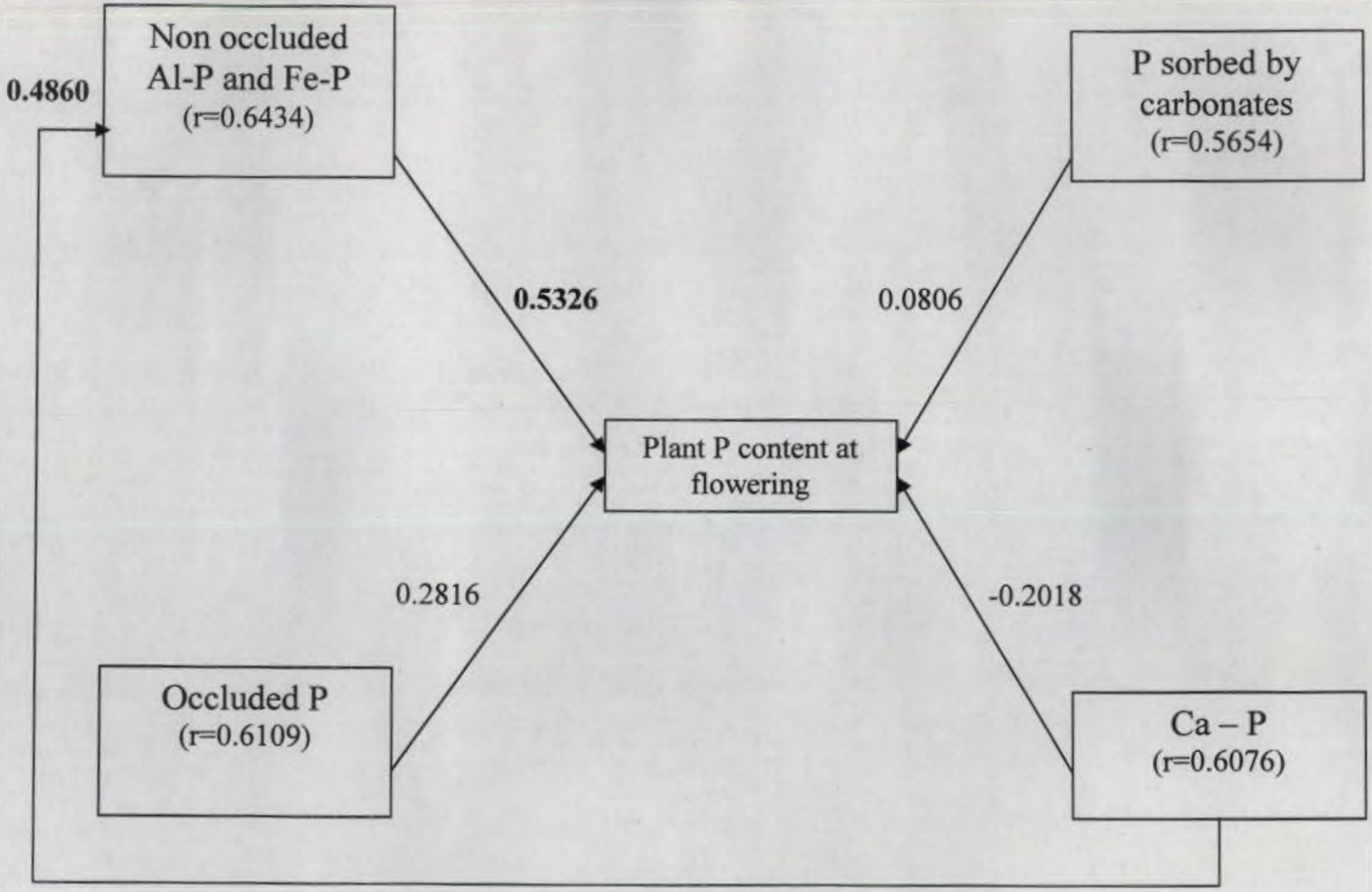

Fig. 24. Schematic diagram representing the contributions of different fractions of P to plant P content at flowering

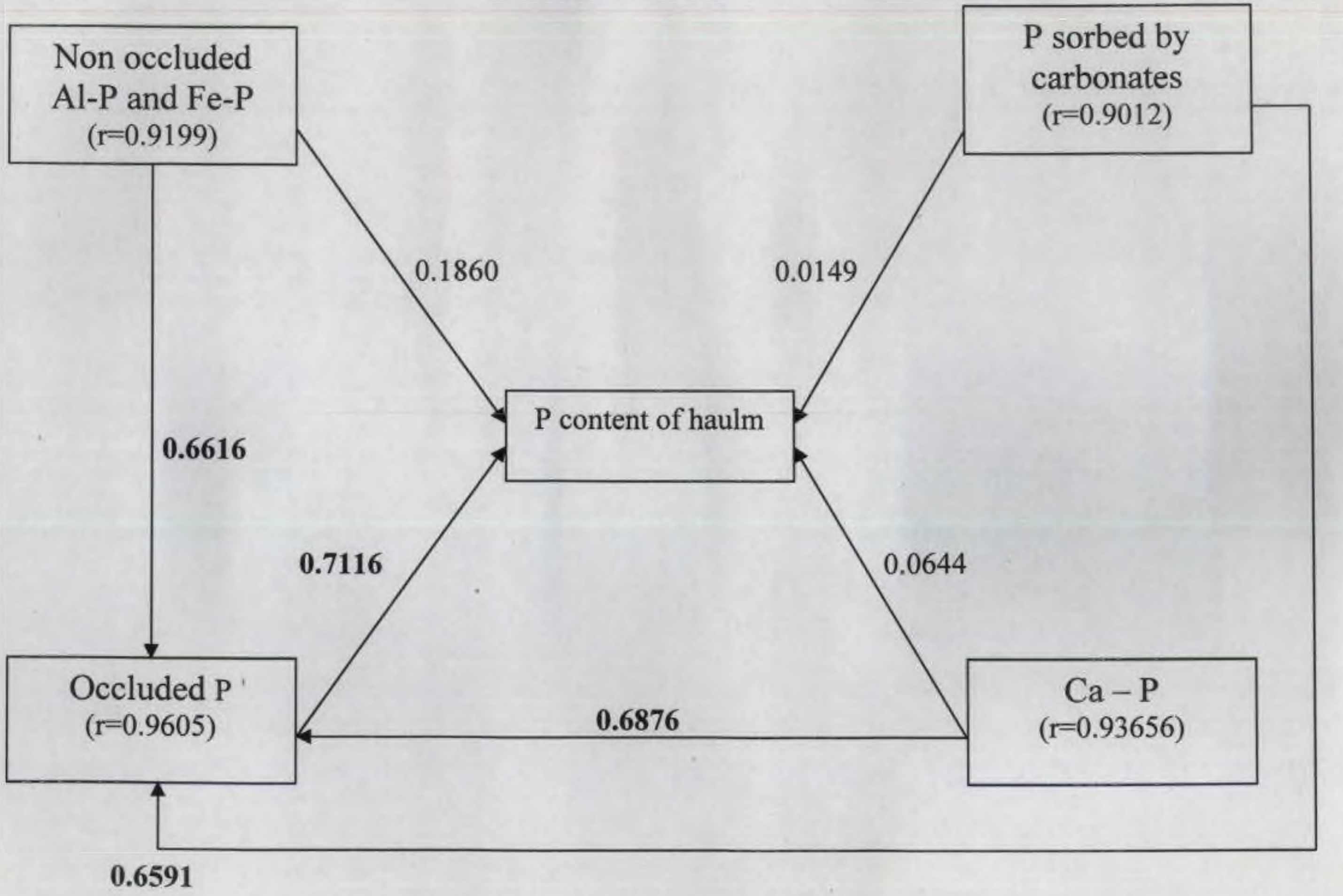

Fig. 25. Schematic diagram representing the contributions of different fractions of P to plant P content at harvesting

5.9 RADIOASSAY OF PLANT P

It was clear from the data on Table 38 that the highest ^{32}P activity in plants was recorded for the highest level of applied P at 15 DAS. The trend also showed the minimum fixation of applied P, was in sodium silicate treated pots there by increasing the ^{32}P content in plants. However, the data showed a different trend at flowering. The phosphorus applied at 30 kg P_2O_5 ha^{-1} recorded the highest ^{32}P content in plant (Table 39) and the activity was the lowest at the highest level of applied P. This might be due to the dilution effect of the activity due to better growth at higher levels.

5.10 PERCENTAGE P DERIVED FROM FERTILIZERS

The Table 40 on percentage of available P derived from fertilizer showed that only at the highest level of applied P (45 kg P_2O_5 ha^{-1}) contributed to the available pool immediately after application and it was the highest in sodium silicate treated pots. This is fully supported by data in Table 38 of plant P activity at 15 DAS. This revealed the highest level of applied P, giving the highest activity in plant, which was also more in sodium silicate treated pots.

5.11 DRY WEIGHT

The data on dry weight of haulm (Table 41 and Fig. 26) increased significantly as the level of applied P increased. The findings are in agreement with the findings of Ravankar and Badhe (1975), Kandaswamy *et al.* (1977), Sachidanand *et al.* (1980) and Tanwar *et al.* (2003). This was further substantiated by increased level of available P with increase in applied P, which inturn caused increased P adsorption. However, no significant difference between the amendment was observed in increasing the yield of haulm.

The dry weight of the pods increased significantly with increase in applied P levels (Table 42 and Fig. 27). The results are in agreement with the findings of Tanwar *et al.* (2003). It was also observed that the incorporation of Pongamia leaves enhanced yield in terms of dry weight of pods in comparison with other amendment. Thus the highest pod yield was observed in the treatment comprising 45 kg P_2O_5 ha^{-1}

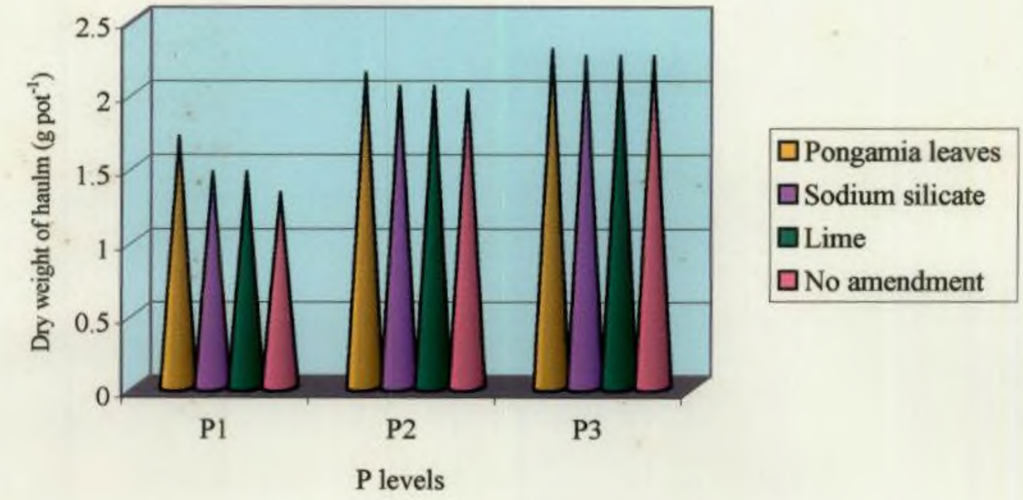

Fig. 26. Effect of levels of P and amendments on dry weight of haulm at harvesting

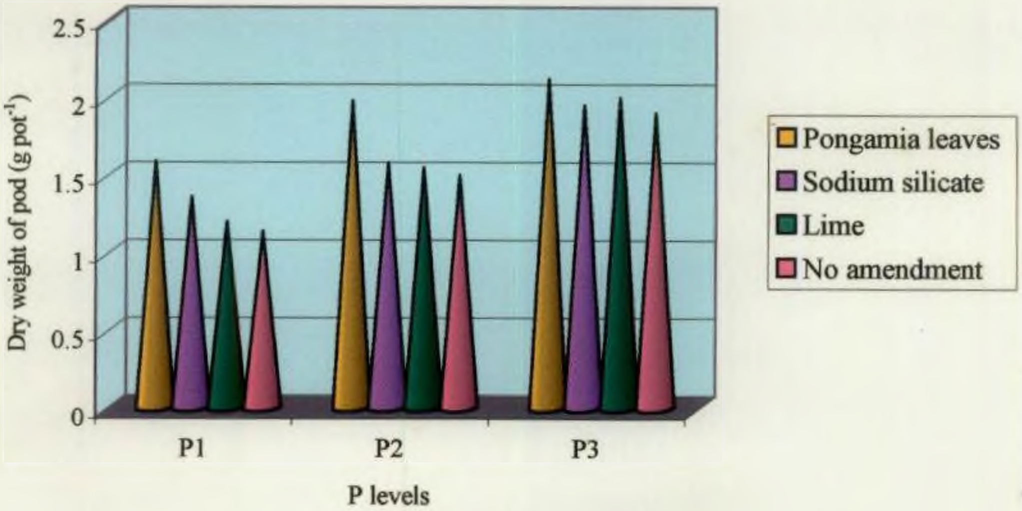

Fig. 27. Effect of levels of P and amendments on dry weight of pods at harvesting

along with Pongamia leaves. These results were well supported by significant correlations (Table 43) of available P and plant P with the dry weight of haulms and pods. Dixit *et al.* (2003) reported a significant and positive correlation between available P in soil and dry weight of maize and wheat.

In brief, it was observed that the phosphorus application at increased rates along with Pongamia leaves improved the available P status. This was found to contribute to different P fractions. The different P fractions i.e. non occluded Al–P and Fe-P, P sorbed by carbonate, occluded P and Ca-P might be in dynamic equilibrium. This was further substantiated by ^{32}P activity derived from different P fractions after the application of radioactive P through fertilizer. The amount of different P fractions non occluded Al –P and Fe-P, P sorbed by carbonate and occluded P were found to decrease from just before sowing to the stage of harvest, while Ca-P fraction remained almost constant. Further Ca-P fraction was dominantly contributing to the available P suggesting that applied P might get transformed to non occluded Al-P and Fe-P, occluded P as well as P sorbed by carbonate, which might be slowly transformed to Ca-P fraction probably Ca (H_2PO_4), the soluble form which is contributing to available P. It was observed that, non occluded Al-P and Fe-P was contributing to plant P as time proceeded due to solubilisation of this fraction. The average percentage of P derived from fertilizer was 22.3 per cent. It could be concluded that application of P at higher levels gave a positive response in terms of available P, plant P, yield and yield attributes. Hence, it should be noted that due to high P fixing capacity, applied P might get fixed to unavailable forms, unless judicious management techniques in terms of incorporation of Pongamia leaves should be strictly practiced.

Summary

6. SUMMARY

A pot culture experiment was carried out at Radiotracer laboratory, College of Horticulture using laterite soil (Ultisol) collected from the main campus of Kerala Agricultural University, Vellanikkara. Collected soils were processed and pots were filled with soil @ 5 kg soil pot^{-1}. Amendments viz. Pongamia leaves, sodium silicate 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. ^{32}P labelled KH_2PO_4 (^{32}P @ 0.4 mCig $^{-1}$P) was added as per the treatments. Nitrogen and potassium were applied as per the package of practice recommendations. Seeds of cowpea variety Kanakamony was 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 @ 5 t ha^{-1}, sodium silicate @ 500 kg SiO_2 ha^{-1}, lime @ 250 kg ha^{-1} and no amendment and an absolute control. The experiment was laid out in CRD with 13 treatments and 4 replications. The salient results of the present study along with the practical implications were summarized below.

- The phosphorus levels at 30 kg P_2O_5 ha^{-1} recorded the maximum height of the plant at 15 DAS, 45 DAS and 60 DAS. The amendment Pongamia leaves has more significant influence in increasing the height of plant in comparison to sodium silicate, lime or treatment without amendment.

- At all the three stages, i.e. just before sowing, flowering and harvesting, application of phosphorus at increasing level from 15 to 45 kg P_2O_5 ha^{-1}, increased the available phosphorus status in a linear fashion in a significant manner. At flowering and harvesting stage, Pongamia leaf incorporation was found to significantly improve the available P compared to lime and sodium silicate.

- As the level of applied phosphorus increased from 15 to 45 kg P_2O_5 ha^{-1}, the different P fractions i.e. non occluded Al-P and Fe-P, P sorbed by carbonate, occluded P and Ca-P were found to increase significantly at all the three stages of sampling. The quantity of P fraction i.e. non occluded Al-P and Fe-P, P sorbed by carbonate, occluded-P were the highest just before sowing and decreased at flowering and was lowest at harvesting whereas Ca-P fraction remained same throughout the growth stages.

- Incorporation of Pongamia leaves enhanced the contribution to non occluded Al-P and Fe-P, P sorbed by carbonates and occluded P significantly compared to sodium silicate and lime at all the three stages.

- Comparison of the quantities of different P fractions, between themselves at different growth stages indicated that non occluded Al-P and Fe-P fraction dominated other fractions of P and it was followed by Ca-P fraction, occluded-P fraction and P sorbed by carbonate fraction in that order.

- The path coefficient analysis showed that the occluded P was found to contribute to available P just before sowing, while at flowering occluded P as well as Ca-P were contributing to available P, of which more significant contribution was by Ca-P. At harvesting, the non occluded Al-P and Fe-P was found to be contributing to available P.

- Radio assay of available P showed that only at the highest level of applied P (45 kg P_2O_5 ha^{-1}), ^{32}P activity was traced out in the available pool at just before sowing; whereas at harvest 30 and 45 kg P_2O_5 ha^{-1} contributed to the available P pool in terms ^{32}P activity.

- Radioassay of different P fractions indicated that the applied P moved quantitatively into the fractions of Ca-P, P sorbed by carbonate and occluded P in that order in a decreasing manner. In Ca-P fraction, the radio activity was the lowest with the lowest level of applied P (15 kg P_2O_5 ha^{-1}) and the highest with applied P level of 30 kg P_2O_5 ha^{-1}. For P sorbed by carbonates, the highest level of applied P produced the highest ^{32}P activity. In occluded P, the highest ^{32}P activity was recorded for applied P of 30 kg P_2O_5 ha^{-1}.

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- As the P level increased from 15 to 45 kg P_2O_5 ha^{-1}, the phosphorus content in plant at 15 DAS, at flowering, in haulms at harvesting and in seeds at harvesting was found to increase significantly. The amendments viz. Pongamia leaves, sodium silicate and lime were found to significantly improve the plant P content at different growth stages.

- Correlation coefficients of available P with plant P content at flowering, haulm P content at harvesting, seed P content at harvesting were positive and significant.

- Path coefficient analysis of different fractions of P on plant P content at flowering revealed that non occluded Al-P and Fe-P contributed to plant P content. As pH increased from 4.9 to mean pH around 5.6, non occluded Al-P and Fe-P, get solubilised to increase the ionic concentration of $H_2PO_4^-$ which inturn absorbed by plant.

- Path coefficient analysis of different fractions of P on plant P content at harvesting showed that occluded-P was significantly contributing to plant P.

- As the applied P level increased, radio active ^{32}P content increased in plant P at 15 DAS. The maximum radioactivity in plant was recorded for amendment sodium silicate. At flowering 30 kg P_2O_5 ha^{-1} recorded maximum radioactivity for plant P.

- Percentage of P derived from fertilizer was maximum for the highest level of applied P at 45 kg P_2O_5 ha^{-1} and for amendment sodium silicate

- The dry weight of haulm and pods increased significantly with increase in level of applied P. The amendment Pongamia leaves was found to increase the dry weight significantly compared to no amendment. The available P content and plant P content have positive and significant correlation with dry weight.

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PHOSPHORUS DYNAMICS IN AN ULTISOL

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ABSTRACT OF THE THESIS

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ABSTRACT

A pot culture experiment was carried out at Radiotracer laboratory of College of Horticulture, Vellanikkara, using laterite soil (Ultisol), from the main campus of Kerala Agricultural University with the objectives to trace the fate of fertilizer P and to study the dynamics of P by the addition of amendments. The experiment included 13 treatments of three levels of P and four amendments and an absolute control. Amendments were added to the respective treatments and kept for wetting and drying cycles for two weeks ^{32}P labelled KH_2PO_4 (^{32}P @ $0.4 mCig^{-1}$ P) was added as per the treatments. Seeds of cowpea @ 3 seeds pot $^{-1}$ were sown.

Application of Phosphorus at different levels significantly contributed to available P status different P fractions i.e. non occluded Al-P and Fe-P, P sorbed by carbonate, occluded P and Ca-P in a linear fashion at all the stages of crop growth i.e. just before sowing, flowering and harvesting. The amendments also contributed to the above pools. Among the amendments Pongamia leaves was found to have better influence in contributing to the above pools except for Ca-P, where lime was found to have a better influence. This was supported by the data on plant P content, where the increasing levels of P and amendments improved the plant P content at 15 DAS, flowering and at harvest. Further Ca-P fraction was dominantly contributing to the available P suggesting that applied P might get transformed to non occluded Al-P and Fe-P, occluded P as well as P sorbed by carbonate, which might be slowly transformed to Ca-P fraction probably $Ca(H_2PO_4)_2$, the soluble form which is contributing to available P. It was observed that, non occluded Al-P and Fe-P was contributing to plant P as time proceeded due to solubilisation of this fraction.

Application of P at increasing level and amendment significantly increased the dry weight of pods and haulm. Radioactive ^{32}P labelled with the applied phosphorus could be traced out in the available pools and fractions of P only at just before sowing, flowering. Percentage of P derived from applied P were the highest for higher level of P and amendment sodium silicate.