ASSESSMENT OF THE FACTORS GOVERNING RESPONSE TO PHOSPHORUS IN THE RICE SOILS OF KERALA

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Assessment of the factors governing response to phosphorus in the rice soils of Kerala" is a bonafide 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, associateship, fellowship or other similar title of any other University or Society.

Vellayani,
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CERTIFICATE

Certified that this thesis entitled "Assessment of the factors governing response to phosphorus in the rice soils of Kerala" is a record of research work done independently by Sri. K. Harikrishnan Nair under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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INTRODUCTION

INTRODUCTION

Phosphorus, one of the "big three" among plant nutrients, is essential for crop production. It is considered as the "master key" to agriculture. It is an essential nutrient input and often its deficiency becomes a major constraint for successful crop production. In India, the finite reserves of this non-renewable resource is getting exhausted emphasising the need for efficient utilisation of available phosphorus resources.

The soil fertility map compiled by Ghosh and Hasan (1979) based on more than 8 million soil tests for available phosphorus indicates that about 46.3 per cent of the districts are in the low category, 51.5 per cent represent the medium fertility class and only 2.2 per cent of the 363 districts in India showed a high phosphorus level. However, the situation in Kerala based on soil test summaries (Anon. 1986) indicates that only Trivandrum out of the 12 districts have nearly 50 per cent of the soils rated as low. Idukki, Palghat and Cannanore districts also have a low rating of around 25 per cent. In short, in the State of Kerala, we have soils with available phosphorus status ranging from very low to medium and none of the areas could be delineated in a map with a cartographic unit as "high" except for a few soil samples rated as high in the soil test summaries. Soil phosphorus is subject to considerable variation in its availability especially in rice soils due to a variety of reasons.

The rice crop varies considerably in its response to phosphorus depending upon the total yield and type of variety. A correct appraisal of the various soil parameters that govern the phosphorus situation is also a pre-requisite to explain some of the possible reasons for response, erratic response or non-response of rice to phosphorus application. The response of rice to phosphorus depends upon many factors viz., soil type, P status of the soil, conditions of submergence, various parameters of the soil such as pH, Organic matter, amount of free oxides of iron and aluminium, clay content etc., in addition to the variety itself.

Lack of response to application of phosphorus in some of the rice soils of Kerala is often being brought forward from different locations by field level officers. Often reports of response and non-response emanate from the same 'Padasekharam' but conclusions become difficult due to differences in varieties used etc. In Kerala, rice is being grown largely in seven major soil types viz., lateritic alluvium (Inceptisol), Kari (Entisol), Kayal (Inceptisol), Karapadam (Inceptisol), coastal sandy alluvium (Entisol), Pokkali (Alfisol) and Kole (Entisol) possessing wide variations in their physico-chemical characteristics. Various soil parameters critically contributing at times towards increased availability and, at other times towards greater fixation of phosphorus have to be studied in greater detail. A balance between these interacting parameters probably is to be hypothesised as at least partially defining the capacity of a soil to respond to application of phosphorus. The type of phosphatic fertiliser - soluble or insoluble - that would enhance available phosphorus levels also needs to be worked out.

Isolated attempts in studying the response pattern of rice to phosphorus fertilization and relating them as due to release of fixed phosphorus during submergence, as due to varietal differences, as due to fixation of added phosphorus etc., have yielded only an isolated picture of a holistic situation. However, no systematic integrated attempt to investigate the various factors governing response to phosphorus in the rice soils of Kerala in nearly all its aspects has been attempted so far. The need for this has been felt both in the University and at field level. Thus the present study attempts to fulfil some of these broad objectives by aiming at the following studies.

1. Characterise the rice soils of the State with special reference to phosphorus.

2. Identify the chemical nature of phosphorus in the rice soils.

3. Study the phosphorus fixing capacity of the rice soils.

4. Investigate the pattern of transformation of phosphorus upon submergence.

5. Study the response of rice varieties to the application of graded doses of phosphorus.

6. Evaluate different sources of phosphorus in the acid soils of Kerala with ^{32}P.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The literature on soil phosphorus and phosphorus nutrition of rice crop is voluminous. A brief review of the more recent work pertinent to various aspects of the present study on rice soils alone is attempted here under 1. General physico-chemical characteristics 2. Phosphorus fractions 3. Phosphorus fixing capacity 4. Pattern of transformation of phosphorus upon submergence 5. Response of rice crop to applied phosphorus and 6. Comparison of different sources of phosphorus for their efficiency on rice crop.

General physico-chemical characteristics of the rice soils.

The physico-chemical characteristics of the rice soils play a dominant role in determining the yield and production levels of rice. These soil characteristics for rice growing areas very considerably depending upon a number of factors. Judicious fertilization and economic crop production require consideration of various soil characteristics in addition to the crop.

Physical properties

Texture

Yadav and Pathak (1963) reported that the Indian coastal sands were coarse textured and intensively leached soils with poor phosphorus reserve. The red loam and lateritic soils possessed a fair amount of total P but were low in P availability. In a study of the Kerala soils, Janardhanan Nair et al. (1966) found that true and apparent specific gravities were functions of coarser particles, while water holding capacity, pore space and volume expansion were related to the finer fractions.

Ghosh et al. (1973) found that Kari soils from Thottappalli, North Parur and Kottampalli of Kerala state were clay loam in texture and rich in organic matter. The bulk density and particle density varied from 1.24 to 1.40 and 2.50 to 2.65 g/cm^3 respectively.

According to Kanno (1978), the term "rice soil" or "paddy soil" is not a taxonomic name but a generic term like forest soils, grass land soils etc. Productivity of rice soils depends much on the geomorphology of the landscape and its hydrologic characteristics. Soil texture is the most important factor determining land suitability for rice because of its effects on water regime, workability when wet and potential fertility. Most of the rice is grown in coarse textured soils because of poor water regimes.

General physical properties

The minimum apparent density was obtained by Venugopal (1969) for Kari soils among the different soil types of

Kerala. Ghildyal (1971) observed that soil compaction to a bulk density of 1.75 g/cm^3 reduces the water requirement of rice to about 16 per cent over soil puddling.

Rice soils have been considered as artificial hydromorphic soils or hydromorphic associates of respective great soil group or low land paddy soil (Kanno, 1978). The inherent soil characters as reported by Matsuzaka (1978), used to determine production capability classes of rice soils are thickness of top soil, effective depth of soil, gravel content of top soil, permeability, redox potential, inherent fertility, available nutrient content and presence of harmful substances.

According to Brady (1982) physical properties of rice soils are generally poor if criteria commonly used to judge these properties are the same as those for dryland soils and the two factors attributed to this are: first, paddy soils especially those of alluvial low lands have been derived generally from fine sediments which are high in clay and the second, the tillage and cultural practices followed and in general, these changes in physical properties do not have detrimental effects on rice yields and production levels common in the tropics. The available mineral element status of rice land is subject to considerable fluctuations due to alternate reduced and oxidised conditions in the soils.

Soil characteristics for rice growing areas vary considerably less under flooded conditions (wet land rice) than under normal upland conditions (dry land rice). Submergence in water generally improve the suitability of soils for rice production.

Ghildyal (1982) reported that submergence affects both the soil physical, as well as physico-chemical environment, under physical environment of rice are factors that affect soil aeration, soil water relations, soil temperature and soil tillage. Various soil management practices adopted to minimise water losses include puddling, compaction, addition of bentonite and sub-surface barrier of asphalt. Compaction is more efficient than puddling in reducing percolation losses.

Chemical characteristics

pH

According to Subramoney (1947), the acidity in Kuttanad soils is responsible for the crop failure occurring in that area. The free sulphuric acid in toxic concentrations is produced in these soils by the biological oxidation of sulphur compounds present in them. The lower horizons of most of the profiles in Kuttanad have a pH value as low as 2

The pH of the soil and of the perculates increases on waterlogging and this may be because of the formation of ammonia in the soil (Ponnamperuma, 1955).

The acid soils with considerably high content of sulphate showed extreme variability in soil reaction (Moorman, 1962). Seasonal variations in these soils especially when subjected to frequent inundation were remarkably high. On inundation, the pH values gradually increased upto neutral point and decreased rapidly to extreme acid range on drying.

Nhung and Ponnamperuma (1965) stated that the acid sulphate soils are extremely acidic and unproductive. The acidity of the soils has been attributed to the presence of aluminium and ferric sulphates and sometimes free sulphuric acid.

According to Ponnamperuma et al. (1966), the pH values of acid soils increased to a fairly stable value of 6.7 to 7.2, twelve weeks after flooding. At this time the solution pH values were 6.5 to 7.0. The increase in soil solution pH of the acid soil was quantitatively related to the potential of $Fe(OH)_3$-Fe^{++} system.

Due to waterlogging, soil pH tended to be neutral and the water soluble Ca^{++}, Fe^{++}, Fe^{+++}, Al^{+++} ions increase, the last three ions being absent in the water extract of non flooded soil samples (Mahapatra, 1968).

The maximum and minimum values of soil pH in 1:2 soil water extracts were observed by Kurup and Aiyer (1973) in Kuttanad soils. During periods of October to November the pH varied most in Kari soils.

Subramoney and Gopalaswamy (1973) in their studies on acid sulphate soils suitable for growing paddy found that there is considerable difference between fresh and dry soils and between upper and lower horizon soil pH values. The undisturbed soils are neutral to strongly acidic.

The acidity in the acid sulphate soils of Kerala is mostly due to dissolved substances such as sulphuric acid, ferric and aluminium sulphates whereas the acidic species of naturally occurring clays are mainly H^+ and Al^{+++} remaining bound to the clay (Panda and Koshy, 1982).

Organic matter and nitrogen

Nair (1945) found that the important feature of the Kari soils of Kerala was their high content of organic matter. The organic matter, exchangeable hydrogen, pH and

C/N ratio were interrolated and had a direct bearing on their low fertility status.

Gopalaswamy (1961) observed a high CEC for Kari soils of Kerala and attributed this to a high content of organic matter.

In Kerala soils, Narayanan Nambiar (1962) found the C/N ratio to vary from 11.9 to 27.0, the average for all the soils being 18.4. The variation in the C/P ratio was from 227.6 to as high as 780.0 with an average of 426.7. The N/P ratio ranged from 10.4 to 44.0, the average being 24.3.

Taha et al. (1967) in their studies on microbiological and chemical properties of paddy soil found that organic matter and total nitrogen fluctuated through out the experimental period. Ammoniacal nitrogen showed a marked increase as a result of waterlogging. Nitrate nitrogen decreased initially on waterlogging and this decrease was more pronounced than that recorded for ammoniacal nitrogen showing thereby that the latter form of soluble nitrogen was held more tightly in the clay minerals of the soil. Drying of the soil increased ammoniacal nitrogen and nitrate nitrogen due to aeration that favoured ammonification and nitrification processes.

Kesny (1970) reported that the C/N ratio in four typical Kerala soils ranged from 12.2 in a submerged rice soil to 23.7 in Kari soil. Varghese (1972) in his studies on acid soils of Kerala recorded 0.49 to 0.55 per cent nitrogen in Kari soils, 0.13 to 0.19 per cent for Karapadam soils and 0.14 to 0.17 per cent for Kayal soils.

Other nutrients

Yadav and Pathak (1963) reported that the Indian coastal sands were poorest in both total and available P. The red loam and lateritic soils possessed a fair amount of total P but were low in P availability.

Kabeerathumma (1969) observed that the phosphorus substantially increased in the limed than in the unlimed samples of Kuttanad soils.

John (1971) in his studies on the organic P status of Kerala soils observed significant positive correlation between organic P with organic carbon, total nitrogen, sesquioxides and silt content of the soil.

The correlation between available P and manganese was observed to be positive by Pathak et al. (1972) and negative correlation between phosphorus and iron and also between manganese and iron.

Ponnamperuma (1972) provided an excellent review of the chemistry of submerged soils and he reported that due to the decrease in redox potential in submerged soils the availability of P together with nitrogen, silicon, iron, manganese and molybdenum increased. He reported that a pH of about 6.6, Eh of 0.30 to 0.14 and a specific conductance of about 2 mmhos/cm at 25°C are most favourable for nutrient uptake by the rice plant and under such conditions the availability of N, P, K, Ca, Mg, Fe, Mn and S is high, the supply of Cu, Zn and MoO_4 is adequate and injurious concentrations of Al, Mn, Fe, CO_2 and organic acids are absent.

Santhakumari (1975) reported that the Karapadan soils were highly deficient in phosphorus and potash, iron, manganese and zinc were present in fairly good quantities and the soils were deficient in copper.

Kanwar (1982) found that in the soils of the humid tropics, the severest limitation is the deficiency of phosphate, accentuated by high phosphate fixing capacity, high acidity, toxicity of Al and Mn and deficiency of Ca, Mg, Zn and B. He opined that phosphate mobilisation through the use of mycorrhizae seems to hold potential for utilising soils with limited P availability.

Pande and Koshy (1982) noted that some highly acid soils in Kerala have as much as 20,000 ppm sulphur with organic carbon going upto 20 per cent and these soils are generally low in phosphorus.

Aiyer et al. (1984) reported that the coastal littoral sandy soils of Kerala are deficient in both N and K, but well supplied with P.

<u>CEC and exchangeable bases</u>

In the rice soils of Kerala, Narayanan Nambiar (1947) reported that calcium was the important replaceable base followed by sodium and potassium.

Donahue (1958) considered the CEC to be a single index of soil fertility. The more clayey a soil, the more was its CEC and hence greater the chances of its being fertile.

Gopalaswamy (1961) observed a high CEC for Kari soils of Kerala and attributed this to a high content of organic matter and the probable presence of illitic and montmorillionitic clay in them.

Manickam (1961) reported a CEC of more than 60 m.e/100 g for black soil clay and less than 50 m.e/100 g for laterite soil clays.

Alexander and Durairaj (1968) noted that CEC of black soils increased with increase in pH. In acid soils the CEC was negatively correlated with pH. According to Krishnamoorthy et al. (1973) the acid soils of Tamil Nadu were found to be poor in bases especially Ca, Mg and K.

Sreedevi Amma and Aiyer (1974) recorded the highest CEC for Kari soils among the major rice soils of Kerala. The magnitude of exchangeable K was in the order Kari > Karapadam > Kayal > Kole > low level laterite soils. Comparatively high values of total, exchangeable, difficult exchangeable and HCl soluble K found in Kari, Karapadam and Kayal soils of Kuttanad were attributed to submergence in salt water from adjoining back waters and due to silt deposition by flood waters.

Phosphorus fractions of rice soils

Soil phosphorus fractionation is important to characterise the soil P and to determine its relative usefulness to crop growth since the various forms of P are related to the availability of soil P. The development of a system of fractionation of soil P with particular reference to the soil under study has a direct bearing on many aspects of soil genesis, soil chemistry, soil fertility and in turn the soil productivity.

<u>Methods of fractionation of soil P</u>

Fractionation of inorganic soil P has been studied over the last three decades. The most commonly employed method is the chemical fractionation depending on the solubility of different forms of P in different solvents. Williams (1937) using NaOH fractionated soil P into (a) an alkali soluble fraction said to include organic P, exchangeable P and the more soluble inorganic P and (b) the 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 (1943 a) divided the soil P into five groups (i) acetic acid soluble (mono, di and tri calcium phosphate); (ii) alkali soluble inorganic (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 (1943 b) further modified this procedure by the addition of 8-hydroxy-quinoline to acetic acid to prevent the re-adsorption of P during the extraction of P with acetic acid.

Williams (1950 a) 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, hydroxy 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, chrystal 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.

The development of soil P fractionation procedure particularly that of Chang and Jackson (1957) and the modified procedure by Petersen and Corey (1966) resulted in a number of studies whose objectives were to critically examine sources of P solubilized by the extractants commonly employed in soil testing. The P extracted was usually derived from several P forms and that some extractants were more specific for certain P forms than others. Based on selective solubility of P in various extractants, Chang and Jackson (1957) fractionated the soil P into Al-P, Fe-P, Ca-P, reductant soluble P and occluded Al and Fe-P.

Frink (1969) reported that the method of Chang and Jackson was adequate for the fractionation of Al and Fe-P, but modifications were needed for the determination of reductant soluble P and Ca-P.

Goswami (1982) stated that if Olsen's $NaHCO_3$ method for extraction of available P in the soil has stood the test of time and by and large widely adopted and suited irrespective of soils or crop situations, P fractionation procedure of Chang and Jackson (Troug's School again) has helped in providing a physical and chemical basis for this test by relating it to plant available discreet forms (fractions) of soil P. Hundreds of research papers following Chang and Jackson (or the modified version of Peterson and Corey) procedure vindicate the usefulness and importance of study of fractions of native soil P or those formed on transformation of applied fertiliser P in the soil

Aiyer et al. (1984) in their studies on the sandy littoral soils of Kerala reported that the extractable P by Chang and Jackson's procedure was less than 50 per cent of the total P. They suggested the modification of Chang and Jackson P fractionation procedure for these sandy soils.

P forms and their relationship with P availability

In a study of nineteen surface and five subsurface calcareous soils Fuller and Mc George (1951) found about one third of the total P in the organic form. The amount was more in the surface soil. Koshy (1952) reported that the soils of Kerala showed a wide variation in organic P ranging from 0.8 to 42.4 per cent of the total P. Jackman (1955) found that organic P was positively correlated with total P and the organic carbon content.

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

Goel and Agarwal (1959) studied the forms of soil phosphorus in genetically related soils of Kanpur and observed that organic P constituted only 10 to 20 per cent of the total P and that it decreased with increased maturity of soils. They further observed that in alkaline soils, calcium phosphate dominated which was supported by Kanwar and Grewal (1960).

Janardhanan Nair (1961), Vijayachandran (1963, 1966), Bhat (1964) and Rajaram (1964) studying the soils of Kerala noted the abundant presence of Fe and Al-P in these soils. Similar observation was made by Mathan (1964) in his study of high level latosols of the Nilgiri hills in Tamil Nadu.

The dominance of surface bounded Fe-P for the dominantly acidic low land rice soils was reported by Chang and Juo (1963) and Al Abbas et al. (1967).

Narayana Nambiar (1962) observed that in Kerala soils the P was present mainly in the form of Fe-P followed in quantity by Al-P, Ca-P and occluded P in a descending order. The sandy soils contained the highest proportion of Al-P.

Fe-P was significantly correlated to the sesquioxide content and there existed significant linear correlation between the fine sand fraction of the soils and the content of Fe-P, Ca-P and occluded Al-P.

Khanna (1967) studied the relationship between inorganic P fractions and soil test values for P using several extractants. He found that the Bray No. 2

extractable P was positively correlated with Ca-P. Olson's P with Al and Fe-P fractions. The Al and Fe-P were positively correlated with Ca-P.

Cholitkul and Tyner (1971) reported that the variation in total P in lowland soils of Thailand could probably be related to differences in the P contents of the parent alluviums, degree of weathering and soil development. No correlation was found between the total P and the clay contents. Among the various inorganic P fractions the surface bounded Fe-P was the dominant one accounting to 34.8 per cent of the mean total P and the reductant soluble P was the second most abundant, 10.8 per cent of the mean total P. The mean Al-P and Ca-P fractions on an average were low, accounting for only 5.1 per cent and 3.7 per cent of the mean total P.

The studies by Mehta et al. (1971) on the vertical distribution of P in the soils of western Rajasthan indicated that the total, organic, inorganic and available P were found to increase with depth of the soil. Organic P was positively correlated with organic carbon and clay. Inorganic P was nearly 53.3 to 90.7 per cent of the total P and the Ca-P was predominant. Positive correlation was obtained between available P and Al-P and Fe-P.

Jose (1973) in his study on P in neutral and alkali soils of South India, observed that Ca-P dominated over Fe and Al-P and Ca-P increased with increasing pH. The reductant soluble and occluded forms of inorganic P decreased with increasing alkalinity and their values were remarkably low in alkali soils.

Kumaraswamy et al. (1973) reported that in calcareous red soils Fe-P and Al-P were the prime sources of phosphates contributing to the plant uptake. In non-calcareous red soils Fe-P, Al-P and saloid bound P were significantly contributing to the plant uptake. In the studies on acid soils, Kanwar and Tripathi (1977) found that they contain most of the inorganic P in the form of Fe-P and Al-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 about 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 the total P. The third abundant fraction was Ca-P, varied between 5.9 to 10.3 per cent. Organic-P was highest in Kari, Kole and Pokkali soils.

Mishra and Khanna (1982) reported that Fe-P was the dominant source of P to the labile pool followed by Al-P in an acid podzolic brown soil. In recently fertilised soils, Al-P showed higher isotopic exchangeability than Fe-P. The opposite was true for unfertilised soils. Acid extractable soil P contributed little to labile P.

Kanwar (1982) stated that the studies on the distribution and forms of P in soils provide useful information in assessing the available P status and degree of chemical weathering of soils.

Cultivation and fertiliser P applications resulted in an increase in the total and inorganic P content for five soils and a decrease in organic P content for seven out of the eight samples. Overall change in total, inorganic and organic P content of cultivated surface soils was +25, +110 and -43 per cent respectively (Sharpley and Smith, 1983).

Sundaresan Nair and Aiyer (1983) investigated the use of Mussoorie rockphosphate in the acid soils of Kerala and concluded that Fe-P fraction was dominant in all the soils accounting for 21.8 to 39.0 per cent of total P. Al P was the second most abundant accounting 12.7 to 25.8 per cent of total P followed by Ca-P. The soils contained only 6.0 to 9.5 per cent reductant P and 2.7 to 5.6 per cent occluded P.

Aiyer et al. (1984) reported that more than 75 per cent of the extractable P in the sandy littoral soils of Kerala was seem to be bound with iron as active Fe-P and occluded Fe-P and the same was found to be significantl correlated with the fine sand fraction of the soil.

Phosphorus fixing capacity (PFC) OF rice soils

pH

The reaction of soils and clay minerals have been considered as the most important factors determining the extent and nature of phosphate fixation capacities (PFC).

At pH 2 to 5, the fixation of P was chiefly owing to the gradual dissolution of iron and aluminium oxides which are precipitated as phosphate. At pH 4.5 to 7.5, phosphates were fixed on the surface of the clay particles and at pH 6 to 10 P precipitated by the divalent cations (Kanwar and Grewal, 1960).

Koshy and Britomutunayagom (1961) in their study on fixation and availability of P in Kerala soils found that soils differed widely in their capacities to fix P, the acid soils with high silica-sesquioxide content had high capacities for P fixation.

Nad et al. (1975) determined the PFC of the soils belonging to different major soil groups and they showed no correlation between pH and P fixation.

The specific adsorption of phosphate, sulphate and molybdate by soil colloids was generally considered to decrease as the pH increased (Parfitt, 1978).

Froisen et al. (1980) observed that liming upto 6.5 or so, often increased P adsorption. When the same soil was limed and then air dried before reaction with phosphate, liming decreased P adsorption . Similar observations were made by Haynes (1983).

Exchangeable ions

The nature of the exchangeable ions present in the colloid complex of the soils play an important role in the P fixation.

Patel and Viswanath (1946) reported that in Indian soils, PFC increased with the increase in exchangeable calcium, exchangeable bases, total CEC and the clay content.

Kanwar and Grewal (1960) found that the PFC of the acidic soils of the Punjab decreased with the increase in the degree of base saturation of soils. A negative correlation between the degree of base saturation and the PFC of the soils was noticed.

Sesquioxides

The sesquioxides present in the free state and in the hydrated form are considered the main cause of PFC in acid soils.

A close correlation between active Fe and Al and the total PFC of the soil was established by a number of workers (Raychaudhuri and Mukherjee, 1941; Coleman et al., 1960; Hsu, 1965 and Vijayachandran, 1966). Significant correlation between the total sesquioxides, iron oxides, aluminium oxides and P fixation was obtained by Metzger (1941), Singh and Das (1945), Fried and Dean (1952), Perkins et al. (1957), Mathan (1964), Vijayachandran (1966), Venkataramana Reddy (1967) and Jose (1973).

The role of sesquioxides on the P fixation was well brought out by Coleman (1942, 1944 a, b); Kanwar (1956); Leaver and Russel (1957) and Fox et al. (1971).

Korhy and Britomutunayagom (1961) stated that acid soils with high silica-sesquioxide content had high capacities for P fixations.

Raychaudhuri and Mukherjee (1963) in an attempt to study the fixation of phosphates in red and laterite soils reported that clay or free sesquioxides accounted for the major part of fixation when the amount of P was small. A lower silicon: sesquioxide ratio tended to increase the fixation.

Simple and multiple correlation and regression studies by Nad et al. (1975) showed that the amount of clay and free oxides in the soils were the two dominant factors determining the PFC. The clay and free oxides together accounted for 69 per cent of the P fixed.

According to Danilo Lopez-Hernandez and Burnham (1982) the most important factor related to P retension were extractable Al and free iron oxides. In southern Scotland peat soils, Cuttle (1983) found that P sorption indices were closely related to the content of extractable iron and aluminium when expressed on volume basis, the indices were low compared with those published for mineral soils and some peats appeared to have almost no capacity to sorb P ions from solution.

Soil texture:

It is generally accepted that most of the P fixing power of soil lies in its finer mechanical fractions, especially clay.

Among the soil separates, clay was found to fix larger quantities of P than did silt or sand (Raychoudhuri and Mukherjee, 1963).

Koshy and Britomutunayagom (1965) observed the mechanism of P fixation in soils and the nature of the retained phosphate. The relative amounts of added P retained by clay and silt and the amount converted to different chemical forms in the soil were determined in an investigation on the behaviour of P in acid soils. The results favoured the chemical precipitation theory of P fixation in soil but did not exclude the possibility of adsorption by clay minerals as well.

Nad et al. (1975) reported that silt content did not show any significant correlation with P fixation while sand showed a negative correlation. Clay and free oxides together accounted for 69 per cent of the P fixed. Danilo Lopez

Hernandez and Burnham (1982) observed that clay content affected P sorption but only at low level of significance.

$CaCO_3$ content

Kanwar and Grewal (1960) stated that the PFC of calcareous soils of Punjab increased with increase in $CaCO_3$ and about 76.2 per cent of P fixation in these soils was attributed to $CaCO_3$ and exchangeable Ca and Mg. The depressing effect of $CaCO_3$ on the solubility of P in acidic soils was also observed by a number of researchers.

Islam and Khan (1967) and Dhawan et al. (1969) reported that fixation of P in alkaline calcareous soils of Rajasthan was significantly correlated with $CaCO_3$ content of the soil. Similar results were obtained by Kumaraswamy and Dhanapalan Mosi (1969), and Jose (1973) in the soils of South India.

Organic matter

The effect of organic matter in reducing the P fixation capacity of soil is well known. Datta and Srivastava (1963) reported that the role of organic matter in reducing the intensity of P fixation by sesquioxides has long been statistically evaluated.

Nad et al. (1975) observed a positive correlation between P fixation and organic carbon content for different major soil groups.

Soil type

Nad et al. (1975) reported that amongst the various soil groups, black, red, laterite, mixed red and black, red and yellow and coastal alluvial soils exhibited higher P fixation than alluvial, grey brown, desert and other soils.

Pattern of transformation of soil P upon submergence

Various changes in moisture regimes in the rice field influence the transformation of native as well as applied P, its availability and in turn the nutrition of the rice crop. The transformation is greatly influenced by the nature of the soil particularly its texture, alternate wetting and drying mostly prevailing in upland rice fields etc. The beneficial effect of soil submergence on the availability of P explains the lack of response of rice to phosphate fertilisers.

Submergence on P availability

The occurrence of a marked increase in the availability of native and added P in flooded soils as compared to well drained soils was well established by Shapiro (1958 a, Basak et al. (1960) observed that under waterlogged condition, soluble P occurred through reduction of iron and aluminium which added to the available P quantum of the soil.

It was indicated from enhanced P water solubility (Ponnamperuma, 1964) that the availability of soil P was increased by submergence. The enhanced P availability was attributed largely to the dissolution of solid phase Fe-P form accompanying drops in redox potentials.

Basak and Bhattacharya (1962) in their study on P transformations in rice soils of Bengal showed an increase of 64 per cent in available P from planting to tillering stage and a gradual decrease after pre-flowering stage to the original level.

Mahapatra (1968) reported that waterlogging resulted in an increase in water soluble P. Basu and Mukherjee (1969) showed that the ferrous iron had a depressing effect on P availability of Ca-P and Al-P. Waterlogging showed greater P availability than in moist conditions.

Islam (1970) reported that the levels of soil P first increased and then decreased with time of submergence under rice cropping. According to Sathyanarayana et al. (1970), in flooded soils containing Fe, available P levels were higher at all depth than in soils containing Ca Mohapatra and Patrick Jr. (1971) observed that the Bray extractable P increased with waterlogging, the increase being greatest in soils with large amount of Fe-P. Mandal and Chatterjee (1972) studied the transformation of applied water soluble P in latosolic lowland rice soils and concluded that the concentrations of added P remaining in solution in equilibrium with soils declined sharply, the rate of such decrease was low in soils poor in free iron oxide and native Fe-P content.

According to Ponnamperuma (1972) in acid soils, the moderating effects of submergence in soil pH and Eh influenced P availability in two ways. First, there was a reduction in levels of soluble forms of elements such as iron, manganese, and aluminium which rendered P unavailable. Second, there was a reduction in the sorption and occlusion of P on soil solids. He further reported that dry land rice was more apt to suffer from P deficiencies than wetland rice, since availability was lower under dryland than under submerged soil conditions, especially with oxisols and ultisols. Also the upland soils tended to be more acid than their wetland counterparts, both because the upland soils were generally more highly weathered and because flooding had a general moderating effect on soil pH.

Prabhakar et al. (1974) found that P availability increased with increasing soil moisture, maximum availability occurring when soils were incubated at 200 per cent field moisture capacity. Organic manures also increased available P especially at 200 per cent field moisture level. The effect of moisture level was apparent in red sandy loam than in black clay loam or alluvial paddy soil.

Mandal and Khan (1975) reported that continuous waterlogged condition appeared to be beneficial in increasing the availability of native P in acid soils. They (1977) in their study on the transformation of fixed P in soils under waterlogged conditions reported that the applied P which was left in the soil in the fixed form after the crop harvest could significantly contribute to the pool of available P in the succeeding season especially during the initial period of plant growth.

Goswami and Banerjee (1978) considered the causes of the increase in available P in soil to be (i) release of P from organic P (ii) increase in solubility of P resulting from decreased soil pH due to the accumulation of CO_2 in calcareous soil (iii) reduction of $Fe\text{-}PO_4.2H_2O$ to $Fe_3(PO_4)_2.8H_2O$ with higher solubility, (iv) higher solubilities of $Fe\text{-}PO_4 2H_2O$ and $Al\text{-}PO_4.2H_2O$ resulting from hydrolysis due to the increase of soil pH in acid and strongly acid soils, (v) release of phosphate ions from the exchange between organic anions and phosphate ions in iron and aluminium phosphates and (vi) increased diffusion of phosphate under submerged conditions.

Verma and Thripathi (1982) observed that waterlogging increased the P availability indices determined by seven soil chemical extractants. The stepwise regression analysis indicated that Fe-P was the most important variable contributing to the total variation in the regression of Olsen, Bray 1-P, Bray 2-P, Truog, Peech and Morgan's extractants and Ca-P in the regression of North Carolina's extractant both in air dry and waterlogged soil. Al-P was the second important variable contributing to the variation in the regression of Olsen, Bray 1-P, Bray 2-P and North Carolina's extractants and Ca-P in the regression of Peech and Morgan's extractants under both air dry and waterlogged conditions. With the exception of Truog's extractant, six other extractants, extract P from the same inorganic P fractions under both air dry and waterlogged conditions indicating their similarity under rice situations. However their suitability had to be judged in relation to plant growth parameters under waterlogged conditions.

Katyal and Venkataramayya (1983) reported that soil solution P was influenced slightly by submergence and increased due to the addition of fertilizer P. Its concentration was about 2.5 times more in the wet season than in the dry season, regardless of the fertilizer application or time of submergence. This increase in water soluble P was attributed to the higher temperature in the first two months of the wet season than in the corresponding periods of the dry season. They further suggested that the availability of P to plants was governed by its conc. in soil solution and in the solid phase and the equilibrium dynamics of these two forms of P.

According to Sharpley and Smith (1983) fertilizer P application and mineralisation of organic P during cultivation increased the available P content. All the P forms in the soils were relatively unaffected by cultivation

2.3.2. Submergence on P fractions

Chang and Jackson (1958) showed that the P added to the soil was converted into Ca, Al and Fe-P in acid and neutral soils. Raising the pH of the soil by the application of lime would help to increase the Ca activity and induce the formation of Ca-P and the subsequent release of P in an available form.

Watts (1968) found that the decrease in pH on drying causes inorganic P to become occluded. By prolonged waterlogging, the occluded P may be converted to more available form due to iron reducing bacteria and the immobilised P may be reversed to some extent.

Mahapatra and Patrick Jr. (1969) opined that the dissolution of coating of hydrated ferric oxide around the soil particles possibly resulted in the release of Fe-P. Islam (1970) reported that the increase in soluble P in acid soils was due to a decrease in Ca, Fe and reductant soluble P concentrations; in near neutral soil, P increased with decrease in Fe-P and Al-P.

Khanna and Mahajan (1971) observed that the transformation of added P in acidic soils was different than in alkaline and calcareous soils. More than half of the conversion of the added P in acid soils was in the form of Al-P (47 to 73 per cent at pH 4.7 and 35 to 56 per cent at pH 6.6) followed by Fe-P (18 to 44 per cent at pH 4.7 and 17.3 per cent at pH 6.6). In alkaline and calcareous soils colloid bound P and Ca-P were much more than in acid soils.

Mahapatra and Patrick Jr. (1971) found that when Al-P increased by 35 per cent and Fe-P by 64 per cent Ca-P did not undergo much change due to waterlogging, the reductant soluble P decreased. Part of the increase in Fe-P was apparently at the expense of reductant soluble Fe-P and in certain soils, part of the increase in Fe-P apparently came from Ca-P.

Mandal and Chatterjee (1972) reported that the transformation of P into Al-P and Fe-P appeared to be directly related to the quantity of these inorganic forms of P already present in the soils, proportionate to the total amount of inorganic soil P.

Patrick et al. (1974) found that alternate wetting and drying caused increased fixation or retention of added soluble P in a number of soils using labelled Al-P, Fe-P and Ca-P. Most of the added P was present in Al-P and Fe-P fractions. Flooding increased the transformation of all the P sources into Fe-P fraction.

Alternate wetting and drying decreased the availability of Al-P in all the soils studied by Mandal and Khan (1975). Under continuous waterlogging, Al-P recorded an initial increase followed by a decreasing trend. While a less acidic soil comparatively rich in Al-P, recorded progressive decreases. Continuous waterlogging for 110 days caused an increase in Fe-P in all soils. But did not bring about any decrease in reductant P and the Ca-P decreased.

Singh and Singh (1976) found a decreasing trend in Al-P and Ca-P and an increasing trend in Fe-P with age of the rice plants. Organic matter favoured significant reduction in Ca-P after three months, increased Al-P and decreased Fe-P were observed after 30 days of its addition.

The amount of fixed Al-P did not practically record any change on re-waterlogging the soil in the next season, particularly during the initial period (Mandal and Khan, 1977). The fixed Fe-P recorded a decrease immediately after re-waterlogging the soils having high P.C whereas in low P fixing soils, it remained unchanged. The fixed Ca-P recorded a gradual increase in the soil rich in native Ca-P, but showed a slow decrease in the soil comparatively poor in this fraction of P.

Singh and Ram (1977) studied the transformation of added water soluble P at two moisture levels, i.e. 50 per cent of field capacity and waterlogging in laterite alluvial and recent alluvial soils of Uttar Pradesh. In all the soils, most of the added P was recovered as inorganic fractions of P within eight days of incubation. Transformation was higher under waterlogged condition. Al-P decreased and Fe-P increased with time. Ca-P remained constant at different moisture regime in laterite soils.

Singhania and Goswami (1978) investigated the transformation of applied P in rice-wheat cropping sequence on alluvial, black, red and laterite soils of India. P applied to rice increased Al-P and Fe-P in all soils; reductant P in alluvial and laterite soils while it increased Fe-P in black and red soils.

Verma and Tripathi (1982) observed that all the native inorganic P fractions increased upon waterlogging with the maximum increase of 70.7 per cent in Fe-P.

Response of rice to phosphorus

Response of rice plants to applied P is very often inconsistent. Work carried out by many scientists have yielded conflicting results.

Varietal variation

Mahapatra (1961) obtained no response to phosphorus by eight indica varieties of rice during the main season in Orissa. An excess of P over the actual requirement was suggested (Russel, 1961) to depress the crop yields. From an experiment conducted at Bagwai, M.P. to study the response of rice varieties to three levels of P, Verma (1961) concluded that the improved varieties gave higher response than a local variety.

Plant species differed more in their reaction to the supply of soil P than to soil K and N (Black, 1968). Various theories viz., the ionic equilibrium theory, the root character theory and the P requirement theory were proposed to account for the difference in response to P among species.

The first case of varietal difference in the susceptibility to P deficiency was reported in 1970 (IRRI, Annual Report, 1970). IR-8 was severely injured by P deficiency, while IR-5 and H-4 grew well on P deficient soils.

Dev et al. (1971) recorded varietal differences to P response in rice using ^{32}P tracer technique. They concluded that IR-8 and Jaya were less efficient in utilising fertilizer P as compared to Culture-95 and IR-62288.

Ponnamperuma (1972) screened rice varieties and lines resistant to mineral stresses by growing them in P deficient and P sufficient culture solutions in Green House.

Yogeswara Rao et al. (1973) observed quadratic response functions of the rice variety IR-8 and showed the optimum P rate to vary from 18 to 66 kg/ha depending on season and P status. Gopala Rao et al. (1974) found that IR-5 rice did not respond for P beyond 40 kg/ha.

In a pot experiment with five rice varieties, Gupta et al. (1975) observed that the varieties differed in their response to P and they recommended that the high yielding dwarf varieties should be given additional fertiliser than local varieties. Average paddy yields increased from 45.1 g/pot without any P application to 66.0 g/pot with 100 ppm of P.

Morphological differences in root system became exceedingly important in determining the amount of P taken up by the plants (Gabelman, 1976). Plant species and varieties differed markedly in their power to obtain P from the soil. The more deficient the soil, the more pronounced was the difference in varieties (Gabelman, 1976 and Gerloff, 1976).

Kamath and Oza (1979) reported the varietal differences in respect of P responce. They observed that the mechanism governing the rate of nutrient movement through the soil to the root was also an important consideration for soil nutrient availability to a particular crop and its variety. Besides this, the plant roots could change the pH, salt content and ion composition of the rhizosphere region. These changes affected the availability of plant nutrients including P. The ability of different cultivars to modify the rhizosphere was different since the nature of root exudates might also be different.

Mahendran (1979) while investigating on the possible reasons for lack of response to P in Kerala by rice crop reported that the high yielding varieties absorbed higher amounts of P than traditional varieties. Further, there was significant variation in the response of varieties to applied P in a soil with low PFC and low available P status. The identification of varieties which were poor responders suggested that in a rice-rice-rice cropping system, alternation of responding and non-responding varieties may enable the skipping of P in atleast alternate seasons.

Plant species vary in the amounts of P they obtain from the soil (Sumio Itoh and Barber, 1983). It depends on the number of root hairs, amount of root surface/g of plant, rate of plant growth and the P flux kinetics of the roots. Roots may solublise P in the rhizosphere soil by exudates or microbiological activity. If solublization occurs, observed uptake will exceed the uptake predicted by a mathematical model.

P uptake

Bear (1949) using radio active isotope of P had shown that plants generally obtained unusually high proportion of P from that was already present in the soil. Stanford and

Nelson (1949) observed an initial increase in the utilization of applied P by plants, but later the absorption from soil P.

Mitchell (1957) reported that maximum absorption of P by plants occurred mostly in the early stages of growth. The recovery of added P by plants was to the extent of 10 to 30 per cent only and the rest converted into unavailable forms.

A strong positive interaction between the rates of applied nitrogen and the rates of applied P on the uptake of both soil and fertilizer P was noted by Simpson (1961). Thomas (1964) recorded a maximum recovery of only 21.7 per cent of the added P. The fertilizer P fractions in the plants increased progressively with increasing doses (Venkatachalam et al. 1969 a, 1969 b).

DeDatta et al. (1966) reported that only 8 to 27 per cent of the total P in the rice plant was derived from the applied P; 80 to 90 per cent of the applied P remained in the soil for the succeeding crops.

Venkatachalam et al. (1967) observed that direct method of application of P to paddy utilised more of the fertilizer P than the indirect method of utilisation of superphosphate applied to paddy through a preceding green manure crop. The fraction of P in the plant derived from fertilizer was significantly higher at 80 kg P_2O_5/ha than at 40 kg P_2O_5/ha. The soil with low available P status gave the highest fertilizer P in plant while the other soils testing higher available P had less fertilizer P in the plants.

Goswami et al. (1971) found that the critical levels for P_2O_5 for rice were 15 to 20, 30 to 46 and 67 to 69 kg/ha for red, black and coastal alluvial soils respectively. The wide range of critical values may be attributed to the difference in the PFC of the soils. Gupta and Ram (1971) in their study on P uptake by paddy in Vindian soils reported that plant growth as well as P uptake was better in alluvial and Dhonka soils and in both soils available P was better correlated with P uptake.

Rice extracted P from Fe-P in its earlier growth period for the yield and Al-P towards later stage affecting P uptake (Ramamoorthy and Bisen, 1971). Neither Bray's nor Olsen's extractants in the present form was suitable to evaluate P on these black soils of Coimbatore for the rice crop.

Kumaraswamy et al. (1973) reported that as the growth of the rice crop advanced, the plants had taken more of fertilizer P which was available in greater amounts than the soil P fraction. An increased uptake of P with increasing levels of N by paddy crop was noted by Alexander et al. (1974).

Fageria et al. (1982) found that the uptake of N, P and K increased with higher levels of P and age of the plant. Keramidas and Polyzopoulos (1983) reported that a number of P intensity indices including P concentration, activity of the H_2PO_4 ions and certain chemical potentials were found to satisfactorily predict P uptake by rye grass. Simple intensity indices such as P concentration in either $CaCl_2$ or H_2O extracts proved as good as more elaborate ones.

Aiyer et al. (1984) could not get significant correlation between inorganic P fractions with the actual plant uptake in the sandy littoral soils of Kerala thereby showing that plants probably take up more than one form of P or the dissolution of thorium phosphate in the various reagents along with normal inorganic forms fractionated, prevented a definite relationship to be established.

Dry matter yield

Kadam (1945) obtained substantial increase of rice yield in laterite soils with bone meal. Ishizuka and

Tanaka (1950) found response to P when rice was grown in solution culture with 20 ppm of P. Davin (1951), Parthasarathy (1953) and Desai et al. (1954) reported significant increase in yield when P was supplied in combination with nitrogen. Verma (1960) noticed marked increase in grain yield when P was given along with N. He also found that P when applied alone increased the yield. But the differences were not significant.

Davide (1964) reviewing P fertilisation on paddy concluded that unless a soil is deficient in P, yield response to addition of P fertilisers in field experiments would not be obtained. Very little effect of P on grain and straw yield was noted by Enyi (1964), but the effective tillers increased with increased P supply.

Datta and Shinde (1965) had shown that the dry matter yield of rice to be more under waterlogged condition than under upland situations.

Venkatachalam et al. (1969 a) observed that the grain yield as well as total P uptake increased due to P application. Ramamurthy and Bisen (1971) reported that in the Black soil of Coimbatore, Ca and Fe bonded P in the surface soil and Ca and Al bonded P in the sub-soil to be important contributions to the grain yield of rice.

Nair et al. (1972) in their investigations at Rice Research Station, Pattambi, during four consecutive seasons in the same field to study the response of rice to P manuring in conjunction with Mg and Spartin found that P application resulted in increased yields from second season onwards.

Kumaraswamy et al. (1973) reported that the dry matter yield of rice at 35th day after transplantation depended upon the added fertilizer P to the extent of 68 and 78 per cent in calcareous red soil and non-calcareous red soil respectively and the contribution of soil available P to dry matter yield at this stage was not significant in both soils. The dependence of grain plus straw yield at final stage on the added P as well as soil available P was not significant under both the soils.

Both tillering and yield in many rice cultivars increased with increasing rates of P from 20 to 40 kg/ha in black alkali soil with a pH of 7.0 and no tillering was noticed due to lack of P (Katyal et al. 1975).

The critical soil water soluble P content below which plants yielded little or no grain was 0.05 ppm and highest yields were obtained with 50 ppm added P_2O_5 to give an average soil water P content of 0.084 ppm during vegetative growth (Katyal, 1978). Delaying P application for 14 days after transplantation reduced yields and increased time to maturity with a greater effect in the dry than wet season. Fifty per cent less P was needed to avoid P deficiency when it was applied at transplanting as superphosphate.

Upadhyay and Pathak (1981) observed that P increases both total and percentage dry matter and grain yield of rice. The critical P content at tillering was found to be 0.25 per cent.

Fageria et al. (1982) found that upland rice responded upto 67 kg P/ha. Dry matter production, leaf area index and number of tillers per unit area were increased with the use of higher levels of P. The maximum number of tillers per m^2 was reached between 60 to 70 days of growth and then started to decline. Rice grain yields were increased by 254, 309 and 355 per cent respectively with 22, 44 and 66 kg P/ha in the first year and by 101 and 138 per cent with 22 and 44 kg P/ha respectively in the second year.

Application of P upto 30 ppm substantially increased leaf, stem and root dry matter yield of rice (Alam, 1983).

<u>Response of rice to P application</u>

Sethi (1940) recorded no response to P application singly or in combination in his experiments for five years.

Sethi et al. (1952) concluded that unlike nitrogenous fertilizers, the response to P was not general, but limited to a few stations. In certain cases no response or little response was observed by Banerjee and Digar (1957). In some situations they noticed a response after few years of application. Such observations were also made by Dhawan et al. (1957) and Digar and Mondal (1957).

Ghosh et al. (1960) observed a positive response to P application in all kinds of soils in India. Datta and Shinde (1965) observed that though per cent utilization of added P and "A value" increased under waterlogged condition, the crop met its major demand of P from the native P in the soil. Raheja (1966) reviewing a series of experiments conducted in Madras State reported a nil or no significant response to P application. Tiwari and Singh (1969) found that P application had positive significant response in yield, plant height, tiller number and number of grains per ear head, but there was no effect on the weight of 1000 grains. There was a general response in grain yield and P uptake to P application as observed by Venkatachalam et al. (1969 a).

Terman (1970) concluded that marked yield response by rice was obtained at much lower rates of applied P than was obtained for most of the upland crops. Response to P was obtained for rice in almost all the districts in India and it was particularly high in case of districts whose nutrient index for P was low (Goswami et al. 1971). Mahopatra and Patrick Jr. (1971) reported that lowland rice showed considerably less response to P than did upland crops grown on the same soil.

Anonymous (1973) in field trails conducted in the All India Co-ordinated Agronomic Experiment scheme of 1969-70 to 1972-73 revealed that responses to 30 kg P_2O_5/ha was significant at Kharagpur (lateritic soil). Significant residual responses to P application were obtained and the residual effect was as high as direct effect giving a response of about 1100 kg/ha. At Bhuvaneswar, residual response was significant for rabi rice. However in the year 1971-72 no response to P application on kharif rice was obtained at Bhuvanesuar (lateritic soil). In 291 tests in India within the period of 1968-70 response to P ranged from 4 to 16 kg grain/ha at 60 kg P_2O_5/ha (DeDatta, 1982). Sreenivasa Raju and Kamath (1983) observed significant responses of rice to P application. Similar observations were also obtained by Datta and Gupta (1984), Ram Singh et al. (1985) and Samiei and Singh (1985).

Reasons for response

Stewart (1947) pointed out lack of response to P due to improper method of application. Nelson (1957) obtained no response to various rates of P application even on soils deficient in P and this lack of response was attributed to fixation of added P, transformation of native P to available forms under flooded conditions and inadequacy of the analytical methods used to evaluate the available P in the soil. Goel and Agarwal (1959) found that the mature soils which contained more of iron and aluminium phosphates responded to P fertilizers, whereas the less mature soils high in Ca-P did not respond to application of P.

The tolerance of the plant to the deficiency of P was associated with genetic control especially over depth of rooting. The difference in behaviour of P in flooded soil was attributed to be the reason for the poor response of wetland rice than did upland (Mahapatra and Patrick Jr. 1971). Rajendran et al. (1971) studied the response in yield of Co-25 paddy as influenced by soil series and manuring in three major soil types of Tamil Nadu viz., black, red and alluvial soils and they found lack of significant response to P in all the soils with medium to medium high available P status indicating that independent effect of P could at best be expected only in soils of very low to low P status.

Ponnamperuma (1976) viewed P deficiency as the most important factor limiting the yield of rice on Ultisols, Oxisols, Acid sulphate soils, Andosols and some Vertisols. Not only were these soils low in available P, but they also fixed considerable amounts of added P and therefore large amounts of P might be required to produce a response.

The responses to added P depends on soil type, P status of the soil, condition of submergence, various chemical parameters of the soil like pH, organic matter status, amount of free oxides of iron and aluminium, clay content etc. (Mandal, 1979).

P deficiency in paddy soil is not as common as N deficiency and the response of rice to P is also not as significant as to N. The status of soil P is changeable; it may very significantly in a relatively short time or within a limited distance. This should be taken into account in the application of P fertilizers to paddy soil

(Lu Ru-Kun et al. 1982). They further reported that the soils which were responsive to P failed to give a response after continuous P fertilizer application, conversely, the soils which were not responsive to P have become response when no P fertilizer has been applied for several years. Singh (1983) opined that the methods of evaluation of soil P may not correctly predict the P response as the determination of nutrient status in this manner may not adequately simulate the conditions under which the crop is grown.

<u>Comparison of P sources for their efficiency on rice crop</u>

With the verification of the accuracy and precision possible with levels of ^{32}P, extensive use of tagged P fertilizers in experiments has been shown to be economically practical. The significance and limitations of specific isotope criteria such as percentage of total P in the plant or grain derived from the fertilizer, crop utilisation of the applied P and A-values as indices of soil and for fertilizer P availability can be well studied.

Kurup and Koshy (1968) found that water soluble P from superphosphate was as efficient as citric acid soluble P in the Kuttanad soils. Atanasiu (1971) investigated the efficiency of various forms of P fertilizers in India on lateritic soils and concluded that the citrate soluble P had better effects than water soluble forms. This was particularly so in soils of low pH. The P uptake from citrate soluble P was higher than that from water soluble P.

Gupta (1971) in his green house study showed that application of monocalcium phosphate increased the amount of Al-P but Fe-P and Ca-P accounted for most of the P in the available soil P. Motsara and Datta (1971) compared the effectiveness of rock phosphate and superphosphate in acid soils for the crops viz., rice, wheat, maize and peas and found that there were significant differences in yield with increase in the quantity of rock phosphate. Eighty kg P_2O_5/ha of rockphosphate gave the same yield as that obtained in an equivalent dose of superphosphate in the case of paddy, wheat and maize, but greater yield was obtained with peas with rock phosphate and superphosphate. In their residual study, rockphosphate was found to be significantly better than superphosphate with respect to crop yields and residual P status of soils.

The effect of different P fertilizers in the soils of Chambal in Rajasthan was studied by Chauhan (1972) and found that the available P increased with the increasing doses of fertilizers and with time. In these areas superphosphate was found to be the best P fertilizer.

Datta et al. (1972) compared basic slag, blast furnace slag and some indigenous phosphatic deposits for their effectiveness in acid soils and observed that basic slag benefited crops through its supply of both Ca and P in acid soils.

The release of P in available form from insoluble phosphate materials such as rock phosphate, bone meal and basic slag by the addition of organic matter was investigated by Mandal and Khan (1972) and showed that within 15 days of application more than 86 per cent of the P added as superphosphate was converted to unavailable forms. Both basic slag and rock phosphate maintained in the soil a higher amount of available P than superphospate. Bone meal behaved slightly inferior to superphosphate in supplying available P. Organic matter application did not bring about additional release of available P. They concluded that rock phosphate and basic slag were more effective than superphosphate.

With Laccadiv phosphate and Mussoorie phosphate in different soils, Singh and Datta (1973) observed that citrate solubility of the phosphate rock and pH of the soil appeared to be the most important factors governing the availability and the particle size of the rock phosphate had little effect on solubility at low pH.

Engelstad et al. (1974) conducted green house studies to evaluate several phosphate rocks for flooded rice and showed that a close relationship existed between the first crop yield response to applied P and citrate solubility. The residual effect of the triple superphosphate remained higher than that of phosphate rocks.

Kumaraswamy and Krishnamoorthy (1974) with ^{32}P labelled superphosphate on Co-10 finger millet found that the fraction of P in plants derived from fertilizer increased progressively with increasing dose of added P, proportion of fertilizer P being significantly higher at harvest stage than on the 35th day. Fertilizer P remained in more available form throughout the crop growth than the native soil P and the percentage utilisation of added P on the 35th day after transplantation increased with increasing dose of P in calcareous and non-calcareous red soils.

Minhas and Kick (1974) in a pot experiment on the effect of superphosphate and rock phosphate on yield and P uptake by rye grass and red clover observed that superphosphate gave better results in the earlier part of the experiment while in later periods, rock phosphate gave better results. Fractionation of inorganic P in soil before and after the experiment showed that the major part of the added rock phosphate was transformed into water soluble and loosely bound Al and Fe-P fractions and became available for plant growth. In acid soils, rock phosphate could thus easily replace superphosphate and become an economical source of P.

Chine and Black (1975) observed that the solubility product constant for a carbonate apatite in a Florida phosphate rock decreased with an increase in the proportion of the phosphate rock dissolved in the solubility determination. The percentage efficiency of Mussoorie phosphate, Laccadiv and Udaipur rock phosphate compared to superphosphate was 78, 62 and 54 respectively

(Dasarath Singh and Manikar, 1976). Singh (1976) studied the order of efficiency of rock phosphate from different deposits in an alkaline soil and found as Laccadiv > Mussoorie > Udiapur. This was related to their solubility. The P availability from all these sources increased with increase in the levels of P application from 60 to 180 kg P_2O_5/ha and with incubation period upto 75 days. Farm yard Manure (60 tonnes/ha showed little effect on the availability of P from rock phosphate.

Saranganath et al. (1977) observed that citrate soluble and insoluble phosphates to be as efficient as water soluble P for growing rice on acid soils. They further showed that when rock phosphate was applied two weeks before flooding, the available P status and response to its application was the same as those for soluble phosphates.

Madhusoodhanan Nair (1978) showed that priming of the rock phosphate in moist aerobic soils transformed a substantial part of the applied P to Fe-P but with apparently no change in Al-P. On the other hand transformation of applied P to Al-P was more in soils treated with superphosphate at flooding.

Sundaresan Nair and Aiyer (1983) reported an increase in grain yield at 45 kg P_2O_5/ha with superphosphate and Mussoorie phosphate in Kari and Kayal soils. In the Karapodam and Kole soils, increase in yield was obtained only at higher doses of Mussoorie phosphate and superphosphate. In the lateritic alluvium, response to both higher and lower levels of Mussoorie phosphate was obtained.

Negi (1979) related the uptake of P by wheat and maize from ^{32}P labelled P fertilizers to dry matter yields and P uptake from soil at two growth stages. The dry matter yield and P content of wheat were positively correlated with the uptake of P from soil and from fertilizers at both growth stages, the importance of fertilizer P increased and that of soil P decreased at the latter growth stage. At both the growth stages the dry matter yield of maize was positively correlated with uptake from soil and the P content was particularly correlated with P uptake from fertilizer.

Kanwar et al. (1982) reported that the most important charactoristic of phosphatic fertilizer that affected the response or uptake by crops was its water solubility. P fertilizors varied in their solubility from practically nil to 100 per cent which had a bearing on its agronomic effectiveness. Chemical composition of the fertilizer, granule size and method of application influenced markedly the response to phosphatic fertilizers.

Sekhon (1982) had reviewed the works on the effect of different P fertilizer forms in India within the past 20 years and accordingly (i) at low P doses i.e., less than 60 kg P_2O_5/ha, the water soluble or partially water soluble P forms with a large water soluble component or partially water soluble P forms with a small water soluble component; at higher P doses, the differences are small or the relationship is reversed and (ii) besides pH value of the soil, other parameters influencing the efficiency of P forms of different solubility are the natural supply with available P of the soil, the level of the applied P doses, the form of the concomitant fertilizers, the duration of the plant growth, the water supply, the P fixing capacity of soil etc.

Borthakur (1983) obtained better response for rainfed rice in acidic soils to a mixture of rock phosphate and single superphosphate in the ratio of 1:1. Singh and Rao (1983) observed the residual effect of superphosphate, dicalcium phosphate and rock phosphate in lateritic soils of Maharashtra. Residual response of rock phosphate is more than direct response and it is desirable to allow a reaction period before sowing (Tandon, 1983).

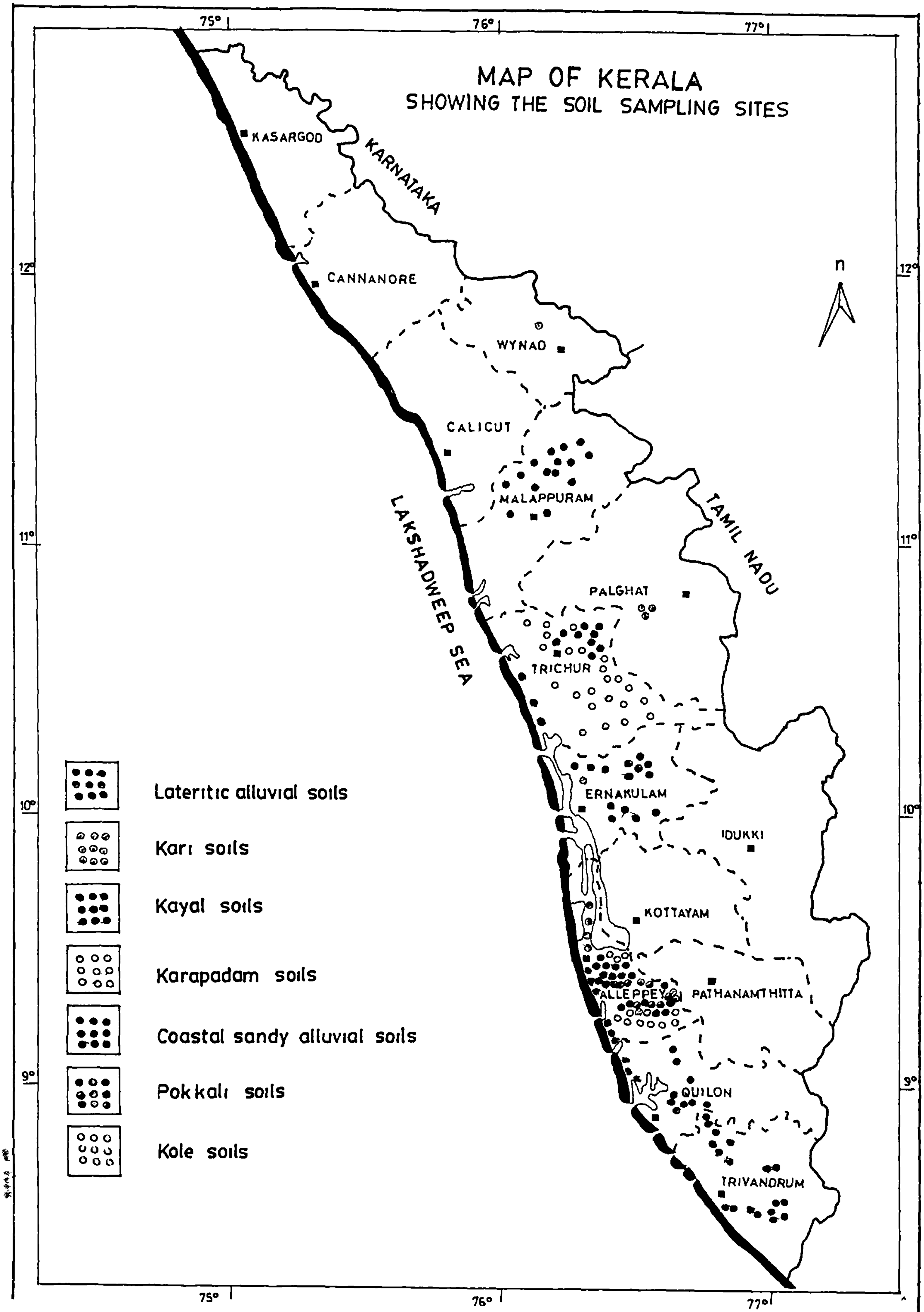
MATERIALS AND METHODS

MATERIALS AND METHODS

The investigations carried out in this thesis include (1) Assessment of the general physico-chemical characteristics of the soil samples collected from various rice growing areas representing the major rice soil groups in Kerala (2) Fractionation of soil P (3) Phosphorus fixing capacity of the soils (4) Studies on the pattern of transformation of P in selected soils under submergence (5) Response studies with two rice varieties to the application of graded doses of P and (6) comparison of two sources of P on rice crop with ^{32}P.

1. <u>General physico-chemical characteristics of rice soils</u>

A total of one hundred and fifty one surface soil samples (0-6" depth) were collected. They represent the seven major rice growing soils viz., (i) lateritic alluvium (Inceptisol) covering Trivandrum, Quilon, Trichur, Palghat, Malappuram and Wynad districts (ii) Kari soils (Entisol) from Alleppey and Kottayam districts (iii) Kayal soils (Inceptisol) of Alleppey district (iv) Karapadam soils (Inceptisol) from Alleppey district (v) Coastal sandy alluvium (Entisol) from Quilon, Alleppey and Trichur districts (vi) Pokkali soils (Alfisol) of Ernakulam district and (vii) Kole soils (Inceptisol) from Trichur district in Kerala. The exact locations from which soil


MAP OF KERALA
SHOWING THE SOIL SAMPLING SITES
75°
76°
77°
12°
11°
10°
9°
n
KASARGOD
KARNATAKA
CANNANORE
WYNAD
CALICUT
MALAPPURAM
TAMIL NADU
LAKSHADWEEP SEA
PALGHAT
TRICHUR
ERNAKULAM
IDUKKI
KOTTAYAM
ALLEPPEY
PATHANAMTHITTA
QUILON
TRIVANDRUM
Lateritic alluvial soils
Kari soils
Kayal soils
Karapadam soils
Coastal sandy alluvial soils
Pokkali soils
Kole soils

samples were collected are given in Appendix I. The air dried samples were ground and passed through a 2 mm sieve. The samples so prepared were kept in labelled bottles for further studies.

Soil samples were analysed for the following physico-chemical characteristics as per the method noted against each.

Sl. No.	Particulars of analysis	Name of procedure/ method	Author
I.	Physical analysis		
(i)	Mechanical analysis	Bouyoucos Hydrometer method	Piper, 197
(ii)	Physical constants	Method of Keen and Raczkowski	Wright, 193
II.	Chemical analysis		
(i)	Soil reaction	in 1:2.5 soil water suspension	Jackson, 1967
(ii)	Electrical conductivity	do.	do.
(iii)	Total N	Modified Kjeldahl Method	do.
(iv)	Total P	Vanadomolybdate method	Hesse, 197
(v)	Total K	Flame photometer method	Jackson, 1967
(vi)	Organic carbon	Walkley and Black's rapid titration method	Piper, 197
(vii)	C.E.C. and exchangeable bases	Neutral Normal ammonium acetate method	Jackson, 1967
(viii)	Total sesquioxides, Fe_2O_3, Al_2O_3	In the HCl extract each analysis was done	do.
(ix)	Total CaO and MgO	Versenate titration method	do.

2. Fractionation-soil P

2. 1. Total phosphorus

This was estimated by perchloric acid digestion method as described by Jackson (1967). One gm of soil passed through 0.5 mm sieve was taken in 100 ml Erlenmeyer flask, 10 ml of concentrated nitric acid and 15 ml of 60 percent $HClO_4$ were added. The digestion was carried out at 130°C until the solution appeared colourless. After digestion, the flask was cooled and 50 ml of distilled water was added. The solution was filtered and the filtrate was collected in a 100 ml volumetric flask. The total P was determined in an aliquot of this solution by the vanadomolybdate method.

2. 2. Fractionation of soil inorganic phosphorus

The fractionation of soil P excepting the reductant soluble P was done by the modified procedure of Peterson and Corey (1966) after Chang and Jackson (1957).

(i) Saloid bound phosphate (1 N NH_4Cl extractable P)

One gm of soil that passed through a 0.15 mm sieve was placed in a 100 ml centrifuge tube and 50 ml of 1 N NH_4Cl solution was added. The suspension was shaken for

30 minutes and centrifuged. The saloid bound-P in the supernatant solution was determined by the chlorostannous-reduced molybdophosphoric blue colour method in H_2SO_4 system as described by Jackson (1967).

(ii) Aluminium phosphate (0.5 M NH_4F extractable P):

To the soil in the centrifuge tube, 50 ml of 0.5 M NH_4F solution made to pH 8.2 with NH_4OH was added, shaken for an hour and centrifuged. The supernatant solution was filtered through activated carbon and the Al bound P in a 10 ml aliquot of the filtrate was estimated by the chlorostannous reduced molybdophosphoric blue colour method in HCl system (Jackson, 1967) after adding 15 ml of 0.8 M boric acid to eliminate the interference of fluoride.

(iii) Iron phosphate (0.1 M NaOH extractable P)

The above soil residue left after the determination of Al-P was washed twice with 25 ml portions of saturated NaCl solution, centrifuged and the washings discarded. The soil was then shaken for 17 hours with 50 ml of 0.1 M NaOH and centrifuged. The supernatant liquid was transferred to another centrifuge tube and 5 drops of conc. H_2SO_4 were added to flocculate the organic colloids. It was again centrifuged and filtered through activated carbon. The Fe-bound P in the filtrate was determined by the chlorostannous-reduced molybdophosphoric blue colour method in H_2SO_4 system.

(iv) Reductant soluble phosphorus

The soil left in the centrifuge tube was washed twice with saturated NaCl solution and the washings were discarded. The soil was then suspended in 25 ml of 0.3 M sodium citrate solution, 1 g of sodium dithionite was added and shaken for 15 minutes. The content was heated to 80°C in a water bath, diluted to 50 ml, shaken for 5 minutes and centrifuged. The supernatant solution was collected in a volumetric flask and the soil residue was washed twice with saturated NaCl solution. The washings were also collected and made upto mark. The reductant soluble P in the solution was estimated as described by Chang et al. (1966).

To 5 ml aliquot, 5 ml of water, 1 ml of 0.5 M $FeCl_3$ and 4 ml of 1N NaOH were added. The solution was heated on a hot plate at 80 to 90° C to oxidise the dithionite and precipitate the citrate in alkaline solution. The dark brown precipitate formed was filtered and the filtrate was collected into 50 ml volumetric flask after washing the residue with 5 ml portion of a

0.1N NaOH. The reductant soluble P was determined in the solution by the chlorostannous-reduced molybdophosphori blue colour method in HCl system.

(v) Occluded phosphate

To the soil left in the tube after the dithionite citrate extraction and NaCl washing, 50 ml of 0.1 N NaOH was added, shaken for an hour and centrifuged. The occluded-P in the supernatant solution was determined by the chlorostannous-reduced molydophosphoric blue colour method in HCl system.

(vi) Calcium phosphate (0.25N H_2SO_4 extractable P)

The soil residue was then washed twice with NaCl solution. Fifty ml of 0.25N H_2SO_4 was added, shaken for an hour and centrifuged. The Ca-bound-P in the supernatant liquid was estimated by the chlorostannous-reduced molybdophosphoric blue colour method in H_2SO_4 system.

2. 3. Organic phosphorus

This was estimated by the method of Mehta et al. (1954). One gram of soil was placed in a 100 ml centrifuge tube, 10 ml of conc. HCl added and the suspension heated on a steam plate for 10 minutes. An additional 10 ml of conc. HCl was added, allowed to stand at room temperature for an hour, diluted with 50 ml of water and centrifuged. The clear supernatant solution was collected in a 250 ml volumetric flask containing 50 ml of water.

Thirty ml of 0.5N NaOH was added to the soil in the centrifuge tube and the suspension allowed to stand at room temperature for an hour. It was then centrifuged and the supernatant liquid collected in the volumetric flask containing the acid extract. Then 60 ml of 0.5N NaOH was added to the tube, and kept in an oven at 90°C for 8 hours. The suspension was centrifuged and the supernatant liquid collected in the volumetric flask containing the previous extracts. The combined extract was diluted with water and made upto volume.

An aliquot of 15 ml was pipetted into a 50 ml beaker and 1 ml of 72 per cent $HClO_4$ added and digested until the colour of the solution was clear. The solution was transferred to a 50 ml volumetric flask and made upto the mark. A 10 ml aliquot was used for the estimation of total P by chlorostannous-reduced molybdophosphoric blue colour method in HCl system. Inorganic P was determined in an aliquot of combined soil extracts. The organic P was calculated as follows.

Organic P = Total P extracted-Inorganic P.

2. 4. Total inorganic phosphorus

This was calculated by the difference between the total P extracted by perchloric acid method and organic P extracted by Mehta et al. (1954) method.

2. 5. Non-extractable inorganic phosphorus

This was calculated by difference as follows:

Total P - Sum of six inorganic P fractions estimated by fractionation + Organic P.

3. Phosphate fixing capacity of the soils

This was estimated by the method of Patel and Viswanath (1946).

Ten gram of air dried soil, passed through a 70 mesh sieve was placed in a 50 ml centrifuge tube and 100 ml of diammonium dihydrogen phosphate solution, containing one mg P_2O_5 in one ml of the solution and adjusted to pH 7.0 was added. The content was shaken for 24 hours in a mechanical shaker. The suspension was centrifuged and the P content in the clear solution was estimated by the vanadomolybdophosphoric yellow colour method in HNO_3 system as described by Jackson (1967). The decrease in concentration was taken as the amount of P fixed.

4. Pattern of transformation of P under submergence.

Fourteen out of the 151 soils collected were selected based on the content of total P to represent the major rice growing soils in Kerala. Those that recorded lowest and highest total P under each soil type were included in the study. Samples were taken from plough layer of cultivated fields, air dried and stored until used. Depending on the fractionation and extraction methods to be followed, required number of soil samples were weighed into extraction bottles. Incubation was done at 26°C under waterlogged conditions. A measured amount of distilled water was added to submerge the soils about 4 cm above its surface. Glucose @ 0.2 per cent was added to all the waterlogged soils to provide a small amount of readily available energy source to stimulate reducing conditions (Verma and Thripathi, 1982). The bottles were stoppered with corks in which tiny holes were made for gas exchange and kept in the laboratory for 16 weeks corresponding to the period of harvest of rice crop under waterlogged condition.

The soil P fractionation studies except the reductant soluble P was carried out by the modified procedure of Peterson and Corey (1966) after Chang and Jackson (1957). The reductant soluble iron P was analysed by a slightly modified method of Chang et al. (1966). The soil available P was determined by the following methods.

(i) Bray No.1 method (Bray and Kurtz, 1945).

Five grams of soil was shaken with 35 ml of the extracting solution (0.03N NH_4F in 0.025 N HCl) for 5 minutes. The suspension was immediately filtered and P in the filtrate was determined by the chlorostannous-reduced molybdophosphoric blue colour method in HCl system, after adding 1 ml of 0.8M boric acid to a 10 ml aliquot of the extract.

(ii) Bray No.2 method (Bray and Kurtz, 1945).

Five grams of soil was shaken with 35 ml of the extracting solution (0.03N NH_4F in 0.1N HCl) for 5 minutes. The suspension was immediately filtered and P in the filtrate was determined by the chlorostannous-reduced molybdophosphoric blue colour method in HCl system, after adding 1 ml of 0.8M boric acid to a 10 ml aliquot of the extract.

(iii) <u>Olsen's method</u> (Olsen et al. 1954)

Five grams of soil was shaken with 50 ml of 0.5M $NaHCO_3$ solution (adjusted to pH 8.5 with NaOH) and half a teaspoon of Darco G.60 charcoal for 30 minutes. The suspension was filtered and P in the filtrate was determined by the chlorostannous-reduced molybdophosphoric blue colour method in HCl system.

(iv) <u>Truog's method</u> (Truog, 1930)

One gram of soil was shaken with 200 ml of 0.002N H_2SO_4 (buffered to pH 3.0 with $(NH_4)_2SO_4$ for 30 minutes. The suspension was immediately filtered and P in the clear filtrate was determined by the chlorostannous reduced molybdophosphoric blue colour method in H_2SO_4 system.

5. <u>Response of rice to graded doses of phosphorus</u>

A pot experiment in C.R.D. was conducted in 1982 at College of Agriculture, Vellayani to study the response of two rice varieties to the application of graded doses of phosphorus and to assess the relationship between P uptake with available P by different methods and P fractions at various growth stages. The soil used was collected from the Vellayani kayal.

The details of the experiment are given below:

No. of varieties	=	2
V_1	=	Short duration, Jyothi.
V_2	=	Medium duration, Mashoori.
No. of treatments	=	6
T_1	=	Zero P_2O_5 (Control)
T_2	=	30 Kg P_2O_5/ha
T_3	=	45 "
T_4	=	60 "
T_5	=	90 "
T_6	=	120 "
No. of replications	=	2

Bulk soil was collected from the Kayal area of the College of Agriculture, Vellayani and spread on polythene sheets, air dried and ground to pass through a 2 mm sieve. A representative soil sample was taken and analysed for its initial physico-chemical characteristics. Required number of earthen pots were filled with 10 kg each of the processed soil. The soil in the pots was well puddled with water. N and K as per package of practices for rice by the Kerala Agricultural University by way of urea and Muriate of potash were applied basally and mixed with the soil.

Phosphorus as superphosphate as per the treatments was also given basally and well mixed with the soil a day before the sowing of seeds.

Sprouted seeds of Mashoori and Jyothi were sown @ 5 seeds per hill on 30-4-1982. After the establishment of the seedlings, thinning was done to get atleast 3 seedlings per hill. Prophylactic plant protection measures were taken against the pests and diseases. The pots were irrigated frequently so as to provide 5 cm submergence continuously through out the crop growth.

The second dose of N and K at the time of maximum tillering stage and the final dose at the panicle initiation stage were given as scheduled in the package of practices.

Biometric observations were taken at 30th day and 60th day after sowing and also at harvest stage. Soil samples were taken at all the three stages and analysed for their available P content by four methods (Bray 1, Bray 2, Olsen and Truog), the soil inorganic P was fractionated into saloid-P, Al-P, Fe-P, Reductant-P, Ca-P and Occluded-P. The total P uptake at each stage was also estimated.

The Jyothi crop was harvested on 7-8-1982 and the Mashoori on 4-9-1982. At harvest, observations on yield characteristics viz., grain, straw and total dry matter production in addition to the biometric characteristics were recorded.

6. <u>Comparative evaluation of two sources of phosphorus on rice crop with ^{32}P.</u>

A pot experiment in C.. .D. was designed to study the comparative efficiency of two sources of phosphorus in rice. The experiment with seven soils and seven treatments was laid out in the pot culture yard of the Radioisotope laboratory of the Tamil Nadu Agricultural University, Coimbatore in April 1983.

The soils representing the major rice growing areas in Kerala were selected based on their total P content. The soils, recorded the lowest total P, included for the study were

1.	Vellayani	(S_1)	representing	lateritic alluvial soils
2.	Karuvatta	(S_2)	"	Aquepts Kari soils
3.	Moncompu	(S_3)	"	Aquents Karapadom soils
4.	Mathikayal	(S_4)	"	Aquepts Kayal soils
5.	Panangad	(S_5)	"	Aquepts Pokkali soils
6.	Chalakudy	(S_6)	"	Aqualfs Coastal sandy alluvial soils Psamments
7.	Kanjanikole	(S_7)	"	Kole soils Aquepts

Bulk soils were collected from the paddy growing regions and transported to the Radioisotope laboratory, Tamil Nadu Agricultural University, Coimbatore. The soils were spread on polythene sheets, air dried and ground to pass through a 2 mm sieve. About 500 g from each soil type was taken for analysing the initial physico-chemical characteristics. Required number of earthenware pots were filled with 5 kg each of the processed soil. The soil in the pots was well puddled with water. N and K as per package of practices by way of urea and muriate of potash were applied basally and mixed with the soil.

The treatments included two sources of phosphorus, labelled ^{32}P as monocalcium mono phosphate (MCP) and labelled ^{32}P as tricalcium phosphate (TCP) and were

T_1	=	Control (Zero P_2O_5)		
T_2	=	Monocalcium mono phosphate	(30 kg P_2O_5/ha)	
T_3	=	" "	(60 kg	")
T_4	=	" "	(90 kg	")
T_5	=	Tricalcium phosphate	(30 kg	")
T_6	=	" "	(60 kg	")
T_7	=	" "	(90 kg	")

^{32}P labelled monocalcium mono phosphate with the specific activity of 0.3 millicurie/g of P and ^{32}P labelled tricalcium phosphate with the specific activity of 0.3 millicurie/g of P were prepared. Upon drying, the fertilizer mixtures were well powdered and used for the experiment. The specific activity and the total P content of the prepared fertilizer samples were found out following the method of McKenzie and Doan (1948) and using a Geiger Muller Counter (GCS 1313 of ECI Ltd., Hyderabad) and by vanadomolybdate method respectively. Based on the total P content of the fertilizer samples, the required quantity of the fertilizers to supply the graded doses of P as monocalcium mono phosphate and tricalcium phosphate were separately weighed and kept in small polythene covers. A day before the sowing of seeds, the ^{32}P labelled fertilizers were applied to the individual pots and the same were thoroughly mixed with the soil, well puddled again.

Sprouted seeds of paddy var. Jyothi were sown on 14-4-1983 @ 5 seeds per hill. After the establishment of the seedlings, thinning was done to get atleast 3 seedlings per hill. Plant protection measures were taken against pests and diseases. The pots were irrigated frequently so as to provide 5 cm continuous submergence. The second and the final dose of N and K were applied at the time of maximum tillering stage and at panicle initiation stage respectively.

Biometric observations were taken at the panicle initiation stage on height of plant, number of productive tillers per hill, weight of roots, weight of straw and total dry matter. Soil samples were also collected at this stage. The root and straw samples were separately collected, dried, ground and these samples along with the processed soil samples were analysed for their specific activity and total P content.

The crop was harvested on 16-8-1983. At harvest stage, observations on yield characteristics like grain and straw yield, weight of roots and total dry matter produced were recorded (as in the case of the samples collected at the panicle initiation stage). The root, straw and grain were separately processed for analysis. Soil samples were also collected, processed and analysed. The total P content of the root, straw, grain and soil samples was determined by the vanadomolybdate method. Since there was insufficient counts in these samples, triple acid extract of the samples was taken and the P was precipitated as ammonium phosphomolybdate and the precipitate after (making moisture free) washing with alcohol was taken in planchets and used for taking counts with G.M. counter.

RESULTS

RESULTS

1. General characteristics of the rice soils with special reference to phosphorus

The rice soils selected for the present investigation were studied in detail for their important physico-chemical characteristics with special reference to phosphorus content, availability and such other parameters that may help to define or have a bearing on soil phosphorus. The data on the important physico-chemical characteristics of the soils are presented in Appendix II.

Normally the soils are categorised as lateritic alluvium (Inceptisol), Kari (Entisol), Kayal (Inceptisol), Karapadam (Inceptisol), coastal sandy alluvium (Entisol), Pokkali (Alfisol) and Kole (Inceptisol) based on certain characteristic locally recognisable features or based on local names derived from such features etc. The broad categorisation under Soil Taxonomy is indicated in brackets. An effort to classify the soils by either the method of principal component analysis (Kyuma, 1981) or classificatory analysis (Singh and Chowdhury, 1979) was attempted. The broad objective of this exercise was to recognise some characteristic of the soils that could be defined based on either P content or factors influencing P availability.

1.1. Principal component analysis

The method of principal component analysis is used for attaining a "parsimonious summarisation of a mass of observations", in other words, it is used to extract the hidden essence of a thing or material that is not directly measured.

Given $\underline{n}$ samples, each of which is defined by $\underline{p}$ characters, they can be expressed as $\underline{n}$ points scattered in a $\underline{p}$ - dimensional space. The principal component analysis aims at reducing the $\underline{p}$ axes to orthogonal $\underline{m}$ axes, where $\underline{m} < \underline{p}$, with a minimum loss in information. Mathematically this produces a set of new $\underline{m}$ variables from the original $\underline{p}$ variables by an orthogonal transformation.

When the two variables X_1 and X_2 are highly correlated, the axes can be rotated to the position of Y_1 and Y_2, so that the variance along the Y_1 axis becomes maximum and that along the Y_2 axis, minimum. If the latter is sufficiently small, we can neglect the Y_2 and regard the Y_1 alone as a compound character of X_1 and X_2. Thus the number of axes is reduced from 2 to 1 with a minimum loss of information.

Principal component analysis has been used for grouping the 151 soil samples (lateritic alluvium-55, Kari-15, Kayal-15, Karapadam-17, coastal sandy alluvium-12, Pokkali-17 and Kole-20) covering the rice growing areas of Kerala, choosing nine important parameters which govern P content or P availability viz., P fixing capacity, pH R_2O_3, CEC, silt, clay, total P, Bray 1-P and organic carbon content. The first two principal components contributed 58.01 per cent of the total variability. The Eigen values and Eigen vectors (Lamda-1 and Lamda-2) extracted from the intercorrelation matrix of the 9 parameters of the soil corresponding to the two principal components are given belc

Eigen values, Eigen vectors (Lamda-1 and Lamda-2) of the nine characteristics of the soils.

Sl. No.	Soil characters	Eigen values	Eigen vectors	
			Lamda-1	Lamda-2
1	P fixing capacity	3.0643	0.5201	0.0986
2	pH	2.1543	-0.1615	0.1051
3	R_2O_3	1.2955	0.4641	0.2464
4	CEC	1.1166	0.0494	-0.6024
5	Silt	0.4928	0.4422	-0.1666
6	Clay	0.3808	0.4473	0.1580
7	Total-P	9.2442	0.1088	-0.2402
8	Bray 1-P	0.1447	-0.2745	0.1769
9	Organic carbon	0.1044	0.0512	-0.6375

If P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8 and P_9 are the 9 parameters for any particular soil, the two principal components are calculated as

$$X_1 = 0.5201P_1 - 0.1615P_2 + 0.4641P_3 + 0.0494P_4 + 0.4422P_5 + 0.4473P_6 + 0.1088P_7 - 0.2745P_8 + 0.0512P_9$$

$$X_2 = 0.0986P_1 + 0.1051P_2 + 0.2464P_3 - 0.6024P_4 - 0.1866P_5 + 0.1580P_6 - 0.2402P_7 + 0.1769P_8 - 0.6375P_9$$

The values of the principal components so calculated for the 151 soil samples are presented in Table 1.

The X_1 and X_2 values obtained were positive and negative respectively and they were plotted in the graph to represent any particular soil sample. Such a representation of the 151 soil samples is given in Fig. 1. After examining the scatter diagram carefully, nearby points are grouped and six clusters were thus obtained and they are described below.

Cluster I

This cluster included 16 soils (10.60 per cent of the total of 151 soils) from lateritic alluvium (5), Kari (2), coastal sandy alluvium (5) and Pokkali (4) which had the total P less than 250 ppm as given below.

Table 1. Values of the Principal Components (X_1 and X_2) of the rice soil samples.

Sl. No.	X_1 (+)	X_2 (-)	Sl. No.	X_1 (+)	X_2 (-)
1.	106.13	137.27	26.	166.00	245.64
2.	96.61	78.08	27.	136.66	180.33
3.	96.85	83.68	28.	149.21	236.32
4.	84.26	58.94	29.	129.34	194.00
5.	85.82	59.14	30.	73.71	72.71
6.	84.79	88.21	31.	131.16	164.97
7.	94.21	110.79	32.	124.34	107.95
8.	101.20	90.33	33.	164.05	242.93
9.	71.03	29.59	34.	79.34	58.37
10.	74.31	36.10	35.	90.60	90.44
11.	96.18	84.35	36.	72.82	56.57
12.	91.38	68.06	37.	82.52	72.00
13.	96.69	107.55	38.	70.31	48.53
14.	96.77	137.84	39.	90.68	72.75
15.	90.77	54.24	40.	87.56	75.39
16.	112.82	118.15	41.	123.00	169.14
17.	122.59	124.07	42.	133.39	181.10
18.	97.88	142.33	43.	138.16	185.81
19.	111.77	150.63	44.	154.37	250.04
20.	94.31	108.07	45.	129.79	200.06
21.	100.53	116.12	46.	236.72	366.81
22.	128.50	168.27	47.	120.78	165.31
23.	125.38	178.53	48.	93.31	80.34
24.	120.73	190.73	49.	102.83	119.08
25.	122.77	96.72	50.	152.14	258.43

Contd......

Sl. No.	X_1 (+)	X_2 (-)	Sl. No.	X_1 (+)	X_2 (-)
51.	162.00	260.24	76.	146.91	190.62
52.	110.02	170.14	77.	160.25	264.00
53.	131.17	171.75	78.	153.63	230.18
54.	114.03	138.11	79.	158.51	229.64
55.	69.08	37.14	80.	159.54	263.51
56.	122.55	169.33	81.	161.34	254.28
57.	105.18	84.18	82.	126.33	169.39
58.	90.76	91.02	83.	160.77	217.03
59.	99.72	35.15	84.	148.67	197.01
60.	110.82	122.10	85.	134.40	201.58
61.	104.52	110.00	86.	152.00	223.18
62.	109.35	130.13	87.	125.48	115.09
63.	92.43	88.84	88.	183.73	259.29
64.	108.43	127.25	89.	163.04	210.50
65.	120.02	138.40	90.	163.46	228.33
66.	66.25	39.05	91.	141.91	177.25
67.	83.58	90.68	92.	119.11	137.02
68.	99.02	121.58	93.	100.00	80.42
69.	64.02	57.52	94.	86.03	94.05
70.	82.21	83.06	95.	124.84	133.61
71.	138.80	166.00	96.	118.53	145.57
72.	144.58	198.86	97.	141.27	170.45
73.	243.09	421.15	98.	107.25	172.58
74.	140.11	202.60	99.	122.53	164.23
75.	143.00	200.99	100.	115.45	149.31

Contd.......

Sl. No.	X_1 (+)	X_2 (−)	Sl. No.	A_1 (+)	A_2 (−)
101.	156.64	240.79	126.	52.84	53.86
102.	172.97	260.06	127.	47.22	54.12
103.	75.68	82.03	128.	45.17	61.68
104.	66.92	75.30	129.	71.31	103.55
105.	70.92	72.77	130.	104.31	109.04
106.	69.95	96.77	131.	117.44	160.91
107.	50.00	136.00	132.	104.36	78.04
108.	63.59	99.39	133.	176.20	220.58
109.	59.67	29.96	134.	152.41	176.20
110.	55.58	40.18	135.	159.63	194.79
111.	67.37	88.65	136.	152.43	200.63
112.	50.26	40.20	137.	148.03	208.95
113.	55.68	41.70	138.	103.17	108.18
114.	57.34	46.04	139.	128.79	130.25
115.	91.56	129.25	140.	182.77	263.90
116.	85.61	98.75	141.	124.19	161.09
117.	91.11	125.99	142.	174.99	231.82
118.	80.12	102.85	143.	108.03	90.02
119.	90.64	140.91	144.	165.97	260.10
120.	88.00	140.08	145.	88.69	85.25
121.	103.97	145.56	146.	143.08	202.12
122.	111.19	100.80	147.	123.05	149.01
123.	68.56	79.58	148.	134.28	184.49
124.	75.06	94.47	149.	131.35	134.53
125.	69.48	49.74	150.	103.81	87.68
			151.	104.32	83.80

Sl. No.	Soil Sample No.	Soil type	Total P (ppm)
1	9	Lateritic alluvium	162
2	10	"	184
3	36	"	186
4	38	"	221
5	55	"	186
6	66	Kari soil	169
7	69	"	245
8	109	Coastal sandy alluvium	149
9	110	"	185
10	112	"	129
11	113	"	244
12	114	"	108
13	125	Pokkali soil	226
14	126	"	229
15	127	"	227
16	128	"	241

Cluster II

Altogether 40 soils, 16 from lateritic alluvium, 6 from Kari, 2 from Karapadom, 6 from coastal sandy alluvium, 5 from Pokkali and 5 from Kole soils were included in this cluster, the total P of the soils ranged from 251 to 450 ppm. The maximum number of soils (26.49 per cent) belonged to this group as detailed below.

Sl. No.	Soil sample No.	Soil type	Total P (ppm)
1	2	Lateritic alluvium	362
2	3	"	381
3	4	"	283
4	5	"	280
5	6	"	445
6	8	"	422
7	11	"	383
8	12	"	322
9	15	"	263
10	30	"	323
11	34	"	266
12	35	"	445
13	37	"	309
14	39	"	306
15	40	"	309
16	48	"	289
17	57	Kari	365
18	58	"	361
19	59	"	364
20	63	"	423
21	67	"	381
22	70	"	342
23	93	Karapadam	423
24	94	"	409
25	103	Coastal sandy alluvium	366
26	104	"	325
27	105	"	309
28	106	"	421
29	108	"	388
30	111	"	386

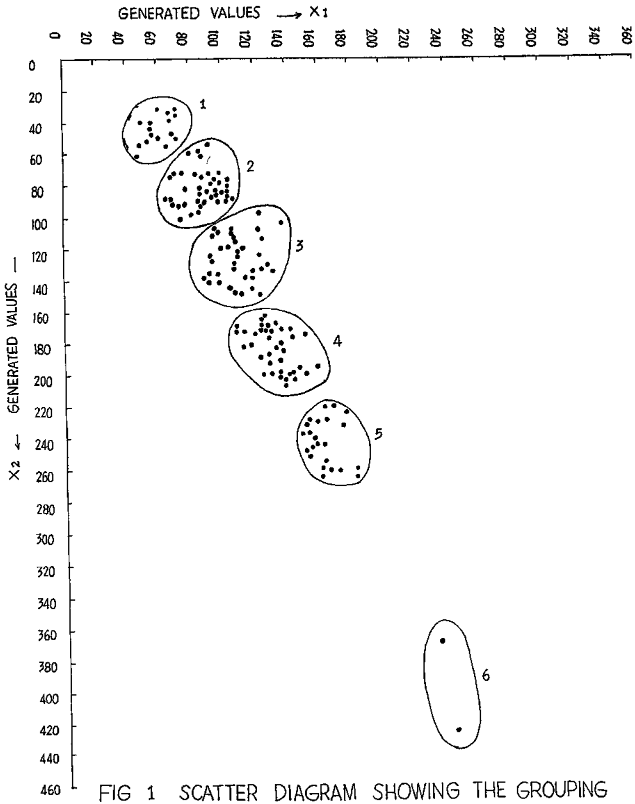


FIG 1 SCATTER DIAGRAM SHOWING THE GROUPING OF 151 RICE SOILS

Sl. No.	Soil sample No.	Soil type	Total P (ppm)
31	116	Pokkali	445
32	118	"	448
33	123	"	345
34	124	"	409
35	129	"	424
36	132	Kole	349
37	143	"	426
38	145	"	384
39	150	"	398
40	151	"	386

Cluster III

The third cluster formed with 35 soils (23.18 per cent of the total of 151 soils) from lateritic alluvium (14), Kari (6), Karapadam (5), coastal sandy alluvium (1), Pokkali (5) and Kole (4). As indicated below the total P content of the various soils belonging to this group varied from 451 to 650 ppm.

Sl. No.	Soil sample No.	Soil type	Total P (ppm)
1	1	Lateritic alluvium	585
2	7	"	461
3	13	"	461
4	14	"	584
5	16	"	522
6	17	"	564
7	18	"	602
8	19	"	643
9	20	"	482
10	21	"	523
11	25	"	464
12	32	"	507
13	49	"	482
14	54	"	604
15	60	Kari	523
16	61	"	528
17	62	"	529
18	64	"	545
19	65	"	643
20	68	"	481
21	87	Karapadam	505
22	92	"	502
23	95	"	564
24	96	"	606
25	100	"	605
26	107	Coastal sandy alluvium	460
27	115	Pokkali	581
28	117	"	543
29	119	"	601
30	120	"	625
31	121	"	631
32	138	Kole	489
33	139	"	588
34	147	"	506
35	149	"	604

Cluster IV

A total of 36 soils (23.84 per cent of the total soils) belonging to lateritic alluvium (13), Kari (1), Kayal (8), Karapadam (4), Pokkali (3) and Kole soils (7) come under this group which has its total P ranging from 651 to 900 ppm as given below.

Sl. No.	Soil sample No.	Soil type	Total P (ppm)
1	22	Lateritic alluvium	686
2	23	"	764
3	24	"	806
4	27	"	766
5	29	"	822
6	31	"	721
7	41	"	684
8	42	"	783
9	43	"	806
10	45	"	882
11	47	"	688
12	52	"	721
13	53	"	745
14	56	Kari	706
15	71	Kayal	900
16	72	"	841
17	74	"	884
18	75	"	845
19	76	"	820
20	82	"	703
21	84	"	842
22	85	"	822

Sl. No.	Soil sample No.	Soil type	Total P (ppm)
23	92	Karapadam	744
24	97	"	723
25	98	"	668
26	99	"	683
27	122	Pokkali	782
28	130	"	704
29	131	"	783
30	134	Kole	781
31	135	"	853
32	136	"	900
33	137	"	894
34	141	"	705
35	146	"	865
36	148	"	801

Cluster V

This cluster containing 22 soils from lateritic alluvium (6), Kayal (6), Karapadam (6), and Kole (4) account for 14.57 per cent of the total of 151 soils under study. The total P of the soils belonging to this group ranged from 901-1250 ppm as indicated below.

Sl. No.	Soil sample No.	Soil type	Total P (ppm)
1	26	Lateritic alluvium	1062
2	28	"	1007
3	33	"	1032
4	44	"	1121
5	50	"	1101
6	51	"	1201
7	77	Kayal	1141
8	78	"	1101
9	79	"	961
10	80	"	1011
11	81	"	1061
12	83	"	921
13	86	Karapadam	910
14	88	"	1101
15	89	"	921
16	90	"	960
17	101	"	987
18	102	"	1210
19	133	Kole	981
20	140	"	1201
21	142	"	1002
22	144	"	1101

<u>Cluster VI</u>

Though two soils, one each from lateritic alluvium and Kayal could not be observed as clustering together, the distance between them was too short to afford making each of them into a separate group. Further, since the total P of both has been found to be above 1250 ppm, they have been classified under the sixth cluster as noted below. This formed 1.32 per cent of the total of 151 soils under study.

Sl. No.	Soil sample No.	Soil type	Total P (ppm)
1	46	Lateritic alluvium	1544
2	73	Kayal	1763

1.2. Classificatory analysis

The technique of classificatory analysis for solving the problems related to breeding for varieties in various crops was adopted by Singh and Chowdhuri (1979). This method has been extended to the classification of soils for purposes of studies on their P status and related aspects considering nine important parameters viz., P fixing capacity, pH, R_2O_3, CEC, silt, clay, total P, Bray 1-P and organic carbon content which were used for principal component analysis and presumed to be governing phosphorus status of rice soils of Kerala. This method was attempted since it offered greater possibility of testing the significance, if they could be clustered.

The mean, range of variation, standard deviation, coefficient of variation and the index score for each parameter was worked out and presented in Table 2.

Table 2. Mean, range of variation, standard deviation, coefficient of variation and index score for the soils.

Sl. No.	Soil Parameter	Mean	Range of variation	Standard deviation	Coefficient of variation (%)	Index score 1	Index score 2	Index score 3
1.	P fixing capacity	46.71	29.50 – 66.00	8.16	17	< 45.39	45.40 to 48.04	> 48.04
2.	pH	4.33	2.60 – 5.70	0.80	19	< 4.20	4.21 to 4.46	> 4.46
3.	R_2O_3	16.54	5.80 – 32.00	5.55	35	< 15.64	15.65 to 17.45	> 17.45
4.	CEC	8.37	2.45 – 21.12	3.64	44	< 7.77	7.78 to 8.96	> 8.96
5.	Silt	16.18	2.00 – 44.00	8.17	51	< 14.85	14.86 to 17.51	> 17.51
6.	Clay	19.41	1.60 – 53.60	11.49	59	< 17.54	17.55 to 21.28	> 21.28
7.	Total P	603.73	108.00 – 1763.00	298.34	49	< 555.17	555.18 to 652.29	> 652.29
8.	Bray 1-P	5.25	0.40 – 26.81	5.01	95	< 4.44	4.45 to 6.07	> 6.07
9.	Organic carbon	1.69	0.15 – 3.24	0.85	49	< 1.55	1.56 to 1.83	> 1.83

The two parameters which are most variable as indicated by the coefficient of variation viz., Bray 1-P with 95 per cent and clay with 59 per cent variations were selected. Bray 1-P was taken in the X-axis and clay in the Y-axis. The means of Y values were plotted against the means of X values for each soil sample. A particular soil sample was thus represented by a glyph on the graph. The index score in turn are decided on the basis of range of variability.

It has been observed that the tendency for clustering of soils is very sparse by this method and hence no meaningful inference on the characteristics of the soils could be drawn by this procedure.

2. Phosphorus fractions of rice soils

Analysis of variance of total P and of different P fractions of seven rice soils are presented in Appendix III. The mean values of total P, various P fractions and the percentage of each fraction to total P of the soils studied are given in Table 3 to 14.

Significant variations in total P and P fractions for all soil groups were noted.

Table 3. Mean Values for total P (ppm) of rice soils

Sl. No.	Soil type	Sample size	Total P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	577.69	-	143.45	143.45	136.66	156.91	136.66	128.59
2.	Kari	15	433.67		-	179.82	174.46	190.73	174.46	168.21
3.	Kayal	15	962.53			-	174.46	190.73	174.46	168.21
4.	Karapadam	17	741.24				-	185.68	168.92	162.46
5.	Coastal sandy alluvium	12	280.83					-	185.68	179.82
6.	Pokkali	17	484.04						-	162.46
7.	Kole	20	710.70							-

2.1. Total P (ppm)

The coastal sandy alluvium recorded the lowest total P (280.8) and the Kayal soils, the highest (962.5). The total P recorded for each soil type was between the ranges from 162 to 1544, 169 to 706, 703 to 1763, 409 to 1210, 108 to 460, 226 to 783 and 349 to 1201 respectively for lateritic alluvium (Inceptisol), Kari (Entisol), Kayal (Inceptisol), Karapadam (Inceptisol), coastal sandy alluvium (Entisol), Pokkali (Alfisol) and Kole (Inceptisol) soils. Lateritic alluvium has a mean total P content significantly higher than that of both Kari and coastal sandy alluvium. But total P content of Kari soil itself is significantly more than that of coastal sandy alluvium.

2.2.1. Saloid P (ppm)

The mean saloid P was found to be lowest in coastal sandy alluvium (7.5) and highest in Karapadam soils (35.2). Much significant difference in saloid P content could not be noticed among Kari, coastal sandy alluvium, Pokkali and Kole soils. Karapadam and Kayal soils were not significantly different in their saloid P content. The range of values of this P fraction for the various soil types were from 9 to 69, 3 to 25, 13 to 54, 7 to 110, 0 to 16, 0 to 25 and 0 to 46 for lateritic alluvium, Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils respectively.

The average percentage contribution of saloid P to total P was 4.42, 3.07, 2.79, 4.75, 2.67, 1.92 and 2.44 respectively for lateritic alluvium, Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils. On an average, the saloid P contributed 3.22 percent to total P of the soils studied.

2.2.2. Al-P (ppm)

The lowest Al-P fraction of 30.4 was recorded for Kari soils, the highest being 116.2 for Kole soils. The mean Al-P levels in Kayal, Karapadam, lateritic alluvium and Pokkali were not significantly different from that of the highest value recorded for the Kole soils. The mean Al-P content of coastal sandy alluvium and Pokkali soils was very nearly on par with the lowest value recorded for Kari soils. Lateritic alluvium, Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils respectively recorded the Al-P content in the range from 24.6 to 368.9, 15.2 to 56.8, 25.1 to 184.5, 39.1 to 210.5, 18.4 to 112.8, 13 to 136 and 30.4 to 345; the mean percentage contribution of Al-P to total P for these soils were 17.21, 7.00, 10.63, 13.76, 18.71, 15.68 and 16.34 respectively. The mean percentage of Al-P to total P for all the soils collectively was found to be 13.81 per cent.

Table 4 to 13.

MEAN VALUES OF VARIOUS P FRACTIONS OF RICE SOILS

No. 4. Saloid P (ppm)

Sl. No.	Soil type	Sample size	Saloid-P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	25.56	-	7.95	7.95	7.57	8.69	7.57	7.02
2.	Kari	15	13.33	-	-	9.96	9.66	10.56	9.66	9.32
3.	Kayal	15	26.87	-	-	-	9.66	10.56	9.66	9.32
4.	Karapadam	17	35.10	-	-	-	-	10.29	9.36	9.00
5.	Coastal sandy alluvium	12	7.50	-	-	-	-	-	10.29	9.96
6.	Pokkali	17	9.29	-	-	-	-	-	-	9.00
7.	Kole	20	17.35	-	-	-	-	-	-	-

No. 5. Al-P (ppm)

Sl. No.	Soil type	Sample size	Al-P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	99.41	-	34.49	34.49	32.86	37.72	32.86	30.92
2.	Kari	15	30.36	-	-	43.23	41.94	45.86	41.94	40.44
3.	Kayal	15	102.34	-	-	-	41.94	45.86	41.94	40.44
4.	Karapadam	17	101.96	-	-	-	-	44.64	41.02	33.06
5.	Coastal sandy alluvium	12	52.53	-	-	-	-	-	44.64	43.23
6.	Pokkali	17	76.02	-	-	-	-	-	-	39.06
7.	Kole	20	116.21	-	-	-	-	-	-	-

2.2.3. Fe-P (ppm)

While the coastal sandy alluvium recorded the lowest Fe-P content of 28.1, the Kayal soils were found to have the highest concentration of 151.3 followed by Kole soils with 127.6. The Kayal and Kole soils were having quantities of Fe-P statistically not different. Significant difference could not be observed in Fe-P levels among lateritic alluvium, Kari, Karapadam and Pokkali soils. The Fe-P ranged from 14 to 212, 41 to 76, 99 to 310, 52 to 146, 14 to 48, 51 to 165 and 27 to 217 for lateritic alluvium, Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils respectively. In these soils, the mean percentage contribution of Fe-P to total P were respectively 13.23, 18.02, 15.72, 12.05, 10.00, 20.31 and 17.95. The mean percentage of Fe-P to total P for all the soils collectively was observed to be 15.49 per cent.

2.2.4. Ca-P (ppm)

The Ca-P was found to be lowest for coastal sandy alluvium (19.1) and highest for Kayal soils (71.5). The mean Ca-P content of Kayal soils was significantly greater than the mean Ca-P of all other soil types. The differences between the mean values of Ca-P of Kari, Karapadam and Kole soils were not significant. Pokkali and lateritic alluvium were fairly on par with respect to this fraction. The

No. 6. Fe-P (ppm)

Sl. No.	Soil type	Sample size	Fe-P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	76.45	-	23.55	23.55	22.49	25.75	22.43	21.11
2.	Kari	15	78.13	-	-	29.52	28.63	31.31	28.63	27.61
3.	Kayal	15	151.27	-	-	-	28.63	31.31	28.63	27.61
4.	Karapadam	17	89.35	-	-	-	-	30.48	27.73	26.67
5.	Coastal sandy alluvium	12	28.08	-	-	-	-	-	30.48	29.52
6.	Pokkali	17	96.47	-	-	-	-	-	-	26.67
7.	Kole	20	127.60	-	-	-	-	-	-	-

No. 7. Ca-P (ppm)

Sl. No.	Soil type	Sample size	Ca-P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	36.00	-	13.78	13.78	13.12	15.07	13.12	12.35
2.	Kari	15	37.90	-	-	17.27	16.75	18.32	16.75	16.15
3.	Kayal	15	71.51	-	-	-	16.75	18.32	16.75	16.15
4.	Karapadam	17	49.17	-	-	-	-	17.83	16.22	15.60
5.	Coastal sandy alluvium	12	19.07	-	-	-	-	-	17.83	17.27
6.	Pokkali	17	28.41	-	-	-	-	-	-	15.60
7.	Kole	20	42.71	-	-	-	-	-	-	-

Ca-P content varied from 3 to 102, 9.4 to 64.2, 28.1 to 167.5, 20.5 to 125.9, 3.5 to 39.1, 6.3 to 62.3 and 11.2 to 76.3 for lateritic alluvium , Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils respectively; and the mean percentage contribution of Ca-P to total P for these soils were respectively 6.23, 8.74, 7.43, 6.63, 6.79, 5.86 and 6.01. The Ca-P contribution to total P expressed as a percentage for all the soils collectively was 6.79.

2.2.5. Reductant-P (ppm)

The coastal sandy alluvium and Kayal soils recorded the lowest (26.8) and highest (85.4) mean reductant P respectively. The reductant P in Kayal soils was significantly different from that of all other soil groups. Kari, Karapadam and Kole soils showed not much difference in this fraction while lateritic alluvium, coastal sandy alluvium and Pokkali were on par. The ranges of values of this fraction for various soil types were 2.1 to 100.6, 10.5 to 74.8, 31.8 to 196.1, 24.9 to 136.0, 3.4 to 66.8, 7.6 to 70.3 and 13.4 to 98.2 respectively for lateritic alluvium, Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils; and the mean percentage contribution of this fraction to total P in these soils were respectively 6.13, 10.50, 8.87, 8.04, 9.55, 7.75 and 7.83 with the mean for all the soils being 8.25.

2.2.6. Occluded-P (ppm)

The lowest concentration of occluded-P of 8.5 was recorded for coastal sandy alluvium, the highest being 27.6 for Kayal soils. Significant difference in this fraction could not be observed between lateritic alluvium, Kari, Karapadam and Kole soils. The Pokkali and coastal sandy alluvium were on par. But the difference between Kayal soils and all other soil groups was significant. The occluded-P ranged from 1.5 to 51.2, 3.7 to 30.6, 9.2 to 54.6, 9.2 to 52.9, 0.8 to 26.4, 2.2 to 28.1 and 4.3 to 36.1 for lateritic alluvium, Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils respectively. It has been observed that the mean percentage contributions of occluded-P to total P for these soils were respectively 3.10, 3.57, 2.87, 2.46, 3.04, 2.40 and 2.67, the average percentage contribution of this fraction to total P for all the soil groups being 2.82.

2.2.7. Sum of inorganic P (ppm)

The sum of inorganic P was found to be lowest for coastal sandy alluvium (142.5) and highest for Kayal soils (464.9). Kayal soil among all the soil types recorded significantly higher sum of inorganic P levels compared to all other soil types. Significant difference in this

No. 8. Reductant P (ppm)

Sl. No.	Soil type	Sample size	Reductant-P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	35.42	-	14.84	14.84	14.13	16.23	14.13	13.30
2.	Kari	15	45.52	-	-	18.60	18.04	19.73	18.04	17.40
3.	Kayal	15	85.39	-	-	-	18.04	19.73	18.04	17.40
4.	Karapadom	17	59.59	-	-	-	-	19.20	17.47	16.80
5.	Coastal sandy alluvium	12	26.82	-	-	-	-	-	19.20	18.60
6.	Pokkali	17	37.56	-	-	-	-	-	-	16.80
7.	Kole	20	55.66	-	-	-	-	-	-	-

No. 9. Occluded-P (ppm)

Sl. No.	Soil type	Sample size	Occluded-P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	17.89	-	6.34	6.34	6.04	6.93	6.04	5.68
2.	Kari	15	15.47	-	-	7.94	7.71	8.43	7.71	7.43
3.	Kayal	15	27.62	-	-	-	7.71	8.43	7.71	7.43
4.	Karapadam	17	18.22	-	-	-	-	8.20	7.46	7.18
5.	Coastal sandy alluvium	12	8.54	-	-	-	-	-	8.20	7.94
6.	Pokkali	17	11.62	-	-	-	-	-	-	7.18
7.	Kole	20	18.98	-	-	-	-	-	-	-

fraction between lateritic alluvium, Kari and Pokkali soils was not observed; the Kole and Karapadam soils were on par when the difference between Pokkali and coastal sandy alluvium was significant. The sum of inorganic P ranged from 75.6 to 739.2, 106.5 to 364.0, 350.0 to 862.4, 203.8 to 592.9, 55.6 to 214.2, 116.8 to 436.8, 180.2 to 714.0 for lateritic alluvium, Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils respectively; the mean percentage contribution of this fraction to total P for these soils were 50.33, 50.84, 48.30, 47.68, 50.75, 53.90 and 52.04 respectively. When all the soil groups were taken together, the percentage contribution of sum of inorganic P to total P was 50.37.

2.2.8. Organic P (ppm)

The lowest content of organic P was recorded for coastal sandy alluvium (124.6) and the highest for Kayal soils (433.9). Compared to other soil types, the Kayal soils recorded higher range of values for organic P. Significant differences could not be noted between Karapadam and Kole; lateritic alluvium and Kole; Pokkali, Kari soils, and coastal sandy alluvium. Lateritic alluvium recorded significantly different levels of organic P compared to Pokkali, Kari and coastal sandy alluvium. The organic P ranged from 81.6 to 689.8, 54.5 to 292.6, 322.0 to 697.6, No. 10. Sum of inorganic P (ppm)

Sl. No.	Soil type	Sample size	Sum of inorganic P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	290.73	-	76.74	76.74	73.11	83.94	73.11	69.79
2.	Kari	15	220.48	-	-	96.20	93.33	102.04	93.33	89.98
3.	Kayal	15	464.95	-	-	-	93.33	102.04	93.33	89.98
4.	Korapodam	17	353.42	-	-	-	-	99.34	90.37	86.91
5.	Coastal sandy alluvium	12	142.53	-	-	-	-	-	99.34	96.20
6.	Pokkali	17	261.36	-	-	-	-	-	-	86.91
7.	Kole	20	369.83	-	-	-	-	-	-	-

No. 11. Organic P (ppm)

Sl. No.	Soil type	Sample size	Organic P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	257.80	-	58.82	58.82	56.04	64.34	56.04	52.73
2.	Kari	15	191.99	-	-	73.74	71.53	78.21	71.53	68.97
3.	Kayal	15	433.91	-	-	-	71.53	78.21	71.53	68.97
4.	Karapadam	17	347.27	-	-	-	-	76.14	69.26	66.62
5.	Coastal sandy alluvium	12	124.63	-	-	-	-	-	76.14	73.74
6.	Pokkali	17	199.69	-	-	-	-	-	-	66.62
7.	Kole	20	302.28	-	-	-	-	-	-	-

198.2 to 552.0, 50.4 to 233.2, 91.2 to 306.2 and 151.8 to 456.0 respectively for lateritic alluvium, Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils and the mean percentage contribution of organic P to total P was also respectively in the order 44.63, 44.27, 45.08, 46.85, 44.38, 41.18 and 42.53. For all the soils taken together the mean value for organic P to total P was 44.32.

2.2.9. Non-extractable P (ppm)

The non-extractable P was lowest for coastal sandy alluvium (13.7) and highest for Kayal soils (56.6). Significant differences between Kayal soils and all other soil types were observed. Karapadam and Kole soils, lateritic alluvium, Pokkali and Kari soils were on par. Kole soils were significantly different from lateritic alluvium, Kari, coastal sandy alluvium and Pokkali soils. The ranges of values of this fraction were 2 to 115, 7 to 34, 31 to 137, 18 to 93, 2 to 30, 15 to 40 and 14 to 88 for lateritic alluvium, Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils respectively and the mean percentage contribution of non-extractable P to total P for these soils respectively were 5.05, 4.89, 5.88, 5.48, 4.87, 4.92 and 5.43. About 5.34 per cent mean contribution was observed for this fraction to total P when all the soil types were considered together.

2.2.10. Total inorganic P (ppm)

The coastal sandy alluvium and Kayal soils recorded the lowest (156.3) and highest (524.2) content of total inorganic-P respectively. Significant differences between Kayal soils and all other soil groups were noted. Not much difference between Kole and Karapadam soils was observed. The differences between Kole and lateritic alluvium, Pokkali, Kari and coastal sandy alluvium were significant. There was not much difference between lateritic alluvium with Karapadam, Kari and Pokkali; similarly Kari with Pokkali and coastal sandy alluvium. The total inorganic P ranged from 80.4 to 854.2, 114.5 to 393.0, 381 to 994.4, 210.0 to 685.9, 57.6 to 239.2, 134.8 to 476.8 and 197.2 to 802.0 respectively for lateritic alluvium, Kari, Kayal, Karapadam coastal sandy alluvium, Pokkali and Kole soils. The mean percentage contribution of the total inorganic P to the total P in those soils were respectively 55.50, 55.73, 54.46, 53.19, 55.65, 58.82 and 57.47. The mean percentage contribution of this fraction to total P for all soils was 55.61.

2.3. Phosphorus fractions and soil properties

The correlation coefficients between each P fraction and important soil properties of all soil groups viz., No. 12. Non extractable P (ppm)

Sl. No.	Soil type	Sample size	Non-extractable-P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	29.15	-	10.08	10.08	9.61	11.03	9.61	9.04
2.	Kari	15	21.20	-	-	12.65	12.27	13.41	12.27	11.83
3.	Kayal	15	56.60	-	-	-	12.27	13.41	12.27	11.83
4.	Karapadam	17	40.59	-	-	-	-	13.06	11.88	11.42
5.	Coastal sandy alluvium	12	13.67	-	-	-	-	-	13.06	12.65
6.	Pokkali	17	23.88	-	-	-	-	-	-	11.42
7.	Kole	20	38.60	-	-	-	-	-	-	-

No. 13. Total inorganic P (ppm)

Sl. No.	Soil type	Sample size	Total inorganic-P	Critical Difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	320.63	-	85.61	85.61	81.75	93.06	81.75	76.92
2.	Kari	15	241.68	-	-	107.57	104.36	114.10	104.36	100.62
3.	Kayal	15	524.22	-	-	-	104.36	114.10	104.36	100.62
4.	Karapadam	17	394.28	-	-	-	-	111.07	101.04	97.18
5.	Coastal sandy alluvium	12	156.27	-	-	-	-	-	111.07	107.57
6.	Pokkali	17	285.25	-	-	-	-	-	-	97.18
7.	Kole	20	408.43	-	-	-	-	-	-	-

Table 14. Mean percentage P fraction to total P of rice soils.

Fraction	All soils		Lateritic alluvium		Kari		Kayal		Karapadam		Coastal sandy alluvium		Pokkali		Kole	
	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%
Total P	599.0	-	577.7	-	433.7	-	962.5	-	741.2	-	280.8	-	484.9	-	710.7	-
Saloid-P	19.3	3.2	25.6	4.4	13.3	3.1	26.9	2.8	35.2	4.8	7.5	2.7	9.3	1.9	17.4	2.4
Al-P	82.7	13.8	99.4	17.2	30.4	7.0	102.3	10.6	101.9	13.8	52.5	18.7	76.0	15.7	116.2	16.4
Fe-P	92.9	15.5	76.5	13.2	78.1	18.0	151.3	15.7	89.4	12.1	28.1	10.0	98.5	20.3	127.6	18.0
Ca-P	40.7	6.8	36.0	6.2	38.0	8.7	71.5	7.4	49.2	6.6	19.1	6.8	28.4	5.9	42.7	6.0
Red.P	49.4	8.3	35.4	6.1	45.5	10.5	85.4	8.9	59.6	8.0	26.8	9.6	37.6	7.3	55.7	7.8
Occluded-P	16.9	2.8	17.9	3.1	15.5	3.6	27.6	2.9	18.2	2.5	8.5	3.0	11.6	2.4	19.0	2.7
Sum of inorganic-P	301.8	50.4	290.7	50.3	220.5	50.8	465.0	48.3	353.4	47.7	142.5	50.8	261.4	54.0	369.8	52.0
Organic-P	265.4	44.3	257.8	44.6	192.0	44.3	433.9	45.1	347.3	46.9	124.6	44.4	199.7	41.2	302.3	42.5
Non-extractable P	32.0	5.3	29.1	5.1	21.2	4.9	56.6	5.9	40.6	5.5	13.7	4.9	23.9	4.9	38.6	5.4
Total inorganic P	333.7	55.6	320.6	55.5	241.7	55.7	524.2	54.5	394.3	53.2	156.3	55.7	285.3	58.8	408.4	57.5

pH, organic carbon, total P, R_2O_3, Fe_2O_3, Al_2O_3, CaO, MgO, CEC, exchangeable calcium, exchangeable magnesium, sand, silt, clay, P fixing capacity, other P fractions, C/P ratio, C/N ratio, Fe_2O_3/Al_2O_3, active P and total of P fractions were worked out and are given in Tables 15 to 24.

2.3.1. Saloid P

In lateritic alluvial soils, significant positive correlations were observed between saloid-P with total P, Ca-P, reductant P, occluded P, sum of inorganic-P, organic P, total inorganic P and total of P fractions and negative correlation with C/P ratio. When the saloid P content was positively correlated with CaO in Kayal soils, significant positive correlation was obtained between saloid P and reductant P in Karapadam soils. Significant positive correlations were observed between saloid P with total P, Al-P, Fe-P, Ca-P, reductant-P, occluded P, sum of inorganic P, organic P, non-extractable P, total inorganic P, active P and total of P fractions but negative correlation with C/P ratio in Pokkali soils. For Kole soils, significant negative correlations were obtained between saloid P with reductant P and occluded P.

Table 15 Correlation Coefficients between Saloid P and Soil Properties

Sl. No.	Soil Type	Sample Size	pH	Organic Carbon	Total P	R_2O_3	Fe_2O_3	Al_2O_3	C_aO	M_gO	C E C	Exch C_a	Exch Mg	Sand	Silt	Clay	P F C	Al - P	Fe -P	C_a - P	Red - P	Occluded P	Sum of Inorganic P	Organic P	Non Extractable P	Total Inorganic P	C/P ratio	C/N ratio	Fe_2O_3/Al_2O_3	Active P	Total of P fractions
1.	Lateritic Alluvium	55	-.09	-.02	.33*	.08	.04	.13	-.21	-.10	-.05	.01	-.05	-.06	-.04	.10	.00	.14	.22	.35*	.36*	.34*	.33*	.35*	.23	.32*	-.35*	.22	-.10	.22	.30*
2.	Kari	15	.20	.36	.44	.27	.30	.20	.18	.34	.17	.14	.20	.37	-.04	-.29	-.27	.18	.26	.29	.23	.40	.47	.41	.30	.46	-.17	.29	-.28	.41	.44
3.	Kayal	15	.20	.23	-.07	-.05	.13	-.32	.65**	.25	-.03	-.03	-.04	.15	-.13	-.13	-.08	.34	.04	-.44	-.48	.47	.08	.04	.20	-.11	.05	-.17	.41	-.01	-.10
4.	Karapadam	17	.14	-.13	-.03	.16	.09	.23	.11	.05	.28	-.30	.27	.32	.42	.15	.18	.26	-.22	-.46	-.51*	-.42	.03	-.09	-.08	.02	-.05	-.09	-.23	.04	-.06
5.	Coastal sand alluvium	12	.19	.15	.14	.28	.13	.30	.30	.31	-.05	-.05	-.06	-.17	.08	-.08	-.38	.34	.15	-.08	- 14	-.14	.17	.14	-.01	.15	-.08	-.09	.04	.25	.13
6.	Pokkali	17	-.26	-.32	.73**	.32	.32	.32	-.27	-.25	-.30	-.28	-.31	-.28	.19	.18	.25	.61*	.60*	.52*	.58*	.53*	.72**	.74**	.66**	.72**	-.50*	.13	.09	.65**	.71**
7.	Kole	20	-.11	-.41	-.17	.07	.12	.12	.04	.14	-.35	-.35	-.35	-.22	.12	.28	.10	.18	-.17	- 44	-.58**	-.46*	-.11	-.25	-.07	-.11	-.03	.28	-.09	.04	-.17

* Significant at 5 percent level

** Significant at 1 percent level

2.3.2. Al-P

Significant positive correlations were noted between Al-P with organic carbon, total P, R_2O_3, Al_2O_3, CEC, exchangeable calcium, exchangeable magnesium, sand, Fe-P, Ca-P, reductant P, occluded P, sum of inorganic P, organic P, non-extractable P, total inorganic P, active P and total of P fractions and negative correlations with clay and PFC for lateritic alluvial soils. Al-P was negatively correlated with R_2O_3 and exchangeable magnesium for Kari soils. In Kayal soils, Al-P was positively correlated with CaO and active P. Significant positive correlations between Al-P with total P, Fe-P, sum of inorganic P, organic P, non-extractable P, total inorganic P, active P and total of P fractions and significant negative correlations between Al-P with C/P and C/N ratio were obtained for Karapadam soils. Al-P was positively correlated with total P, sum of inorganic P, non-extractable P, total inorganic P, C/N ratio, active P and total of P fractions in coastal sandy alluvium. In Pokkali soils, significant positive correlations between Al-P with total P, R_2O_3, Fe_2O_3, Al_2O_3, PFC, all the P fractions, active P and total of P fractions and significant negative correlations between Al-P with pH, organic carbon, CaO, MgO, CEC, exchangeable calcium, exchangeable magnesium

Table 16 Correlation Coefficients between Al-P and Soil Properties

Sl.No	Soil Type	Sample Size	pH	Organic Carbon	Total P	R_2O_3	Fe_2O_3	Al_2O_3	C_aO	M_gO	C E C	Exch Ca	Exch Mg	Sand	Silt	Clay	P fixing capacity	Saloid P	Fe - P	Ca -P	Red - P	Occluded P	Sum of inorganic P	Organic P	Non Extractable P	Total inorganic P	C/P ratio	C/N ratio	Fe_2O_3/Al_2O_3	Active P	Total of P fractions
1.	Lateritic alluvium	55	.23	.35*	.89**	.34*	.25	.34*	.12	.06	.39**	.42**	.39**	.37**	-.24	-.37**	-.34**	.14	.92**	.57**	.59**	.57**	.92**	.83**	.84**	.92**	-.20	-.04	.05	.97**	.90**
2.	Kari	15	.47	.35	-.03	-.52*	-.51	-.46	.42	-.10	.51	.50	.52	.42	-.16	-.20	-.50	.18	.01	-.26	.21	-.31	.04	.11	.15	.05	.10	.11	-.50	.36	-.02
3.	Kayal	15	.33	.34	.31	-.22	-.17	-.26	.54*	.37	.34	.35	.34	.19	-.47	-.44	-.25	.34	.25	.31	.24	-.32	.30	.40	.25	.26	-.21	-.03	.05	.67**	.33
4.	Karapadam	17	.18	.15	.86**	.03	.05	008	.14	-.07	.03	.002	.04	-.07	.08	.04	-.04	.26	.74**	.27	.20	.31	.68**	.80**	.80**	.87**	-.63**	-.72**	-.13	.94**	.85**
5.	Coastal Sandy alluvium	12	.01	-.34	.59*	-.30	-.004	-.47	.17	.44	-.22	-.22	-.22	-.21	-.11	.45	-.10	.34	.57	.19	.09	.02	.65*	.49	.62*	.66*	-.52	.61*	-.23	.91**	.59*
6.	Pokkali	17	-.57*	-.48	.88**	.51*	.51*	.51*	-.53*	-.55*	-.50*	-.50*	-.49*	-.55*	.44	.23	.51*	.61*	.72**	.55*	.55*	.56*	.87**	.87**	.64**	.88**	.76**	.23	.16	.96**	.87**
7.	Kole	20	.53*	.11	.56*	-.51*	.57**	.45*	.52*	.55*	.25	.26	.26	.45*	.22	-.38	-.54*	.18	.38	.15	.20	.14	.61**	.42	.66**	.62**	.27	.06	-.48*	.96**	.66**

* Significant at 5 percent level

** Significant at 1 percent level

and sand were observed. The correlation coefficients between Al-P and pH, total P, Fe_2O_3, Al_2O_3, CaO, MgO, sand, sum of inorganic P, non-extractable P, total inorganic P, active P and total of P fractions were positive and significant when negative correlations between Al-P with R_2O_3, clay and Fe_2O_3/Al_2O_3 were recorded for Kole soils.

2.3.3. Fe-P

In lateritic alluvium, significant positive correlations between Fe-P and organic carbon, CEC, exchangeable calcium, exchangeable magnesium, sand, all the P fractions other than saloid P, active P and total of P fractions and negative correlations with R_2O_3, Fe_2O_3, clay and P fixing capacity were observed. Significant positive correlations were obtained between Fe-P and total P, sum of inorganic P, organic P, non-extractable P, total inorganic P and total of P fractions for Kari soils. Kayal soils recorded significant positive correlations between Fe-P and total P, Ca-P, reductant P, sum of inorganic P, organic P, non-extractable P, total inorganic P, active P and total of P fractions and negative correlation with C/P ratio. Significant positive correlations between Fe-P and total P, Al-P, sum of inorganic P, organic P, non-extractable P, total inorganic P, active P and total of P fractions and

Table 17 Correlation Coefficients between Fe-P and Soil properties

Soil Type	Sample Size	P H	Organic Carbon	Total P	R_2O_3	Fe_2O_3	Al_2O_3	C_aO	M_gO	C E C	Exch.Ca	Exch.Mg	Sand	Silt	Clay	P fixing capacity	Saloid P	Al - P	Ca - P	Red - P	Occluded P	Sum of in-organic P	Organic P	Non extra-ctable P	Total in-organic P	C/P ratio	C/N ratio	Fe_2O_3/Al_2O_3	Active P	Total of P fraction
Lateritic alluvium	55	.25	.35*	.91**	-.37*	-.31*	-.24	.16	.07	.38**	.42**	.38**	.37**	-.28	-.35*	-.36*	.22	.92**	.65**	.67**	.64**	.94**	.85**	.85**	.94**	-.26	-.13	-07	.94**	.91**
Kari	15	.[illegible]2	.27	.67**	-.28	-.25	-.[illegible]0	.28	.49	.15	.10	.17	.38	-.06	-.28	-.37	.26	.01	.24	.10	.29	.74**	.57*	.66**	.74**	-.29	.03	-.20	42	.58*
Kayal	15	.26	.16	.91**	-.29	-.31	-.18	.23	.13	.11	.12	.11	.21	.04	.12	-.31	.04	.25	.52*	.59*	.38	.90**	.91**	.81**	.89**	-.65**	-.18	-.24	.69**	.87**
Karapadam	17	-.19	.01	.85**	.21	.22	-.19	-.22	-.17	-.06	-.03	-.05	-.19	.20	.15	.13	-.22	.74**	.41	.41	.45	.81**	.85**	.81**	.82**	-.73**	-.48	.11	.79**	.82**
Coastal Sandy alluvium	12	-.26	-.39	.58	13	.31	-.13	-.08	.30	-.39	-.39	-.38	-.21	.01	.35	.34	.15	.57	.36	.32	.20	.67*	.48	.44	.65*	.56	.34	.37	.65*	.58
Pokkali	17	-.[illegible]0	- 07	84**	.19	.20	.17	- 23	- 31	-.10	-.10	-.11	-.20	-.01	.44	.17	.60*	.72**	.53*	.59*	.53*	.85**	.82**	.78**	.86**	-.49	-.15	.22	.76**	.81**
Ko le	20	.[illegible]0	.19	.87**	.19	-.27	-.11	.25	.23	.17	.17	.16	.10	.01	-.07	-.24	.17	.38	.54*	.54*	.54*	.89**	.77**	.88**	.89**	- 51*	.07	-.39	.54*	.81**

* Significant at 5 percent level

** Significant at 1 percent level

negative correlation with C/P ratio were noted for Karapadam soils. Significant positive correlations between Fe-P and sum of inorganic P, total inorganic P and active P were observed for coastal sandy alluvium. For Pokkali soils, significant positive correlations between Fe-P and total P, all P fractions, active P and total of P fractions were recorded. Significant positive correlations between Fe-P and total P, Ca-P, reductant P, occluded P, sum of inorganic P, organic P, non-extractable P, total inorganic P, active P and total of P fractions and negative correlations with C/P ratio were obtained in the case of Kole soils.

2.3.4. Ca-P

Significant positive correlations between Ca-P and total P, reductant P, occluded P, sum of inorganic P, organic P, non-extractable P, total inorganic P and total of P fractions were noted for all soils. Significant positive correlations between Ca-P and organic carbon, CEC, exchangeable calcium, exchangeable magnesium, sand, saloid P, Al-P, Fe-P and active P and negative correlations between Ca-P and clay and C/P ratio were observed for lateritic alluvial soils. For Kari soils the correlations between Ca-P and Fe_2O_3, Fe_2O_3/Al_2O_3 and active P were positive and significant and significant negative correlations between Ca-P and CEC, exchangeable calcium, exchangeable magnesium

Table 18 Correlation Coefficients between Ca-P and Soil Properties

Sl.No.	Soil Type	Sample Size	P H	Organic Carbon	Total P	R_2O_3	Fe_2O_3	Al_2O_3	CaO	MgO	C E C	Exch.Ca	Exch.Mg	Sand	Silt	Clay	P fixing Capacity	Saloid P	Al -P	Fe - P	Red - P	Occluded P	Sum of inorganic P	Organic P	Non-extractable - P	Total inorganic P	C/P ratio	C/N ratio	Fe_2O_3/Al_2O_3	Active P	Total of P fraction
1.	Lateritic alluvium	55	.23	.32*	.86**	-.26	-.21	-.20	.12	.13	.33*	.33*	.33*	.32*	-.25	-.29*	-.26	.35*	.57**	.85**	.98**	.99**	.84**	.86**	.81**	.84**	-.45**	-.10	-.02	.74**	.86**
2.	Kari	15	-.39	-.03	.84**	.51	.56*	.35	-.40	-.04	-.53*	-.58*	-.56*	-.16	-.05	.19	.37	.29	-.26	.24	.97**	.91**	.79**	.88**	.64*	.78**	-.71**	.23	.59*	.79**	.89**
3.	Kayal	15	.02	.12	.70**	.05	.24	.27	-.04	.29	-.05	-.05	-.05	-.08	.04	.02	-.01	-.44	-.31	.52*	.96**	.96**	.74**	.55*	.76**	.76**	-.41	-.16	-.62*	.49	.73**
4.	Karapadam	17	-.01	.39	.66**	.01	-.04	.06	-.14	-.15	.28	.30	.29	.22	-.30	-.09	-.06	-.46	.27	.41	.98**	.96**	.66**	.62**	.68**	.66**	-.37	-.16	-.29	.58*	.70**
5.	Coastal sandy alluvium	12	-.06	-.36	.89**	-.11	.39	-.59*	-.03	.13	-.35	-.36	-.36	.13	.04	-.15	.16	-.08	.19	.36	.98**	.95**	.85**	.90**	.78**	.35**	-.76**	.19	.62*	.58	.89**
6.	Pokkali	17	-.54*	-.48	.83**	.43	.40	.48	-.51*	-.51*	-.44	-.43	-.45	-.50*	.34	.36	.43	.52*	.55*	.53*	.98**	.99**	.83**	.83**	.61*	.63**	-.64**	.25	-.27	.76**	.85**
7.	Kole	20	.25	.01	.77**	-.01	-.07	.04	.14	.08	.15	.17	.15	.05	.32	-.31	-.02	-.44	.15	.54*	.93**	.98**	.70**	.85**	.63**	.69**	-.71**	-.10	-.21	.41	.76**

* Significant at 5 percent level

** Significant at 1 percent level

and C/P ratio were observed. In the case of Kayal soils significant positive correlations were noted between Ca-P and Fe-P and negative correlation between Ca-P and Fe_2O_3/Al_2O_3. The correlation between Ca-P and active P was significant and positive for Karapadam soils. For coastal sandy alluvium, the Ca-P was significant and negatively correlated with Al_2O_3, C/P ratio and Fe_2O_3/Al_2O_3. Significant positive correlations between Ca-P and saloid P, Al-P, Fe-P, and active P and negative correlations with pH, CaO, MgO, sand and C/P ratio were observed for Pokkali soils. With regard to Kole soils, the correlations between Ca-P and Fe-P, was positive and significant and between Ca-P and C/P ratio the r value was negative and significant.

2.3.5. Reductant-P

Significant positive correlations between reductant P and total P, Ca-P, occluded P, sum of inorganic P, organic P, non-extractable P, total inorganic P and total of P fractions were observed for all soil types. Reductant P was positively correlated with organic carbon, CEC, exchangeable calcium, exchangeable magnesium, sand, saloid P, Al-P, Fe-P and active P and negatively correlated with R_2O_3, clay, C/P and Fe_2O_3/Al_2O_3 ratio for lateritic alluvial soils, the r values were also significant. For Kari soils, significant positive correlations between reductant P and R_2O_3, Fe_2O_3, Fe_2O_3/Al_2O_3 and active P and significant

TABLE 19 Correlation coefficients between Reductant P and Soil Properties

Soil Type	Sample Size	P H	Organic Carbon	Total P	R_2O_3	Fe_2O_3	Al_2O_3	C_aO	M_gO	C E C	Exch. Ca	Exch. Mg	Sand	Silt	Clay
Lateritic alluvium	55	.24	.36*	.87**	-.30*	-.26	-.17	.14	.15	.57**	.37**	.37**	.36*	-.27	-.[illegible]*
Kari	15	-.48	-.12	.77**	.55*	.61*	.40	-.44	-.17	-.58*	-.62*	-.63*	-.26	.03	.19
Kayal	15	.08	.09	.77**	.06	.22	.21	-.02	-.22	-.03	-.03	-.03	-.01	.03	-.04
Karapadam	17	-.04	.40	.62**	.03	-.02	.08	-.17	-.14	.30	.32	.31	.23	-.30	-.11
Coastal sandy alluvium	12	-.11	-.39	.82**	-.05	.41	-.53	-.10	.05	-.36	-.37	-.37	.05	.07	-.12
Pokkali	17	-.54*	-.46	.85**	.42	.40	.47	.50*	.50*	.43	-.42	-.44	.51*	.33	.40
Kole	20	.32	.18	.76**	-.17	-.21	-.14	.18	.14	29	.30	.28	.19	.11	-.36

Soil Type	P fixing capacity	Saloid P	Al-P	Fe-P	Ca - P	Occluded P	Sum of inorganic P	Organic P	Non-extractable - P	Total inorganic-P	C/P ratio	C/N ratio	Fe_2O_3/ Al_2O_3	Active P	Total of P fraction
Lateritic alluvium	-.28	.36*	.59**	.67**	.98**	.98**	.85**	.98**	82**	.85**	-.44**	-.13	-.68**	.76**	.87**
Kari	.47	.23	-.21	.10	.97**	.86**	.70**	.82**	64*	.70**	-.75**	.24	.63*	.76**	.84**
Kayal	-.04	-.[illegible]	-.24	.59*	.96**	.88**	.79**	.65**	82**	.82**	-.49	-.16	-.51	.53*	.79**
Karapadam	-.05	-.51*	.20	.41	.98**	95**	61*	.59*	.[illegible]4**	.62**	.35	.10	.28	.52*	.66**
Coastal sandy alluvium	.23	-.14	09	.32	.98**	.98**	.80**	82**	.68*	.80**	-.71*	11	.62*	.49	.84**
Pokkali	.41	.58*	.55*	.59*	.98**	.96**	85**	.85**	.63**	.85**	-.65**	.22	-.19	.76**	.87**
Kole	-.18	-.58**	.20	.54*	.93**	.92**	.70**	.31**	.63**	.69**	-.60**	-.18	-.21	.44	.76**

* Significant at 5 percent level

** Significant at 1 percent level

negative correlations between reductant P and CEC, exchangeable calcium, exchangeable magnesium and C/P ratio were noted. The r values between reductant P and Fe-P and active P for Kayal soils were positive and significant. Significant positive correlation between reductant P and active P and negative correlation between reductant P and saloid P were obtained for Karapadam soils. The reductant P for coastal sandy alluvium was positively correlated with Fe_2O_3/Al_2O_3 and negatively correlated with C/P ratio. For Pokkali soils, significant positive correlations between reductant P and CaO, MgO, sand, saloid P, Al-P, Fe-P and active P and significant negative correlations with pH and C/P ratio were obtained. The correlation between reductant P and Fe-P was positive and significant but with saloid P and C/P ratio, significant negative correlations were recorded for Kole soils.

2.3.6. Occluded P

For lateritic alluvial soils, significant positive correlations between occluded P and organic carbon, total P, CEC, exchangeable calcium, exchangeable magnesium, sand, all P fractions, C/P ratio, active P and total of P fractions and negative correlation with clay were recorded. Significant positive correlations between occluded P and total P, R_2O_3, Fe_2O_3, Ca-P, reductant P, sum of inorganic P, organic P, non-extractable P, total inorganic P, Fe_2O_3/Al_2O_3, active P and total of P fractions and significant negative correlations with exchangeable calcium, exchangeable magnesium and C/P ratio were observed for Kari soils. For Kayal soils, significant positive correlations between occluded P and total P, Ca-P, reductant P, sum of inorganic P, non-extractable P, total inorganic P and total of P fractions and significant negative correlations with Fe_2O_3/Al_2O_3 were obtained. Karapadam soils showed significant positive correlations between occluded P and total P, Ca-P, reductant P, sum of inorganic P, organic P, non-extractable P, total inorganic P, active P and total of P fractions. Significant positive correlations between occluded P and total P, Ca-P, reductant P, sum of inorganic P, organic P, non-extractable P, total inorganic P and total of P fractions and significant negative correlations with Al_2O_3 and C/P ratio were obtained for coastal sandy alluvial soils. Pokkali soils recorded significant positive correlations between occluded P and pH, total P, all the P fractions, active P and total of P fractions and significant negative correlations with CaO, MgO and C/P ratio. Significant positive correlations between occluded P and total P, Fe-P, Ca-P, reductant P, sum of inorganic P, organic P, non-extractable P, total inorganic P and total of P fractions and significant negative correlations with saloid P and C/P ratio were observed for Kole soils.

Table. 20 Correlation Coefficients between Occluded P and Soil Properties

Soil Type	Sample Size	pH	Organic Carbon	Total P	R_2O_3	Fe_2O_3	Al_2O_3	CaO	MgO	C E C	Exch. Ca	Exch. Mg	Sand	Silt	Clay	P fixing capacity	Saloid P	Al - P	Fe - P	Ca - P	Red - P	Sum of inorganic P	Organic P	Non-extractable-P	Total inorganic - P	C/P ratio	C/N ratio	Fe_2O_3 / Al_2O_3	Active P	Total of P fractions
Lateritic alluvium	55	.24	.32*	.86**	-.28	-.22	-.22	.14	.15	.34*	.34*	.34*	.33*	-.25	-.31*	-.27	34*	.57**	.64**	.99**	.98**	.83**	.87**	.81**	.83**	.45**	-.13	-.01	.74**	.86**
Kari	15	-.40	-.10	.82**	.52*	.57*	.37	-.38	.11	-.51	-.57*	-.52*	-.26	.02	.20	.41	40	-.31	.29	.91**	.86**	.77**	.65**	.64*	.77**	-.68**	.12	.60*	.69**	.86**
Kayal	15	.02	.11	.58*	-.06	-.26	.29	-.01	-.38	-.001	-.004	-.002	-.09	.01	-.003	.003	-.47	-.32	.38	.96**	.88**	.64*	.45	.64*	.65**	-.37	-.17	-.67**	.43	.64*
Karapadam	17	.06	.43	.67**	-.03	-.09	.02	-.08	-.08	.33	.34	.34	.26	-.28	-.19	-.13	-.42	.31	.45	.96**	.95**	.69**	.64**	.74**	.70**	-.31	-.18	-.31	.61*	.71**
Coastal sandy alluvium	12	-.06	-.31	.77**	-.15	.34	-.61*	-.09	.001	-.33	-.34	-.33	.17	.05	-.24	.16	-.14	.02	.20	.95**	.98**	.74**	.78**	.69*	.74**	-.64*	.10	.58	.42	.78**
Pokkali	17	.51*	.48	.82**	.43	.40	.48	-.49*	-.49*	-.43	-.41	-.44	-.48	.35	.29	.43	.53*	.56*	.53*	.99**	96**	.83**	.82**	.64**	.83**	-.62**	.27	-.28	.77**	85**
kole	20	.25	.05	.75**	-.01	-.06	.03	.13	.08	.20	.22	.21	.08	.28	-.33	-.02	-.46*	.14	.54*	.58**	92**	.69**	.62**	.61**	.69**	-.66**	-.15	-.18	.40	.75**

* Significant at 5 percent level
** Significant at 1 percent level

2.3.7. Sum of inorganic P

In all soil types, significant positive correlations between sum of inorganic P and total P, Fe-P, Ca-P, reductant P, occluded P, organic P, non-extractable P, total inorganic P, active P and total of P fractions and significant negative correlations with C/P ratio were recorded. Significant positive correlations between sum of inorganic P and organic carbon, CEC, exchangeable calcium, exchangeable magnesium, sand, saloid P and Al-P and significant negative correlations with R_2O_3, clay and PFC were obtained for lateritic alluvial soils. For Karapadam soils, the correlations between sum of inorganic P and Al-P and Fe-P were positive and with C/N ratio, it was negative and the r values were significant. Significant positive correlations between sum of inorganic P and Al_2O_3, Al-P, Fe-P and Fe_2O_3/Al_2O_3 were recorded for coastal sandy alluvial soils. When significant negative correlations between sum of inorganic P and pH, CaO, MgO and sand were obtained for Pokkali soils the relationships were positive and significant with saloid P and Al-P. For Kole soils, significant positwe correlations were obtained between sum of inorganic P with pH and Al-P.

Table 21 Correlation Coefficients between sum of inorganic P and Soil properties

Soil Type	Sample size	PH	Organic Carbon	Total P	R_2O_3	Fe_2O_3	Al_2O_3	C_aO	M_gO	C E C	Exch. Ca	Exch. Mg	Sand	Silt	Clay	P fixing capacity	Saloid P	Al - P	Fe - P	Ca - P	Red - P	Occluded P	Organic P	Non-extractable-P	Total inorganic P	C/P ratio	C/N ratio	Fe_2O_3/Al_2O_3	Active P	Total of P fraction
Lateritic alluvium	55	25	.38**	.99**	-.35*	-.28	-.28	15	.09	.40**	.43**	.41**	.39**	-.28	-.37**	-.34*	.33*	.92**	94**	.84**	.85**	.83**	.95**	.92**	1.0**	-.35*	-.08	-.02	98**	.99**
Kari	15	.002	.21	.98**	.07	.13	.03	.02	.26	.17	-.24	-.18	.19	-.07	-.09	-.05	.47	.04	.74**	.79**	.70**	.77**	.93**	.88**	1.0**	- 66**	.17	.18	.67**	.97**
Kayal	15	.26	.14	.99**	-.25	-.34	-.04	.28	.03	.14	.14	.14	.14	-.17	-.22	-.25	-.08	.30	.90**	.74**	.79**	.64*	.94**	.95**	1.0**	-.66**	-.22	.44	.68**	99**
Varapadam	17	.05	.25	.98**	.09	.04	.13	-.04	-.15	.09	.09	.11	-.04	.04	.03	.02	.03	.88**	.81**	.66**	.61*	.69**	.92**	.95**	1.0**	-.71**	-.58*	-.23	.98**	.99**
Coastal sandy alluvium	12	-.09	-.47	.98**	-.20	.33	.66*	.03	.32	.42	-.43	.43	-.07	.001	.15	.13	.17	.65*	.67*	.85**	.80**	.74**	.92**	.87**	1.0**	-.85**	.42	.61*	.90**	.99**
Pokkali	17	-.55*	-.43	.99**	.46	.45	.47	-.50*	-.54*	-.43	-.42	-.43	-.50*	.52	.38	.44	.72**	.87**	.85**	.83**	.85**	.83**	.98**	.87**	1.0**	-.73**	.15	.03	.97**	.99**
Kole	20	.40*	.14	.98**	-.28	-.36	-.20	.41	.42	.22	.24	.23	.18	.08	-.24	-.32	-.11	.61**	.89**	.70**	.70**	.69**	.89**	.98**	1.0**	-.64**	.05	-.44	.77**	.98**

* Significant at 5 percent level

** Significant at 1 percent level

2.3.8. Organic P

The correlation coefficients between organic P and total P, Ca-P, reductant P, sum of inorganic P, non-extractable P, total inorganic P, active P and total of P fractions were positive and with C/P ratio, the r values were significant and negative for all soil types. Significant positive correlations between organic P and organic carbon, R_2O_3, CEC, exchangeable calcium, exchangeable magnesium, sand, saloid P and Al-P and significant negative correlations with clay and PFC were noted for lateritic alluvial soils. For Karapadam soils, the correlation between organic P and Al-P was positive but with C/N ratio it was negative and the r values were significant. The correlation coefficients between organic P with Al_2O_3 and Fe_2O_3/Al_2O_3 were positive and significant in the case of coastal sandy alluvium. Organic P with saloid P and Al-P was positively correlated and with pH, CaO, MgO and sand, negatively correlated for Pokkali soils and the r values were significant. For Kole soils, significant positive correlation was noted between organic P and pH. Significant positive correlations between organic P with Fe-P, and occluded P were noted for all soils except coastal sandy alluvium and Kayal soils respectively.

Table. 22 Correlation Coefficients between Organic P and Soil Properties

Sl. No	Soil Type	Sample Size	pH	Organic Carbon	Total P	R_2O_3	Fe_2O_3	Al_2O_3	C_aO	M_gO	C E C	Exch. Ca	Exch. Mg	Sand	Silt	Clay	P fixing capacity	Saloid-P	Al-P	Fe-P	Ca-P	Red-P	Occluded P	Sum of inorganic P	Non-extractable P	Total inorganic P	C/P ratio	C/N ratio	Fe_2O_3/Al_2O_3	Active P	Total of P fractions
1.	Lateritic alluvium	55	.26	.39**	.99**	.33*	-.27	-.24	.13	.11	.39**	.40**	.39**	.36*	-.23	-.36*	-.32*	.35*	.83**	.85**	.88**	.88**	.87**	.95**	.95**	.96**	-.47**	-.09	-.05	.92**	.98**
2.	Kari	15	.19	.11	.98**	.29	.36	.14	-.15	.14	-.33	-.38	-.33	.03	.01	-.04	.17	.41	.11	.57*	.88**	.82**	.85**	.93**	.66**	.93**	-.77**	.30	.41	.83**	.98**
3.	Kayal	15	.30	.21	.97**	-.30	-.35	-.16	.32	.15	.20	.20	.20	.22	-.15	-.20	-.14	.04	.40	.91**	.55*	.65**	.45	.94**	.87**	.93**	-.72**	-.22	-.32	.84**	.96**
4.	Karapadam	17	-.03	.24	.98**	.11	.07	.14	-.09	-.26	.10	.11	.10	-.04	-.02	.09	.02	-.09	.60**	.85**	.62**	.59*	.60*	.92**	.91**	.93**	-.76**	-.54*	-.17	.90**	.96**
5.	Coastal Sandy alluvium	12	.06	.32	.98**	.18	.35	.66*	.17	.24	-.31	-.32	-.31	.06	.004	-.07	.02	.14	.49	.48	.90**	.82**	.78**	.92**	.91**	.93**	-.83**	.25	.63*	.79**	.97**
6.	Pokkali	17	-.56*	-.43	.99**	.44	.43	.45	-.51*	-.53*	-.43	-.42	-.43	-.52*	.34	.38	.42	.74**	.86**	.82**	.83**	.85**	.82**	.99**	.82**	.99**	-.75**	.18	.05	.96**	.99**
7.	Kole	20	.46*	.19	.96**	-.29	-.37	-.22	.36	.35	.29	.31	.29	.23	.06	-.33	-.34	-.25	.42	.77**	.65**	.81**	.82**	.89**	.85**	.89**	-.69**	-.06	-.44	.64**	.94**

* Significant at 5 percent level

** Significant at 1 percent level

2.3.9. Non-extractable P

For all soil types, significant positive correlations between non-extractable P and total P, Ca-P, reductant P, occluded P, sum of inorganic P, organic P, total inorganic P, active P and total of P fractions and significant negative correlation with C/P ratio were recorded. For lateritic alluvium, significant positive correlations between non-extractable P and organic carbon, CEC, exchangeable calcium, exchangeable magnesium, sand and Al-P and significant negative correlations with R_2O_3, Fe_2O_3, clay and PFC were observed. Significant negative correlation between non-extractable P and Al_2O_3 was observed for coastal sandy alluvial soils. The correlation between non-extractable P and saloid P was positive and significant for Pokkali soils. Significant negative correlations between non-extractable P and Fe_2O_3/Al_2O_3 was observed for Kole soils. The correlation between non-extractable P and Al-P was positive and significant for all soils except for Kayal and Kari soils. All soil types other than coastal sandy alluvium recorded positive significant correlation between non-extractable P and Fe-P.

Table 23 Correlation Coefficients between Non-extractable P and Soil Properties

Sl. No.	Soil Type	Sample Size	pH	Organic Carbon	Total P	R_2O_3	Fe_2O_3	Al_2O_3	CaO	MgO	C E C	Exch. Ca	Exch. Mg	Sand	Silt	Clay	P fixing capacity	Saloid-P	Al-P	Fe-P	Ca-P	Red - P	Occluded P	Sum of inorganic P	Organic P	Total inorganic-P	C/P ratio	C/N ratio	Fe_2O_3/Al_2O_3	Active - P	Total of P fractions
1.	Lateritic alluvium	56	.26	.41**	.95**	-.36*	-.30*	-.25	.12	.10	.43**	.42**	.43**	.42**	-.26	-.42**	-.35*	.23	.84**	.85**	.81**	.82**	.81**	.92**	.95**	.94**	-.34*	-.13	-.06	.91**	.94**
2.	Kari	15	-.15	.02	.90**	.15	.18	.10	-.07	.05	-.32	-.36	-.29	.003	.15	-.16	.13	.30	.15	.66**	.64*	.64*	.64*	.88**	.86**	.90**	-.76**	.21	.21	.80**	.87**
3.	Kayal	15	.09	-.10	.95**	-.01	-.13	.19	.12	-.13	-.05	-.65**	-.05	-.09	-.01	-.02	-.03	-.20	.25	.81**	.76**	.82**	.64**	.95**	.87**	.97**	-.74**	.02	-.39	.84**	.95**
4.	Karapadam	17	.08	.36	.96**	.05	.02	.11	.003	.17	.24	.26	.26	.09	-.09	-.07	-.07	-.08	.80**	.81**	.68**	.64**	.74**	.95**	.91**	.96**	-.60*	-.59*	-.33	.92**	.95**
5.	Coastal sandy alluvium	12	.03	-.35	.92**	-.32	.22	-.74**	.10	.20	-.32	-.33	-.34	.19	-.07	-.03	.02	-.01	.62*	.44	.78**	.68*	.69*	.87**	.91**	.90**	-.78**	.50	.55	.84**	.91**
6.	Pokkali	17	-.43	-.41	.86**	.42	.41	.41	-.40	-.41	-.36	-.35	-.37	-.41	.39	.05	.41	.66**	.84**	.78**	.61*	.63**	.64**	.87**	.82**	.88**	-.61*	.28	.10	.86**	.85**
7.	Kole	20	.40	.07	.96**	.24	.33	.16	.37	.38	.15	.17	.16	.12	-.09	-.16	-.28	-.07	.66**	.88**	.63**	.63**	.61**	.96**	.85**	.99**	-.66**	.11	-.45*	.81**	.96**

* Significant at 5 percent level

** Significant at 1 percent level

2.3.10. Total inorganic P

Significant positive correlations between the total inorganic P and total P, P fractions other than saloid P, Al-P, active P and total of P fractions, and significant negative correlation with C/P ratio were observed for all soil types. The relationship between total inorganic P and Al-P was positive and significant for all soils other than Kari and Kayal. Significant positive correlations between total inorganic P and organic carbon and CEC, exchangeable calcium, exchangeable magnesium, sand and saloid P and significant negative correlations with R_2O_3, silt, Fe_2O_3, clay and PFC were obtained for lateritic alluvial soils. Significant positive correlation between total inorganic P and sand (Kayal) with Fe_2O_3/Al_2O_3 (coastal sandy alluvium) with saloid P (Pokkali) and with pH (Kole) were recorded. Significant negative correlations between total inorganic P and Al_2O_3 (coastal sandy alluvium) with pH, CaO, MgO, and sand (Pokkali) and with Fe_2O_3/Al_2O_3 (Kole) were also observed.

Table. 24 Correlation Coefficients between total inorganic - P and Soil Properties

Sl.No.	Soil Type	Sample size	PH	Organic Carbon	Total P	R_2O_3	Fe_2O_3	Al_2O_3	CaO	MgO	C E C	Exch. Ca	Exch. Mg	Sand	Silt	Clay
1.	Lateritic alluvium	55	.26	** .39	** .99	* -.36	* -.29	-.28	.13	.10	** .41	** .44	** .41	** .40	* -.29	** -.38
2.	Kari	15	-.01	.19	** .99	.08	.13	-.01	-.03	.24	-.19	-.25	-.19	.18	-.06	-.10
3.	Kayal	15	.22	.06	** .99	-.19	-.29	.02	.22	-.02	.09	.09	.09	** .78	-.08	-.13
4.	Karapadam	17	.06	.27	** .99	.08	.03	.13	-.04	-.15	.11	.12	.13	-.02	-.02	.02
5.	Coastal Sandy Alluvium	12	-.08	-.46	** .99	-.22	.32	* -.68	.04	.31	-.42	-.42	-.42	-.03	-.01	.13
6.	Pokkali	17	* -.55	-.43	** .99	.46	.45	.47	* -.50	* -.53	-.43	-.42	-.43	* -.50	.33	.37
7.	Kole	20	* .46	.13	** .98	-.27	-.36	-.20	.41	-.42	.21	.23	.22	.17	.08	-.23

Sl.No.	Soil Type	P fixing capacity	Saloid P	Al - P	Fe - P	Ca - P	Red - P	Occluded -P	Sum of inorganic P	Organic P	Non-extractable - P	C/P ratio	C/N ratio	Fe_2O_3/Al_2O_3	Active P	Total of P fractions
1.	Lateritic alluvium	* -.35	* .32	** .92	** .94	** .84	** .65	** .83	** .99	** .96	** .94	* -.35	-.09	-.02	** .98	** .99
2.	Kari	-.04	.46	.05	** .74	** .78	** .70	** .77	** .99	** .93	** .90	** -.68	.18	.19	** .67	** .97
3.	Kayal	-.20	-.11	.26	** .89	** .76	** .80	** .65	** .99	** .93	** .97	** -.70	-.14	-.43	** .86	** .99
4.	Karapadam	.01	.02	** .87	** .82	** .66	** .62	** .70	** .99	** .93	** .96	** -.69	* -.58	-.25	** .98	** .99
5.	Coastal Sandy Alluvium	.11	.15	* .66	* .65	** .85	** .80	** .74	** .99	** .93	** .90	** -.66	.44	* .61	** .91	** .99
6.	Pokkali	.45	** .72	** .88	** .86	** .83	** .85	** .83	** .99	** .99	** .89	** -.73	.16	.03	** .97	** .99
7.	Kole	-.31	-.11	** .62	** .89	** .69	** .69	** .69	** .99	** .89	** .99	** -.65	.06	* -.45	** .78	** .98

* Significant at 5 percent level

** Significant at 1 percent level

3. <u>Phosphorus fixing capacity of rice soils</u>

Phosphorus fixing capacity (PFC) of 151 samples of soils belonging to seven major rice soil types in Kerala, viz., lateritic alluvium (S_1), Kari (S_2), Kayal (S_3), Karapadam (S_4), coastal sandy alluvium (S_5), Pokkali (S_6) and Kole (S_7) was determined and the mean values are presented in Table 25. To bring out the differences in the PFC, analysis of variance was conducted. The ANOVA (Appendix IV) showed significant variation in PFC among the soils.

The data on the mean PFC bring out the differences among the seven soil types with respect to this property. No significant difference could be noticed among the mean PFC of Lateritic alluvium (S_1), Kari (S_2), Kayal (S_3), Karapadam (S_4) and Kole soils (S_7). These five soil types fixed comparatively and significantly higher quantities of soluble phosphates under experimental situation than either coastal sandy alluvium (S_5) or Pokkali (S_6) soils. The ranges of variation of PFC for lateritic alluvium, Kari, Kayal, Karapadam, coastal sandy alluvium, Pokkali and Kole soils were from 36.00 to 66.00, 42.45 to 62.80, 44.90 to 55.15, 34.65 to 60.25, 31.45 to 39.80, 24.45 to 44.50 and 41.20 to 57.25

Table 25. Mean P fixing capacity (per cent) of rice soils.

Sl. No.	Soil type	Sample size	Mean PFC	Critical difference						
				CD_1	CD_2	CD_3	CD_4	CD_5	CD_6	CD_7
1.	Lateritic alluvium	55	47.87	-	3.85	3.85	3.67	4.22	3.67	3.46
2.	Kari	15	52.75	-	-	4.83	4.69	5.13	4.69	4.52
3.	Kayal	15	50.47	-	-	-	4.69	5.13	4.69	4.52
4.	Karapadam	17	40.47	-	-	-	-	4.99	4.54	4.37
5.	Coastal sandy alluvium	12	36.10	-	-	-	-	-	4.90	4.83
6.	Pokkali	17	37.76	-	-	-	-	-	-	4.37
7.	Kole	20	48.29	-	-	-	-	-	-	-

percent respectively. The mean PFC was 49.57 per cent on an average for the first set of five soil types, i.e. excluding Pokkali and coastal sandy alluvial soils. While the same for the second set of two soil types viz., Pokkali and coastal sandy alluvium was 36.93 per cent. The difference between the two means was also significant. Among all the soils, the coastal sandy alluvium (S_5) recorded the lowest mean PFC of 36.10 per cent while the Kari soils (S_2) fixed highest amount of 52.75 percent of soluble phosphates.

3.1. Factors governing PFC

The PFC of a soil among many factors is mainly guided by the physico-chemical properties of the soil such as pH, organic carbon, total sesquioxides, total Fe_2O_3, total Al_2O_3, total CaO, total MgO, CEC, exchangeable calcium, exchangeable magnesium, sand, silt, clay, C/P ratio, C/N ratio and active P. In view of this, simple correlation coefficients and linear regressions of PFC with soil characteristics were worked out and the results are presented in Table 26 to 42. The significance of these correlation coefficients was tested (Snedecor and Cochran, 1968).

3.1.1. pH

Significant negative correlation between PFC and pH was noted for all soil types. The values of the correlation

Table 26. Estimated regression models and correlation coefficients between P fixing capacity and pH

Sl. No.	Soil type	Sample size	Correlation coefficient (r)	Regression model (Y=a+bx)	SE(b)	Coefficient of determination (r^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Lateritic alluvium	55	-0.9276	Y=151.9588-2.3288X**	0.1288	0.8604**
2.	Kari	15	-0.9707	Y= 82.3635-1.1323X**	0.0777	0.9423**
3.	Kayal	15	-0.9355	Y=107.0918-1.3834X**	0.1449	0.8752**
4.	Karapadam	17	-0.8397	Y=142.1835-2.2035X**	0.3680	0.7051**
5.	Coastal sandy alluvium	12	-0.9137	Y=108.7892-1.1171X**	0.1571	0.8348**
6.	Pokkali	17	-0.9468	Y=68.3328-0.6083X**	0.0534	0.8964**
7.	Kole	20	-0.7600	Y=97.0841-1.3628X**	0.2747	0.5776**

** Significant at 1 per cent probability level.

coefficients ranged from −0.76 (S_7) to −0.97 (S_2). All the regression coefficients of PFC with pH were also negative and significant. It was found that the differences between the values of the correlation coefficients of Kole soils (S_7) with lateritic alluvium (S_1), Kari (S_2) and Pokkali (S_6) were significant. In the case of Kari and Karapadam soils the r values were significantly different.

3.1.2. Organic carbon

Organic carbon was negatively correlated with PFC and was significant for all soil types. The range of variation of the correlation coefficients was from −0.67 (S_4) to −0.94 (S_1). The regression coefficients were also negative and significant. The correlation coefficients of lateritic alluvium (S_1) were significantly different from that of Kari (S_2), Karapadam (S_4) and Kole (S_7) soils. The r values of Karapadam and Pokkali soils were significant.

3.1.3. Total sesquioxides

Significant positive correlations could be observed between PFC and total sesquioxides for all soil types. The values of the correlation coefficients varied from 0.81 (S_5) to 0.99 (S_3 and S_7). The range of values of correlation coefficients were narrow for this factor compared to other

Table 27. Estimated regression models and correlation coefficients between P fixing capacity and organic carbon

Sl. No.	Soil type	Sample size	Correlation coefficient (r)	Regression model (Y=a+bx)	SE(b)	Coefficient of determination (r^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Lateritic alluvium	55	-0.9432	Y=56.5235-0.1431X**	0.0069	0.8896**
2.	Kari	15	-0.7626	Y=77.5975-0.1038X**	0.0244	0.5816**
3.	Kayal	15	-0.8118	Y=73.7002-0.0857X**	0.0171	0.6590**
4.	Karapadam	17	-0.6657	Y=73.0256-0.1054X**	0.0305	0.4432**
5.	Coastal sandy alluvium	12	-0.8334	Y=61.6938-0.1786X**	0.0375	0.6946**
6.	Pokkali	17	-0.9329	Y=59.4053-0.0751X**	0.0075	0.8703**
7.	Kole	20	-0.7905	Y=49.3571-0.0923X**	0.0169	0.6249**

** Significant at 1 per cent probability level.

Table 28. Estimated regression models and correlation coefficients between P fixing capacity and total sesquioxides.

Sl. No. (1)	Soil type (2)	Sample size (3)	Correlation coefficient (r) (4)	Regression model (Y=a+bx) (5)	SE(b) (6)	Coefficient of determination (r^2) (7)
1.	Lateritic alluvium	55	0.9858	Y=-1.3603+0.2134**X	0.0050	0.9718**
2.	Kari	15	0.9363	Y=-19.5180+0.4001**X	0.0416	0.8767**
3.	Kayal	15	0.9875	Y= 33.5935+0.1205**X	0.0053	0.9752**
4.	Karapadam	17	0.9556	Y= 20.5898+0.1873**X	0.0149	0.9132**
5.	Coastal sandy alluvium	12	0.8116	Y= 10.2298+0.6961**X	0.1585	0.6587**
6.	Pokkali	17	0.9617	Y=-13.6462+0.4967**X	0.0366	0.9249**
7.	Kole	20	0.9878	Y= 1.0876+0.1426**X	0.0053	0.9757**

** Significant at 1 per cent probability level.

factors correlated with PFC. Significant positive regression coefficients were also observed for PFC with total sesquioxides. The difference was observed to be significant between the values of the correlation coefficients of coastal sandy alluvium with lateritic alluvium, Kayal and Kole soils. Similarly the correlation coefficients of Kari soil differed significantly with that of lateritic alluvium and Kole soil, when Kole and Pokkali soils differed significantly with respect to the r values between PFC and total sesquioxides.

3.1.4. Total Fe_2O_3

Significant positive correlations were observed between PFC with total Fe_2O_3 for all soils. The values of the correlation coefficients ranged from 0.79 (S_5) to 0.97 (S_4). The regression coefficients were also found to be positive and significant. The z values showed that the differences between the values of the correlation coefficients of coastal sandy alluvial soils (S_5) were significantly different from those of both Karapadam (S_4) and Kole soils (S_7). In respect of the relationship between PFC and total Fe_2O_3, the Karapadam soils (S_4) were more or less on the same status as the Kole soils (S_7).

Table 29. Estimated regression models and correlation coefficients between P fixing capacity and total Fe_2O_3

Sl. No.	Soil type	Sample size	Correlation coefficient (r)	Regression model (Y=a+bx)	SE(b)	Coefficient of determination (r^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Lateritic alluvium	55	0.9194	Y= 7.7112+0.2118X**	0.0124	0.8453**
2.	Kari	15	0.8844	Y= 22.3709+0.5857X**	0.0857	0.7822**
3.	Kayal	15	0.9319	Y= 37.3486+0.1678X**	0.0181	0.8684**
4.	Karapadam	17	0.9748	Y= 22.0535+0.3749X**	0.0222	0.9502**
5.	Coastal sandy alluvium	12	0.7985	Y= 32.6527+0.9986X**	0.2376	0.6376**
6.	Pokkali	17	0.9598	Y=-12.3663+0.7293X**	0.0551	0.9212**
7.	Kole	20	0.9659	Y= 5.2707+0.3081X**	0.0195	0.9330**

** Significant at 1 per cent probability level.

3.1.5. Total Al_2O_3

The PFC was positively correlated with Al_2O_3 for all soil types. The correlation and regression coefficients were significant for all soils except coastal sandy alluvium. The values of the correlation coefficients varied from a low value of 0.38 (S_1) to a high value of 0.97 (S_7). Lateritic alluvium showed significant difference in the correlation coefficient between PFC and Al_2O_3 content than Kari, Kayal, Karapadam, Pokkali and Kole. Coastal sandy alluvium showed significant difference in the correlation coefficient between PFC and Al_2O_3 than Kari, Karapadam, Pokkali and Kole.

3.1.6. Total CaO

Significant negative correlations were noted between PFC and total CaO considering all the soils together. The low and high values for the correlation coefficients were obtained for the Kole (-0.66) and the Pokkali soils (-0.96). The regression coefficients were also negative and significant. The Z values showed that the differences between the magnitude of the correlation coefficients of Pokkali soils with lateritic alluvium and Kole soils were significant. The lateritic alluvium showed significant difference in the correlation coefficient between PFC and total CaO content than Kole soils.

Table 30. Estimated regression models and correlation coefficients between P fixing capacity and total Al_2O_3

Sl. No. (1)	Soil type (2)	Sample size (3)	Correlation coefficient (r) (4)	Regression model (Y=a+bx) (5)	SE(b) (6)	Coefficient of determination (r^2) (7)
1.	Lateritic alluvium	55	0.3808	Y= 27.0717+0.2582X**	0.0861	0.1450**
2.	Kari	15	0.9058	Y=-69.4857+0.9588X**	0.1244	0.8205**
3.	Kayal	15	0.8592	Y= 34.8119+0.2530X**	0.0418	0.7382**
4.	Karapadam	17	0.8991	Y= 21.4006+0.3455X**	0.0434	0.8084**
5.	Coastal sandy alluvium	12	0.4128	Y= 29.9984+0.5561X	0.3880	0.1704
6.	Pokkali	17	0.9561	Y=-15.0716+1.5258X**	0.1208	0.9141**
7.	Kole	20	0.9661	Y= 0.5088+0.2445X**	0.0154	0.9333**

** Significant at 1 per cent probability level.

Table 31. Estimated regression models and correlation coefficients between P fixing capacity and total CaO.

Sl. No. (1)	Soil type (2)	Sample size (3)	Correlation coefficient (r) (4)	Regression model (Y=a+bx) (5)	SE(b) (6)	Coefficient of determination (r^2) (7)
1.	Lateritic alluvium	55	-0.8482	Y= 96.0470-0.8937X**	0.0767	0.7194**
2.	Kari	15	-0.8437	Y= 83.7483-0.9786X**	0.1727	0.7118**
3.	Kayal	15	-0.7721	Y= 66.5361-0.2536X**	0.0572	0.5961**
4.	Karapadam	17	-0.8334	Y=123.2532-1.6195X**	0.2773	0.6946**
5.	Coastal sandy alluvium	12	-0.7662	Y= 67.4896-1.2725X**	0.3375	0.5871**
6.	Pokkali	17	-0.9606	Y= 61.9583-1.4428X**	0.1077	0.9228**
7.	Kole	20	-0.6585	Y= 56.8206-0.5206X**	0.1402	0.4336**

** Significant at 1 per cent probability level.

3.1.7. Total MgO

The MgO content was found to be negatively correlated with PFC in all soil types. The correlation coefficients were significant at 1 per cent probability level in all soils except Kari, Karapadam and coastal sandy alluvium whose r values were found to be significant only at 5 per cent level. Similar results could be obtained in the case of regressions also. The values of the correlation coefficients ranged from -0.53 (S_2) to -0.93 (S_6). The difference between the values of the correlation coefficients between Pokkali and all other soil groups were significant.

3.1.8. Cation Exchange Capacity

The correlation coefficients between PFC and CEC were negative and significant for all soils, the r values ranged from -0.74 (S_7) to -0.96 (S_6). The regression coefficients were also negative and significant. The Z statistic showed significant differences between the values of the correlation coefficients of Kole soils with lateritic alluvium and Pokkali soils.

3.1.9. Exchangeable calcium

Significant negative correlations and regressions were observed for PFC with exchangeable calcium in all soil types.

Table 32. Estimated regression models and correlation coefficients between P fixing capacity and total MgO.

Sl. No.	Soil type	Sample size	Correlation coefficient (r)	Regression model (Y=a+bx)	SE(b)	Coefficient of determination (r^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Lateritic alluvium	55	-0.7840	Y=59.2836-2.0656X**	0.2241	0.6159**
2.	Kari	15	-0.5312	Y=61.7361-0.7734X*	0.3471	0.2822*
3.	Kayal	15	-0.6692	Y=58.9150-0.4075X**	0.1255	0.4477**
4.	Karapadam	17	-0.5534	Y=87.7418-3.3548X**	1.0037	0.3063**
5.	Coastal sandy alluvium	12	-0.5843	Y=57.9333-0.8521X*	0.3742	0.3414*
6.	Pokkali	17	-0.9317	Y=76.4472-1.4503X**	0.1460	0.8681**
7.	Kole	20	-0.6166	Y=50.1453-0.5135X**	0.1546	0.3802**

** Significant at 1 per cent probability level.

* Significant at 5 per cent probability level.

Table 33. Estimated regression models and correlation coefficients between P fixing capacity and C.E.C.

Sl. No. (1)	Soil type (2)	Sample size (3)	Correlation coefficient (r) (4)	Regression model (Y=a+bx) (5)	SE(b) (6)	Coefficient of determination (r^2) (7)
1.	Lateritic alluvium	55	-0.9256	Y=84.3832-0.0590X**	0.0033	0.8567**
2.	Kari	15	-0.8901	Y=72.6301-0.0200X**	0.0028	0.7923**
3.	Kayal	15	-0.8889	Y=61.5764-0.0109X**	0.0016	0.7901**
4.	Karapadam	17	-0.9100	Y=72.2611-0.0178X**	0.0021	0.8281**
5.	Coastal sandy alluvium	12	-0.8162	Y=56.8367-0.0093X**	0.0021	0.6662**
6.	Pokkali	17	-0.9552	Y=60.8536-0.0246X**	0.0020	0.9124**
7.	Kole	20	-0.7408	Y=52.2703-0.0266X**	0.0057	0.5488**

** significant at 1 per cent probability level.

Table 34. Estimated regression models and correlation coefficients between P fixing capacity and exchangeable calcium

Sl. No. (1)	Soil type (2)	Sample size (3)	Correlation coefficient (r) (4)	Regression model (Y=a+bx) (5)	SE(b) (6)	Coefficient of determination (r^2) (7)
1.	Lateritic alluvium	55	-0.9012	Y=80.7757-0.1243X**	0.0082	0.8122**
2.	Kari	15	-0.8758	Y=73.1796-0.0467X**	0.0072	0.7670**
3.	Kayal	15	-0.8884	Y=61.6173-0.0310X**	0.0045	0.7893**
4.	Karapadam	17	-0.8606	Y=71.8330-0.0494X**	0.0075	0.7406**
5.	Coastal sandy alluvium	12	-0.8114	Y=56.7777-0.0232X**	0.0053	0.6584**
6.	Pokkali	17	-0.9541	Y=60.5571-0.0661X**	0.0036	0.9103**
7.	Kole	20	-0.7465	Y=52.6511-0.0776X**	0.0163	0.5573*

** Significant at 1 per cent probability level.

The range of variation of the values of the correlation coefficients was from -0.75 (S_7) to -0.95 (S_6). Except in the case of Pokkali and Kole soils, the differences of the r values between all other sets were found to be not significant.

3.1.10. Exchangeable magnesium

The PFC was negatively correlated with exchangeable magnesium in all cases. Both the correlation and regression coefficients were negative and significant. The r values varied from -0.74 (S_7) to -0.96 (S_6). The correlation coefficients of Kole soils were significantly different from that of lateritic alluvium and Pokkali soils.

3.1.11. Sand

The PFC decreased significantly as the sand content increased for all soils except the coastal sandy alluvium whose correlation was negative but not significant. Same was the case with regard to regressions also. Coastal sandy alluvium and the Kayal soils recorded the lowest and highest r values (-0.52 and -0.92) respectively. The values of the correlation coefficients of coastal sandy alluvium were significantly different from those of lateritic alluvium, Kari, Kayal, Karapadam and Kole soils.

Table 35. Estimated regression models and correlation coefficients between P fixing capacity and exchangeable magnesium

Sl. No. (1)	Soil type (2)	Sample size (3)	Correlation coefficient (r) (4)	Regression model (Y=a+bx) (5)	Se(b) (6)	Coefficient of determination (r^2) (7)
1.	Lateritic alluvium	55	-0.9263	Y=84.4074-0.2952X**	0.0165	0.8575**
2.	Kari	15	-0.8747	Y=72.9543-0.1211X**	0.0171	0.7651**
3.	Kayal	15	-0.8888	Y=61.5821-0.0361X**	0.0052	0.7900**
4.	Karapadam	17	-0.8990	Y=71.3061-0.0705X**	0.0089	0.8082**
5.	Coastal sandy alluvium	12	-0.8111	Y=36.7628-0.0263X**	0.0060	0.6579**
6.	Pokkali	17	-0.9556	Y=60.0084-0.11[illegible]1X**	0.0094	0.9132**
7.	Kole	20	-0.7409	Y=52.3333-0.0830X**	0.0177	0.5489**

** Significant at 1 per cent probability level

Table 36. Estimated regression models and correlation coefficients between P fixing capacity and sand.

Sl. No.	Soil type	Sample size	Correlation coefficient (r)	Regression model (Y=a+bx)	SE(b)	Coefficient of determination (r^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Lateritic alluvium	55	-0.9134	Y= 75.9652-0.0592X**	0.0036	0.8343**
2.	Kari	15	-0.9049	Y= 95.3104-0.0733X**	0.0096	0.8188**
3.	Kayal	15	-0.9231	Y=102.1596-0.0945X**	0.0109	0.8521**
4.	Karapadam	17	-0.9171	Y= 79.7220-0.0614X**	0.0069	0.8411**
5.	Coastal sandy alluvium	12	-0.5240	Y=128.0240-0.0819X	0.0421	0.2746
6.	Pokkali	17	-0.8918	Y=170.1451-0.1435X**	0.0188	0.7953**
7.	Kole	20	-0.8964	Y= 59.3505-0.0487X**	0.0057	0.8035**

** Significant at 1 per cent probability level

3.1.12. Silt

A positive correlation between PFC and silt content was observed for all the soils studied. The correlations and regressions were significant for lateritic alluvium, Karapadam, Pokkali and Kole soils. The range of variation of the values of the correlation coefficients was from 0.24 (S_3) to 0.81 (S_6). The correlation coefficient of Kayal soils differed significantly with that of Pokkali and Kole soils.

3.1.13. Clay

The PFC was positively correlated with the clay in all the soils. Except for Kari and Pokkali soils, the correlations and regressions were significant in all cases. The lowest and highest r values were recorded by Pokkali (0.19) and Karapadam (0.92) respectively. The Z values showed that the differences between the values of the correlation coefficients of lateritic alluvium with that of Kari, Kayal, Pokkali and Kole soils was significant. The correlation coefficients of Karapadam soils were significantl different from those of Kari, Kayal, coastal sandy alluvium and Kole soils.

3.1.14. C/P ratio

A negative correlation between PFC and C/P ratio was observed for all soils. The values of the correlation

Table 37. Estimated regression models and correlation coefficients between P fixing capacity and silt.

Sl. No.	Soil type	Sample size	Correlation coefficient (r)	Regression model (Y=a+bx)	SE(b)	Coefficient of determination (r^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Lateritic alluvium	55	0.6888	Y=23.6878+0.1030X**	0.0149	0.4744**
2.	Kari	15	0.4403	Y=40.9551+0.0308X	0.0174	0.1939
3.	Kayal	15	0.2422	Y=47.5116+0.0133X	0.0147	0.0587
4.	Karapadam	17	0.6950	Y=27.7555+0.0353X**	0.0228	0.4830**
5.	Coastal sandy alluvium	12	0.5638	Y=44.9500+0.2000X	0.0927	0.3179
6.	Pokkali	17	0.8116	Y=33.0494+0.1306X**	0.0243	0.6587**
7.	Kole	20	0.7792	Y=23.1041+0.0682X**	0.0129	0.6072**

** Significant at 1 per cent probability level.

Table 38. Estimated regression models and correlation coefficients between P fixing capacity and clay.

Sl. No.	Soil type	Sample size	Correlation coefficient (r)	Regression model (Y=a+bx)	SE(b)	Coefficient of determination (r^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Lateritic alluvium	55	0.8503	Y=21.1792+0.0762X**	0.0065	0.7230**
2.	Kari	15	0.3440	Y=66.7594+0.0242X	0.0184	0.1183
3.	Kayal	15	0.5439	Y=44.9392+0.0210X**	0.0090	0.2958**
4.	Karappadam	17	0.9190	Y=22.4335+0.1050X**	0.0116	0.8446**
5.	Coastal sandy alluvium	12	0.5887	Y=46.7933+0.1358X*	0.0590	0.3466*
6.	Pokkali	17	0.1942	Y=45.7216+0.0640X	0.0844	0.0377
7.	Kole	20	0.5356	Y=22.3232+0.0621X*	0.0156	0.2869*

* Significant at 5 per cent probability level.

** Significant at 1 per cent probability level.

Table 39. Estimated regression models and correlation coefficients between P fixing capacity and organic C/Organic P

Sl. No. (1)	Soil type (2)	Sample size (3)	Correlation coefficient (r) (4)	Regression model (Y=a+bx) (5)	SE(b) (6)	Coefficient of determination (r^2) (7)
1.	Lateritic alluvium	55	-0.4724	Y=43.6491-0.0010X**	0.0002	0.2232**
2.	Kari	15	-0.4182	Y=52.5627-0.0003X	0.0002	0.1749
3.	Kayal	15	-0.2259	Y=54.4962-0.0006X	0.0008	0.0510
4.	Karapadam	17	-0.4377	Y=59.5543-0.0010X	0.0009	0.1916
5.	Coastal sandy alluvium	12	-0.4270	Y=54.2484-0.0003X	0.0002	0.1823
6.	Pokkali	17	-0.8207	Y=53.6385-0.0003X**	0.0001	0.6735**
7.	Kole	20	-0.2714	Y=39.8608-0.0007X	0.0006	0.0737

** Significant at 1 per cent probability level.

coefficients ranged from -0.23 (S_3) to -0.82 (S_6). The correlation and regression coefficients were significant only for lateritic alluvium and Pokkali soils. The Z statistic showed significant differences between the r values in the case of Pokkali with lateritic alluvium, Kayal and Kole soils.

3.1.15. C/N ratio

The PFC was positively correlated with C/N ratio, the values of the correlation coefficients varied from 0.06 (S_2) to 0.66 (S_3). Significant correlation and regression coefficients were obtained only for lateritic alluvium, Kayal, Pokkali and Kole soils. The differences between the values of the correlation coefficients were not significant for all the soils.

3.1.16. Fe_2O_3/Al_2O_3

The relationship between the PFC and Fe_2O_3/Al_2O_3 was positive. The lowest and highest correlation coefficient were obtained for S_1 (0.29) and S_2 (0.83) respectively. The correlations and regression coefficients were significant for lateritic alluvium, Kari and Karapadam soils only. The value of the correlation coefficient of Kari soils was significantly different from those of lateritic alluvium and Pokkali soils.

Table 40. Estimated regression models and correlation coefficients between P fixing capacity and C/N ratio.

Sl. No. (1)	Soil type (2)	Sample size (3)	Correlation coefficient (r) (4)	Regression model (Y=a+bx) (5)	SE(b) (6)	Coefficient of determination (r^2) (7)
1.	Lateritic alluvium	55	0.5130	Y= 23.9082+0.0084X**	0.0019	0.2632**
2.	Kari	15	0.0585	Y= 43.6269+0.0078X	0.0339	0.0034
3.	Kayal	15	0.6625	Y= 31.2669+0.0253X**	0.0080	0.4389**
4.	Karapadam	17	0.4186	Y=-66.9579+0.1317X	0.0738	0.1752
5.	Coastal sandy alluvium	12	0.3200	Y= 50.5697+0.0011X	0.0010	0.1024
6.	Pokkali	17	0.5401	Y= 39.7675+0.0067X*	0.0027	0.2917*
7.	Kole	20	0.5240	Y= 19.0039+0.0174X*	0.0067	0.2746*

* Significant at 5 per cent probability level.

** Significant at 1 per cent probability level.

Table 41. Estimated regression models and correlation coefficients between P fixing capacity and Fe_2O_3/Al_2O_3 ratio.

Sl. No. (1)	Soil type (2)	Sample size (3)	Correlation coefficient (r) (4)	Regression model (Y=a+bx) (5)	SE(b) (6)	Coefficient of determination (r^2) (7)
1.	Lateritic alluvium	55	0.2892	Y= 31.1413+0.0181X*	0.0082	0.0836*
2.	Kari	15	0.8285	Y= 19.6634+0.7997X**	0.1499	0.6864**
3.	Kayal	15	0.3425	Y= 43.8708+0.0517X	0.0394	0.1173
4.	Karapadam	17	0.4891	Y= 12.1346+0.4056X*	0.1868	0.2392*
5.	Coastal sandy alluvium	12	0.5615	Y= 39.1647+0.0275X	0.1233	0.3153
6.	Pokkali	17	0.3071	Y=-63.9874+0.5606X	0.4465	0.0943
7.	Kole	20	0.3965	Y= 3.6084+0.4740X	0.2586	0.1572

* Significant at 5% probability level

** Significant at 1% probability level

3.1.17. Active P (Al-P+Fe-P+Ca-P)

The correlations between PFC and active P were negative for all soils studied. The values of the correlation coefficients ranged from -0.004 (coastal sandy alluvium) to -0.527 (Pokkali). The correlation coefficients of only lateritic alluvium were significant at 1 per cent probability level while those of Pokkali and Kole soils were significant at 5 per cent level.

3.2. Relative influence of selected independent factors on PFC

Stepwise regression analysis was carried out to assess the relative influence of selected independent factors viz., pH (X_1), R_2O_3 (X_2), CaO (X_3), MgO (X_4), CEC (X_5), organic matter (X_6) and clay content (X_7) on the PFC of seven rice soils and the results are presented in Table 43 to 49.

In lateritic alluvium among the seven independent variables studied, only two (R_2O_3 and CaO) appear to be exerting any significant influence on the dependent variable. All the variables considered together however explain more than 98 percentage of the total variation observed in the dependent variable. In other words, the data gives

Table 42. Estimated regression models and correlation coefficients between P fixing capacity and active P (Al-P+Fe-P+Ca-P)

Sl. No.	Soil type	Sample size	Correlation coefficient (r)	Regression model ($Y=a+bx$)	SE(b)	Coefficient of determination (r^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Lateritic alluvium	55	-0.3502	Y=41.9098-0.0029X**	0.0011	0.1226**
2.	Kari	15	-0.0353	Y=48.7593-0.0012X	0.0092	0.0012
3.	Kayal	15	-0.2590	Y=54.1372-0.0019X	0.0020	0.0671
4.	Karapadam	17	-0.0464	Y=49.2817-0.0005X	0.0028	0.0022
5.	Coastal sandy alluvium	12	-0.0036	Y=52.7709-0.00003X	0.0024	0.00001
6.	Pokkali	17	-0.5273	Y=41.3395-0.0061X*	0.0025	0.2780*
7.	Kole	20	-0.5085	Y=41.8641-0.0034X*	0.0013	0.2586*

* Significant at 5 per cent probability level

** Significant at 1 per cent probability level

statistically good fit to the specified model. A perusal of the stepwise regression models reveals that R_2O_3 is the most significant factor and it alone accounts for about 97 percentage of the total variation.

The effect of pH was significant and its contribution to the PFC was the highest (94 per cent) In Kari soils. About 99 per cent of the total variation was accounted by the seven independent variables taken together, showing a statistically good fit to the specified model. When pH, exert significant negative influence CaO, organic matter and clay produce significant positive influence on the PFC of Kari soils.

The maximum contribution (40 per cent) in the total variation of the PFC has been by CEC followed by CaO, pH, R_2O_3, organic matter, MgO and clay in Kayal soils. In the final regression equation the organic matter alone was found to be significant. However, all the variables taken together contributed 80 per cent of the total variation in PFC for this soil type.

In Karapadam soils, 90 per cent of the total variation in PFC was accounted by R_2O_3 followed by clay. All the variables taken together explain more than 98 per cent of the total variation on the dependent variable. Among the seven independent variables, R_2O_3 and CEC influenced the PFC significantly.

Table 43. Summary results of the stepwise regression analysis for P fixing capacity of lateritic alluvial soils

	$\bar{R}^2$
1. $Y = 8.7207 + 2.1359^{**}X_2$ (0.0498)	0.9720
2. $Y = 43.1188 - 5.4395^{**}X_1 + 1.7145^{**}X_2$ (1.0907) (0.0941)	0.9807
3. $Y = 44.4115 - 5.0540^{**}X_1 + 1.6589^{**}X_2 - 0.2740X_5$ (1.1925) (0.1165) (0.3368)	0.9806
4. $Y = 43.8299 - 5.0834^{**}X_1 + 1.6572^{**}X_2 - 0.2935X_5 + 0.0103X_7$ (1.2129) (0.1178) (0.4572) (0.0445)	0.9802
5. $Y = 40.0874 - 2.3680X_1 + 1.6331^{**}X_2 - 10.0687^{**}X_3 - 0.4399X_5 + 0.0013X_7$ (1.6755) (0.1130) (4.8075) (0.4318) (0.0430)	0.9817
6. $Y = 44.2939 - 2.8905X_1 + 1.6105^{**}X_2 - 14.3917^{*}X_3 + 13.5270X_4 - 0.4732X_5 - 0.0005X_7$ (1.7425) (0.1155) (5.7953) (12.4745) (0.4520) (0.0422)	0.9818
7. $Y = 43.6991 - 2.8685X_1 + 1.6103^{**}X_2 - 14.3865^{*}X_3 + 13.5767X_4 - 0.4384X_5 + 0.0063X_6 - 0.0033X_7$ (1.7749) (0.1167) (5.8557) (12.6096) (0.5255) (0.0473) (0.0521)	0.9815

* Significant at 0.05 level
** Significant at 0.01 level
Figures in parentheosis indicate the standard error.

Table 44. Summary results of the stepwise regression analysis for P fixing capacity of Kari soils

	R^{-2}
1. $Y = 84.3457 - 11.3553^{**}X_1$	0.9429
(0.7749)	
2. $Y = 58.1476 - 8.3265^{**}X_1 + 1.2035X_2$	0.9513
$(1.8536)\ (0.6790)$	
3. $Y = 56.9479 - 8.9771^{**}X_1 + 1.2677X_2 + 0.1712X_5$	0.9483
$(2.3594)\ (0.7149)\ (0.3603)$	
4. $Y = 63.1330 - 13.7607^{**}X_1 + 0.9855X_2 + 36.0393^{*}X_3 + 0.1790X_5$	0.9639
$(2.8201)\ (0.6111)\ (15.1663)\ (0.3021)$	
5. $Y = 63.2343 - 13.7145^{**}X_1 + 0.9827X_2 + 35.9714^{*}X_3 - 0.7821X_4 + 0.1766X_5$	0.9604
$(3.0281)\ (0.6449)\ (16.0039)\ (9.8503)\ (0.3198)$	
6. $Y = 47.0696 - 11.1712^{**}X_1 + 1.5308X_2 + 25.8056X_3 + 1.2169X_4 + 0.2564X_5 + 0.0728X_6$	0.9651
$(3.3571)\ (0.7173)\ (16.6681)\ (9.4044)\ (0.3070)\ (0.0504)$	
7. $Y = 42.3323 - 9.1744^{**}X_1 + 1.1591X_2 + 34.9260^{*}X_3 - 7.4518X_4 - 0.0075X_5 + 0.2376^{**}X_6 + 0.2075^{*}X_7$	0.9787
$(2.7691)\ (0.5854)\ (13.6553)\ (8.2228)\ (0.2651)\ (0.0736)\ (0.0855)$	

* Significant at 0.05 level
** Significant at 0.01 level
Figures in parentheses indicate the standard error.

Table 45. Summary results of the stepwise regression analysis for P fixing capacity of Kayal soils

	$\bar{R}^2$
1. $Y = 66.8399-1.7823^{**}X_5$ (0.6046)	0.4006
2. $Y = 68.7255-5.6313X_3-1.6143X_5$ (27.6656)(1.0375)	0.3568
3. $Y = 26.4711+13.8379X_1-17.4116X_3-2.2797X_5$ (20.3527) (33.1888) (1.4439)	0.3313
4. $Y = 149.2120-4.9844X_1-2.6405X_2-12.0949X_3-3.4599X_5$ (23.7155)(1.8888) (32.0627) (1.6221)	0.3897
5. $Y = 148.1450-3.3348X_1-2.6605X_2-16.3839X_3-3.5395X_5-0.0824X_6$ (25.9644) (1.9872) (38.6343) (1.7406) (0.3628)	0.3325
6. $Y = 123.2750+2.5151X_1-2.3468X_2-30.5561X_3+57.2512X_4-4.0873^{*}X_5-0.1091X_6$ (25.7245) (1.9512) (39.3538) (46.7959) (1.7526) (0.3539)	0.3753
7. $Y = 501.6910-58.9524X_1+1.0146X_2+31.9743X_3-29.4028X_4-1.7989X_5-4.8462^{*}X_6-4.9545X_7$ (29.9697) (1.9283) (37.6354) (47.7290) (1.5682) (1.7860) (1.8472)	0.6534

* Significant at 0.05 level
** Significant at 0.01 level
Figures in paranthcses indicate the standard error.

Table 46. Summary results of the stepwise regression analysis for P fixing capacity of Karapadam soils

	Equation	$\bar{R}^2$
1.	$Y = 20.6072 + 1.8722^{**}X_1$ (0.1545)	0.9073
2.	$Y = 18.7575 + 1.1774^{**}X_2 + 0.4916^{**}X_7$ (0.1696) (0.0989)	0.9642
3.	$Y = 32.5965 + 1.0952^{**}X_2 - 0.5103^{*}X_5 + 0.2587^{*}X_7$ (0.1461) (0.2033) (0.1253)	0.9742
4.	$Y = 48.0757 - 2.7109X_1 + 1.0273^{**}X_2 - 0.5594^{*}X_5 + 0.1666X_7$ (2.0669) (0.1532) (0.2014) (0.1407)	0.9757
5.	$Y = 59.6752 - 2.0338X_1 + 0.8726^{**}X_2 - 7.9914X_3 - 0.7437^{**}X_5 + 0.0669X_7$ (1.9972) (0.1061) (5.8313) (0.2364) (0.1541)	0.9775
6.	$Y = 57.1589 - 2.6405X_1 + 0.8573^{**}X_2 - 8.3040X_3 - 0.6860X_5 + 0.0266X_6 + 0.0943X_7$ (2.2278) (0.2040) (6.2250) (0.3335) (0.1068) (0.1951)	0.9756
7.	$Y = 64.7227 - 2.4720X_1 + 0.8007^{**}X_2 - 9.5645X_3 - 27.2065X_4 - 0.8172^{*}X_5 + 0.0250X_6 + 0.0131X_7$ (2.3090) (0.2224) (6.6956) (41.6510) (0.3963) (0.1100) (0.2363)	0.9744

* Significant at 0.05 level
** Significant at 0.01 level
Figures in parentheses indicate the standard error.

Table 47. Summary results of stepwise regression analysis for P fixing capacity of Coastal sandy alluvium soils

	Equation	$\bar{R}^2$
1.	$Y = 92.3676 - 11.2161^{**}X_1$ (1.6463)	0.8227
2.	$Y = 59.7074 - 8.2320^{**}X_1 + 2.8960X_2$ (2.1008) (1.4737)	0.8636
3.	$Y = 46.8237 - 6.2159X_1 + 3.1556X_2 - 0.1861X_5$ (3.4080) (1.5854) (0.3039)	0.8552
4.	$Y = 60.2915 - [illegible].8890X_1 + 2.8885X_2 + 28.8888X_3 - 0.1342X_5$ (6.3222) (1.7260) (51.7361) (0.3312)	0.8440
5.	$Y = 68.1790 - 10.5502X_1 + 2.8107X_2 + 40.6623X_3 - 0.0974X_5 - 0.1370X_7$ (9.3854) (1.8788) (72.0874) (0.3836) (0.5375)	0.8237
6.	$Y = 63.1879 - 9.9046X_1 + 3.2796X_2 + 2[illegible].8[illegible]44X_3 + 15.0039X_4 - 0.1133X_5 - 0.1933X_7$ (10.2739) (2.3707) (86.9090) (39.2481) (0.4163) (0.5982)	0.8001
7.	$Y = -38.5082 - 12.4454^{**}X_1 + 8.0707^{**}X_2 - 167.5950^{**}X_3 - 3.6143X_4 - 1.2122^{**}X_5 - 3.3013^{**}X_6 + 0.1597X_7$ (4.1464) (0.9232) (35.4900) (11.4326) (0.1869) (0.4344) (0.4344)	0.9845

* Significant at 0.05 level
** Significant at 0.01 level
Figures in parentheses indicate the standard error.

Table 48. Summary results of the stepwise regression analysis for P fixing capacity of Pokkali soils

		$\bar{R}^2$
1.	$Y = -24.8566+5.0234^{**}X_2$	0.9274
	(0.3628)	
2.	$Y = 10.5612+2.7165^{*}X_2-76.3467^{*}X_3$	0.9469
	(0.9627) (27.7810)	
3.	$Y = 16.1696+2.3404X_2-63.0540X_3-0.3155X_5$	0.9440
	(1.2863) (32.7221) (0.6878)	
4.	$Y = 14.1621-1.3919X_1+2.5769X_2-28.0274X_3-0.2514X_5$	0.9410
	(2.7696) (1.4060) (77.4194) (0.7199)	
5.	$Y = -1.4154-3.0701X_1+3.0207^{*}X_2-97.4517X_3+104.0910X_4+0.1290X_5$	0.9483
	(2.7999) (1.3483) (84.4266) (64.3918) (0.7157)	
6.	$Y = -1.8820-2.6874X_1+2.9907^{*}X_2-90.2271+96.0613X_4+0.1998X_5+0.0678X_6$	0.9443
	(3.1157) (1.4069) (63.0348) (70.9145) (0.7728) (0.1931)	
7.	$Y = 3.4195-3.7583X_1+2.9424X_2-80.5623X_3+96.2111X_4+0.0826X_5-0.0627X_6-0.1832X_7$	0.9395
	(4.5512) (1.4831) (106.0260) (74.2830) (0.8809) (0.4363) (0.5426)	

* Significant at 0.05 level
** Significant at 0.01 level
Figures in parentheses indicate the standard error.

Table 49. Summary results of the stepwise regression analysis for P fixing capacity of Kole soils

No.	Equation	$\bar{R}^2$
1.	$Y = 13.2504 + 1.4257^{**}X_2$	0.9757
	(0.0520)	
2.	$Y = 13.2645 + 1.1253^{**}X_2 + 0.0011X_6$	0.9754
	(0.0865) (0.0525)	
3.	$Y = 14.7615 + 1.3871^{**}X_2 - 0.1073X_5 + 0.0060X_6$	0.9744
	(0.1144) (0.2040) (0.0545)	
4.	$Y = 18.1260 + 1.2874^{**}X_2 - 5.6007X_3 - 0.0258X_5 + 0.0505X_6$	0.9747
	(0.1462) (5.2314) (0.2163) (0.0679)	
5.	$Y = 20.6340 - 0.6435X_1 + 1.2588^{**}X_2 - 4.1557X_3 - 0.0014X_5 + 0.0663X_6$	0.9734
	(1.5886) (0.1662) (6.5692) (0.2306) (0.0800)	
6.	$Y = 20.5825 - 0.8210X_1 + 1.2656^{**}X_2 - 9.7499X_3 + 8.6551X_4 + 0.0481X_5 + 0.0763X_6$	0.9740
	(1.5804) (0.1646) (8.1604) (7.6278) (0.2324) (0.0797)	
7.	$Y = 20.5816 - 0.8217X_1 + 1.2656^{**}X_2 - 9.7496X_3 + 8.6547X_4 + 0.0482X_5 + 0.0763X_6 + 0.0000X_7$	0.9720
	(1.7676) (0.1717) (8.8239) (8.5111) (0.2739) (0.0829) (0.0609)	

* Significant at 0.05 level

* Significant at 0.01 level

Figures in parentheses indicate the standard error.

The effect of pH was significant and its contribution in the total variation of the PFC was the highest (82 per cen in coastal sandy alluvium. In the final regression model, except MgO and clay, all the independent variables significantly influenced the PFC of the soil and all the variables taken together accounted for 99 per cent of the total change in PFC.

Among the seven independent variables R_2O_3 explained for the maximum change (92 per cent) in PFC followed by CaO in Pokkali soils. All the variables taken together explain more than 96 per cent on the total variation in PFC. In other words, the data give statistically good fit to the specified model.

In Kole soils, more than 97 per cent of the total variation in PFC was explained by R_2O_3 followed by organic matter. R_2O_3 significantly influenced the PFC of the soil.

4. Pattern of transformation of phosphorus under submergence

4.1. Influence of submergence on inorganic P fractions

The influence of submergence on inorganic P fractions in selected soils based on analysis of variance is given in Appendix V. The mean values for each P fraction under air dry as well as waterlogged conditions for various soil types and the percentage increase in P fractions due to waterlogging are presented in Table 50 to 57. The basic data on individual soils relating to these changes are presented in Appendix II.

4.1.1. Saloid P

The ANOVA revealed that there is significant difference in saloid P among different soil types.

Under air dry condition, the mean saloid P was lowest for coastal sandy alluvium (5.00 ppm) and highest for Kole soils (39.50 ppm). When submerged, the coastal sandy alluviu and Kole soils recorded the lowest (5.37 ppm) and highest (41.67 ppm) mean saloid P respectively. The difference between the means of saloid P for the two states viz., air dry and waterlogged, after 16 weeks was not significant though an increased trend has been noted under waterlogged condition. The mean saloid P for Kole soils was significantl superior over all other soil types which were on par.

The increase in saloid P due to waterlogging ranged from 4 per cent (Kayal soil, E Block) to 25 per cent (coastal sandy alluvium, Chalakudy) with an average of 7.19 per cent. However, even 25 per cent increase could not record significance.

Table 50. Mean Saloid-P (ppm) under air dry and waterlogged conditions.

Soil type	Conditions		Mean
	Air dry (C_1)	Waterlogged (C_2)	
Lateritic alluvium	16.50	17.53	17.02
Kari	16.50	17.37	16.94
Kayal	19.00	19.97	19.49
Karapadam	19.50	20.58	20.04
Coastal sandy alluvium	5.00	5.37	5.18
Pokkali	13.50	14.54	14.02
Kole	39.50	41.67	40.59
Mean	18.50	19.57	

CD (0.05) Conditions (C) = 8.9613

Soils (S) = 16.7650

C x S = 23.7095

Table 51. Mean Al-P (ppm) under air dry and waterlogged conditions.

Soil type	Conditions		Mean
	Air dry (C_1)	Waterlogged (C_2)	
Lateritic alluvium	163.10	182.84	172.97
Kari	21.05	25.50	23.28
Kayal	90.05	112.68	101.52
Karapadam	91.85	115.20	103.52
Coastal sandy alluvium	42.85	53.75	48.30
Pokkali	82.55	101.77	92.16
Kole	187.70	232.48	210.09
Mean	97.02	117.74	

CD (0.05) Conditions (C) = 107.12

Soils (S) = 200.40

C x S = 283.40

4.1.2. Al-P

The difference in Al-P due to soil types, conditions and the interactions between soil types and conditions was not significant. The lowest mean Al-P was recorded for Kari soils (21.05 and 25.50 ppm) and the highest for Kolo soils (187.70 and 232.48 ppm) respectively under air dry and waterlogged conditions. The differences between the mean values of Al-P for soil types, conditions and their interactions were also not significant.

The range of variation in percentage increase of Al-P due to submergence was from 11.01 (lateritic alluvium, Kunnappally) to 26.01 (Karapadam, Kidangara), the average being 23.02.

4.1.3. Fe-P

Significant variation was not observed in this fraction due to soil types, conditions and their interactions The lowest mean Fe-P (17.00 ppm) was noted for coastal sandy alluvium and the highest (204.50 ppm) for Kayal soils under air dry situation. The same soil types recorded the lowest (27.28 ppm) and highest (354.86 ppm) Fe-P under submerged condition. The difference between the mean values of Fe-P for Kayal and coastal sandy alluvial soils alone was found significant. Though waterlogging increased Fe-P in all soils

Table 52. Mean Fe-P (ppm) under air dry and waterlogged conditions.

Soil type	Conditions		Mean
	Air dry	Waterlogged	
Lateritic alluvium	97.50	145.00	121.25
Kari	112.00	156.56	134.28
Kayal	204.50	354.86	279.68
Karapadam	94.00	166.14	130.07
Coastal sandy alluvium	17.00	27.28	22.14
Pokkali	112.50	183.06	147.78
Kole	145.00	258.83	201.92
Mean	111.79	184.53	

CD (0.05) Conditions (C) = 103.25
Soils (S) = 193.16
C x S = 273.17

Table 53. Mean Ca-P (ppm) under air dry and waterlogged conditions

Soil type	Conditions		Mean
	Air dry	Waterlogged	
Lateritic alluvium	52.65	58.84	55.74
Kari	34.95	43.18	39.06
Kayal	116.35	119.89	118.12
Karapadam	73.20	80.38	76.79
Coastal sandy alluvium	21.75	22.59	22.17
Pokkali	24.50	25.27	24.88
Kole	25.10	26.37	25.73
Mean	49.79	53.79	

CD (0.05) Conditions (C) = 42.46
Soils (S) = 79.43
C x S = 112.33

the increase was not significant. The Fe-P of Kayal soils under waterlogged condition was superior to the one for coastal sandy alluvium both under air dry and waterlogged situations.

The lateritic alluvial soils (Kunnappally) showed the lowest percentage increase in Fe-P (38.00) due to waterlogging and the highest (107.67) by the same soil type (Vellayani). The average percentage increase in Fe-P for all soil types was 63.53.

4.1.4. <u>Ca-P</u>

The variation in Ca-P was not significant with respect to soil types, conditions and their interactions. Under both air dry and submerged conditions, the lowest and highest mean Ca-P were observed for coastal sandy alluvium and Kayal soils. The differences between the mean values of Ca-P for Kayal soils and coastal sandy alluvium, Pokkali and Kole soils were significant. The Ca-P was increased due to submergence but the increase was not significant. The interactions between soils and conditions were also not significant.

The percentage increase in Ca-P due to submergence was lowest (2.41) for coastal sandy alluvium (Karunagappally) and highest (14.20) for Kari soils (Kurichikeri), the average being 6.57.

4.1.5. Reductant P

The reductant P was not significantly different among various soils under diverse conditions studied. This P fraction was found to be lowest (29.00 ppm) for coastal sandy alluvium and highest (137.20 ppm) for Kayal soils in air dry situation and under submerged condition, these soils recorded the mean lowest (37.45 ppm) and highest (166.46 ppm) values. Kayal soils were superior to all the other soils except Karapadam. The difference between the mean values of reductant P for air dry and waterlogged conditions was not significant. The reductant P for Kayal soils under waterlogged situation was significantly superior to the one for coastal sandy alluvium both under air dry and submerged conditions.

The percentage increase in reductant P due to submergence ranged from 15.14 (lateritic alluvium, Vellayani) to 28.73 (Kole soils, Kanjanipadam) with an average of 23.92.

4.1.6. Occluded P

Significant variations due to soil types, conditions and the interactions between soils and conditions were not observed for this P fraction. The Kayal and coastal sandy alluvium recorded the highest and lowest mean values, 39.50 and 10.18 ppm respectively.

Table 54. Mean reductant-P (ppm) under air dry and waterlogged conditions.

Soil type	Conditions		Mean
	Air dry (C_1)	Waterlogged (C_2)	
Lateritic alluvium	52.65	65.14	58.89
Kari	74.10	39.78	56.94
Kayal	137.20	166.46	151.83
Karapadam	82.65	104.97	93.81
Coastal sandy alluvium	29.00	37.45	33.52
Pokkali	34.45	43.24	38.85
Kolo	39.10	49.22	44.16
Mean	64.25	72.32	

CD (0.05) Conditions (C) = 48.58
Soils (S) = 90.88
C x S = 128.52

Table 55. Mean Occluded-P (ppm) under air dry and waterlogged conditions.

Soil type	Conditions		Mean
	Air dry (C_1)	Waterlogged (C_2)	
Lateritic alluvium	26.40	27.01	26.71
Kari	17.15	17.58	17.36
Kayal	39.10	39.89	39.50
Karapadam	31.25	31.82	31.54
Coastal sandy alluvium	10.00	10.36	10.18
Pokkali	10.30	10.60	10.45
Kole	10.70	11.17	10.93
Mean	20.70	21.20	

CD (0.05) Conditions (C) = 17.69
Soils (S) = 33.09
C x S = 46.80

The coastal sandy alluvium (Chalakudy) showed the lowest percentage increase (1.56) in occluded P due to waterlogging and highest (4.50) by Kole soils (Enammakkal). The average percentage increase for all soils was 2.73.

4.1.7. Sum of inorganic P

The sum of inorganic P was not significantly different among various soil types under air dry and waterlogged conditions. The coastal sandy alluvium recorded the lowest mean value (141.49 ppm) and Kole soils, the highest (709.97 ppm). The same soil types showed the lowest and highest values under air dry and waterlogged conditions.

The percentage increase in sum of inorganic P due to submergence was lowest (18.24) for lateritic alluvial soils (Kunnappally) and highest (51.33) for the same soil type (Vellayani), the average being 32.33.

4.2. Contribution of each inorganic P fraction in the total variation due to submergence

The percentage contribution of each inorganic P fraction in the total variation due to submergence is given in Table 58.

Table 56. Mean sum of inorganic-P (ppm) under air dry and waterlogged conditions.

Soil type	Conditions		Mean
	Air dry (C_1)	Waterlogged (C_2)	
Lateritic alluvium	408.80	496.35	452.57
Kari	235.25	296.91	266.08
Kayal	606.20	813.75	709.97
Karapadam	392.45	519.09	455.77
Coastal sandy alluvium	126.20	156.70	141.49
Pokkali	277.80	378.47	328.14
Kole	447.10	619.72	533.41
Mean	356.26	468.72	

CD (0.05) Conditions (C) = 292.12
Soils (S) = 546.51
C x S = 772.88

Table 57. Percentage increase of inorganic P fractions due to submergence

Sl. No.	Soil type	Location	Saloid P	Al-P	Fe-P	Ca-P	Reductant P	Occluded P	Sum of inorganic P	Total variation
1.	Lateritic alluvium	Vellayani	5.00	25.49	107.67	2.54	15.14	2.38	51.33	158.22
2.	"	Kunnoppally	6.71	11.01	38.00	12.29	24.30	2.31	18.24	94.62
3.	Kari	Karuvatta	6.25	21.23	50.60	9.15	23.29	2.16	38.03	109.68
4.	"	Kurichikari	4.96	20.99	32.80	14.20	19.79	2.52	22.73	95.26
5.	Kayal	Mathikayal (West)	6.00	25.02	68.90	3.40	25.90	2.29	30.93	131.51
6.	"	E Block (East)	4.00	25.19	75.00	2.90	19.50	1.90	35.58	128.49
7.	Karapadam	Moncompu	5.00	23.45	56.00	6.20	20.99	3.02	26.97	114.66
8.	"	Kidangara	8.00	26.01	86.00	19.40	28.30	1.61	33.98	160.32
9.	Coastal sandy alluvium	Chalakudy	25.00	24.24	56.00	11.97	25.65	1.56	30.81	144.42
10.	"	Karunagappally	4.80	25.75	64.00	2.41	26.73	3.93	22.37	127.62
11.	Pokkali	Panangad	6.00	24.67	58.65	3.16	29.26	3.47	39.35	125.21
12.	"	Maradu	7.96	22.99	64.20	3.11	24.59	2.84	35.34	125.69
13.	Kole	Kanjanipadam	5.00	22.20	39.00	3.13	29.73	3.72	24.61	102.78
14.	"	Enamakkal	6.00	24.00	92.53	7.18	24.69	4.50	42.14	158.90

4.2.1. Saloid P

The contribution from saloid P in the total variation due to submergence ranged from 3.11 per cent (Kayal soils, E Block) to 17.31 per cent (coastal sandy alluvium, Chalakudy) with an average of 5.64 per cent.

4.2.2. Al-P

The Al-P contributed 11.64 per cent (lateritic alluvium, Kunnappally) to 22.03 per cent (Kari soils, Kurichikari) in the total variation due to waterlogging the soils. The average percentage contribution of Al-P in the total variation due to submergence was 18.29.

4.2.3. Fe-P

In all the soil types, the contribution of Fe-P in the total change due to submergence was the highest, ranging from 34.43 per cent (Kari soils, Kurichikari) to 68.05 per cent (lateritic alluvium, Vellayani), the average being 48.93 per cent.

4.2.4. Ca-P

The Ca-P was responsible for the total variation due to waterlogging only by 1.61 per cent in a lateritic alluvium (Vellayani) to 14.91 per cent in a Kari soil (Kurichikari) with an average being at 5.52 per cent.

Table 58. Contribution of each P fraction (percentage) in the total variation due to submergence

Sl. No.	Soil type	Location	Percentage contribution of each P fraction in the total variation						
			Saloid-P	Al-P	Fe-P	Ca-P	Reductant P	Occluded-P	Total variation
1.	Lateritic alluvium	Vellayani	3.16	16.11	68.05	1.61	9.57	1.50	150.22
2.	"	Kunnappally	7.09	11.64	40.16	12.99	25.68	2.44	94.62
3.	Kari	Karuvatta	5.70	19.36	46.13	8.34	18.50	1.97	109.68
4.	"	Kurichikari	5.21	22.03	34.43	14.91	20.77	2.65	95.26
5.	Kayal	Mathikayal	4.56	19.03	52.39	2.59	19.69	1.74	131.51
6.	"	E Block	3.11	19.60	58.37	2.26	15.18	1.48	128.49
7.	Karapadam	Ambcompu	4.36	20.45	40.84	5.41	18.31	2.63	114.66
8.	"	Kidangara	4.99	16.22	53.64	6.49	17.65	1.00	160.32
9.	Coastal sandy alluvium	Chalakudy	17.31	16.78	38.78	8.29	17.76	1.08	144.42
10.	"	Karunagappally	3.76	20.18	50.15	1.89	20.94	3.08	127.62
11.	Pokkali	Panangad	4.79	19.70	46.84	2.52	23.37	2.77	125.21
12.	"	Maradu	6.33	18.29	51.08	2.47	19.56	2.26	125.69
13.	Kole	Kanjanipadam	4.86	21.60	37.95	3.05	28.93	3.62	102.78
14.	"	Enamakkal	3.78	15.10	58.23	4.52	15.54	2.83	156.90

4.2.5. Reductant P

The contribution from reductant P to the total change consequent to submergence ranged from 9.57 per cent in a lateritic alluvium (Vellayani) to 29.93 per cent in a Kole soil (Kanjanipadam). The average contribution by this fraction to the total variation due to submergence was 19.39 per cent.

4.2.6. Occluded P

This fraction of P contributed the lowest, ranging from 1.00 per cent (Karapadam, Kidangara) to 3.62 per cent (Kole soils, Kanjanipadam) and the average share in the total change was 2.22 per cent.

4.3. Effect of submergence on available P by different extractants in different soil types

The ANOVA of the available P for different soil groups by four different extractants under air dry and waterlogged conditions is given in Appendix VI. The mean values of available P by four different methods under both air dried and waterlogged conditions for different soils studied are presented in Table 59.

The ANOVA indicates significant difference in available P extracted by various methods, due to different soil types, condition of extraction and the interaction between method of extraction and condition of extraction.

Table 59. Mean available P (ppm) in various soil types under air dry and waterlogged conditions by different extracts.

	Lateritic alluvium	Kari	Kayal	Karapadam	Coastal sandy alluvium	Pokkali	Kole	Air dry	Waterlogged	Mean (M)
Bray 1	11.66	0.54	2.10	5.93	7.15	12.28	5.30	5.17	7.74	6.45
Bray 2	15.25	1.00	2.60	7.36	1[illegible].24	24.66	7.03	8.23	12.69	10.46
Olsen	5.80	0.34	1.09	2.38	4.48	7.44	2.12	2.92	4.15	3.54
Truog	25.43	2.89	3.76	15.76	22.51	53.64	6.67	8.09	29.23	16.66
Mean (S x C)	14.58	1.19	2.41	7.86	12.35	24.70	5.2[illegible]	6.10	13.45	-
Air dry	9.11	1.26	1.66	4.35	8.48	14.12	3.74	-	-	-
Water-logged	20.07	1.13	3.15	11.35	16.21	35.45	6.82	-	-	-

C.D. (0.05) for comparison between soils = 10.26

" Methods (M) = 0.21

(C x M) = 21.72

The difference between the mean values of available P under air dry and waterlogged conditions was found to be significant. The air dry soils recorded the lowest mean available P (6.10 ppm) and submerged soils, the highest (13.45 ppm).

Among the methods, the lowest mean value for available P (3.54 ppm) was obtained for Olsen (M_3) method and the highest (18.66 ppm) for Truog (M_6) method. The available P as determined by Truog's method was significantly higher to those by Olsen and Bray I.

Kari soils recorded the lowest mean available P (1.19 ppm) and Pokkali soils, the highest (24.78 ppm). The differences between the mean values of available P obtained for Pokkali soils and the one for Kari, Kayal, Karapadam, coastal sandy alluvium and Kole soils were also significant. The available P for lateritic alluvium soils was significantly superior to Kari and Kayal soils.

Table 60 summarises the percentage increase in available P due to submergence observed for different extractants and for different soil types.

Table 60. Percentage increase in available P in different soil types by four extractants due to submergence.

Sl. No.	Soil type		Percentage increase in available P			
			Bray 1	Bray 2	Olsen	Truog
1.	Lateritic alluvium	Vellayani	50.00	61.81	53.06	220.00
2.	"	Kunnappally	64.99	65.00	53.99	250.02
3.	Kari	Kuruvatta	60.00	87.86	60.71	220.00
4.	"	Kurichikari	71.42	84.51	77.27	217.65
5.	Kayal	Mathikayal (West)	58.77	45.83	51.72	160.00
6.	"	E Block (East)	63.77	48.96	51.30	177.37
7.	Karapadom	Moncompu	59.75	59.95	100.00	516.94
8.	"	Kidangara	56.95	52.77	93.05	289.92
9.	Coastal sandy alluvium	Chalakudy	22.92	64.93	14.74	226.08
10.	"	Karunagappally	24.83	64.05	22.95	149.12
11.	Pokkali	Panangad	25.72	43.33	35.23	359.97
12.	"	Maradu	44.12	26.01	27.32	406.53
13.	Kole	Kanjanipadam	80.00	71.06	67.79	124.00
14.	"	Enamakkal	53.94	84.90	53.90	100.00

4.3.1. Bray I

The percentage increase in available P by Bray I extractant due to submergence ranged from 22.92 (coastal sandy alluvium, Chalakudy) to 80.00 (Kole soils, Kanjanipadam) with an average of 52.58.

4.3.2. Bray II

Pokkali soils (Maradu) recorded the lowest percentage increase of available P (26.01) due to waterlogging and Kole soils (Enamakkal), the highest (84.90) and the average being 61.14.

4.3.3. Olsen

The percentage increase of available P due to submergenc was found to be lowest (14.74) for coastal sandy alluvium (Chalakudy) and highest (100.00) for Karapadam soils (Moncompu). The average increase in available P obtained by this method was 54.51.

4.3.4. Truog

Kole soils (Enamakkal) showed the lowest percentage increase of available P (100.00) by Truog's method due to waterlogging and Karapadam (Moncompu), the highest (516.94) with an average of 244.11 per cent.

4.4. Relationship between percentage increase in available P by various methods and percentage increase of different inorganic P fractions due to submergence

Table 61 shows the inter-correlation metrix between porcentage increase in available P estimated by Bray 1, Bray 2, Olsen and Truog's methods and percentage increase in various inorganic P fractions due to submergence of seven soil types under study. It has been observed that none of the correlations is significant.

5. Response of rice to graded doses of phosphorus

5.1. Available P by different extractants at various growth stages of the crop

The ANOVA (Appendix VIII) for available P determined by 4 extractants indicated significant variations due to varieties, treatments, and their interactions at 30th day after sowing for Bray I and Bray II extractants. The effects due to varieties and the interactions between treatments and varieties were not significant for Olsen and Truog's methods respectively.

At 60th day after sowing, significant influences due to varieties and treatments were noted for Bray I, Bray II and Olsen's methods. V x T interactions did not show any significant effect on available P as determined by Bray I

Table 61. Inter-correlation matrix between percentage increase in available P estimated by different methods and percentage increase in inorganic P fractions due to submergence.

	Bray 1	Bray 2	Olsen	Truog	Saloid P	Al-P	Fe-P	Ca-P	Reductant-P	Occluded P
Bray 1	1.000	0.018	0.714	-0.179	-0.502	-0.413	-0.244	0.187	-0.240	-0.086
Bray 2	-	1.000	0.112	0.430	-0.021	0.034	-0.048	-0.034	-0.266	-0.123
Olsen	-	-	1.000	0.253	-0.453	-0.120	-0.049	0.273	-0.192	-0.104
Truog	-	-	-	1.000	0.027	-0.043	-0.122	0.019	-0.069	-0.162
Saloid P	-	-	-	-	1.000	0.116	-0.003	0.415	0.201	-0.413
Al-P	-	-	-	-	-	1.000	0.585	-0.486	0.053	0.057
Fe-P	-	-	-	-	-	-	1.000	-0.413	-0.255	0.011
Ca-P	-	-	-	-	-	-	-	1.000	-0.077	-0.417
Reductant-P	-	-	-	-	-	-	-	-	1.000	0.313
Occluded P	-	-	-	-	-	-	-	-	-	1.000

and Olsen but responded to Bray II and Truog's methods. Significant differences for Truog's extractant due to varieties were also observed.

Varieties, treatments and the interactions among them were significant for Bray I, Bray II and Olsen's extractants.

The mean available P determined by different extractants at various growth stages is given in Table 62 to 64.

The mean available P in soil was low in pots grown with Mashoori variety at all stages of growth and by all extractants except by Truog's method at harvest stage. The available P by all methods tended to decrease with the progress of the crop.

Mashoori was found to be superior to Jyothi in its ability to utilise soil P by recording a low available P in soil by all methods at harvest stage. Among the methods tried, Truog's method recorded the soil available P as highest followed by Bray II, Olsen and Bray I methods irrespective of the varieties. Generally, with the exception of Truog's method, all the methods recorded highest values for soil available P on 30th day after sowing and the lowest at harvest stage, but the declining trend was less marked with the progress of the crop indicating a correspondence of the peak period of absorption or uptake of P with the maximum tillering stage of the crop.

Table 62. Mean estimates of available P (ppm) by different extractants at 30^{th} day after sowing.

	V_1	V_2	Mean	M_1	M_2	M_3	M_4	Mean
T_1	6.54	5.55	6.04	2.48	3.28	4.32	14.10	6.04
T_2	7.51	8.22	7.86	5.23	7.52	8.92	9.81	7.86
T_3	10.75	8.16	9.45	7.81	10.85	10.09	9.08	9.45
T_4	16.10	11.35	13.72	10.00	14.25	14.48	16.19	13.72
T_5	17.18	11.10	14.14	11.05	17.04	13.41	14.26	14.14
T_6	20.13	18.74	19.43	13.55	18.37	13.51	32.32	19.43
Mean	13.04	10.52	-	8.49	11.88	10.79	15.96	
M_1	9.72	7.25						
M_2	13.61	10.16						
M_3	11.99	9.58						
M_4	16.03	15.09						

C.D. (0.05) for comparison of Methods (M) = 1.0793

" Treatments (T) = 1.3219

" (M x T) = 2.6437

" (V) = 0.7632

" (T x V) = 1.8694

With regards to the treatment effects, there was an increase in available P as the dose increased at all growth stages by all methods except Truog. T_1 showed the lowest mean available P by various methods and T_6, the highest by all methods except Truog.

At 30th day after sowing, V_1T_1 and V_2T_1 recorded the lowest mean available P while V_1T_6, the highest value for Bray I. The mean available P estimated by Bray II was lowest for V_2T_1 and highest for V_1T_6. For Olsen's extractant, the lowest and highest mean values for available P were obtained for V_2T_1 and V_1T_5 respectively. The interactions V_2T_3 and V_2T_6 recorded the lowest and highest mean available P by Truog's method.

On 60th day, the mean available P by Bray I extractant were lowest and highest for the interactions V_2T_2 and V_1T_6 respectively. The interactions V_2T_1 and V_1T_6 respectively recorded the lowest and highest mean P values by Bray II and Olsen's methods. The available P estimated by Truog's method were lowest and highest for the interactions V_2T_1 and V_1T_3 respectively.

At harvest stage, the interactions V_2T_1 and V_1T_6 respectively recorded the lowest and highest mean available P by Bray I and Bray II methods. The lowest and highest mean

Table 63. Mean estimates of available P (ppm) by different extractants at 60[th] day after sowing.

	V_1	V_2	Mean	M_1	M_2	M_3	M_4	Mean
T_1	5.09	3.86	4.48	2.04	2.87	2.67	10.32	4.48
T_2	6.11	4.51	5.31	2.56	4.25	3.86	10.58	5.31
T_3	9.19	7.44	8.32	5.92	8.09	8.64	10.63	8.32
T_4	9.39	8.39	9.14	6.79	9.94	10.39	9.44	9.14
T_5	11.87	9.42	10.65	8.77	12.21	11.69	9.93	10.65
T_6	14.36	11.49	12.92	12.20	16.22	12.56	10.72	12.92
Mean	9.42	7.52	-	6.38	8.93	8.30	10.27	-

	V_1	V_2
M_1	6.91	5.84
M_2	9.63	8.23
M_3	9.26	7.34
M_4	11.87	8.67

C.D. for comparison between Methods (M) (0.05) = 0.5443

" Treatments (T) = 0.6666

" Varieties (V) = 0.3849

" (M x T) = 1.3333

" (M x V) = 0.7698

Table 64. Mean estimates of available P (ppm) by different extractants at harvest stage.

	V_1	V_2	Mean	M_1	M_2	M_3	M_4	Mean
T_1	6.00	6.31	6.15	0.98	1.34	1.57	20.74	6.15
T_2	6.12	4.94	5.53	1.67	2.97	3.27	14.42	5.53
T_3	9.67	9.32	9.49	4.50	6.04	5.75	21.69	9.49
T_4	9.71	10.65	10.18	5.31	7.45	7.19	20.78	10.18
T_5	13.25	11.55	12.40	7.84	11.12	9.31	21.34	12.40
T_6	13.02	12.62	12.82	8.17	11.26	10.78	21.07	12.82
Mean	9.63	9.23	-	4.74	6.70	6.31	20.01	

	V_1	V_2	
M_1	5.22	4.27	C.D. for comparison between Methods (0.05) (M) = 1.1920
M_2	7.23	6.09	" Treatments (T) = 1.4598
M_3	6.70	5.92	" (M x T) = 2.9197
M_4	19.36	20.65	

available P were observed by Olsen's extractant for V_2T_1 and V_2T_6 respectively. As regards Truog's method V_2T_2 and V_1T_5 respectively showed the mean lowest and highest values for available P.

Apart from analysing the data independently for each method, a combined analysis (Appendix IX) of the methods was conducted to find out whether any of the methods tried and varieties or various treatments used behave independent of the estimated available P.

On the 30th day after sowing the available P was significantly different for the various methods of estimation. A marked increase in available P was noted by using Truog's extractant (15.96 ppm) and a significantly low value with Bray I (8.49 ppm) though the estimation of P was different for Bray II and Olsen's methods.

T_6 contributed maximum for available P (19.43 ppm) and T_1, the least (6.04 ppm). The treatments T_4 and T_5 were on par. T_2 and T_3, though contributed less to available P, were superior to T_1.

Estimates of available P for T_2, T_3 and T_4 gave more or less the same result when extractants Bray II, Olsen and Truog are used. While a high estimate of P was obtained for treatments T_1 and T_6 by Truog's methods. Bray II also gave a high value compared to Bray I and Olsen for T_6 and T_5. For T_1, all the methods except Truog were on par and the estimates were significantly low compared to the available P by Truog. However, Bray I was found to estimate low P values in all the cases.

The same samples of soil grown to Jyothi variety were found to contain more available P than the same soil after the same period grown to Mashoori. No interaction was noted for varieties and methods of estimation. But significant interaction was obtained for variety with treatments. T_1, T_2 and T_6 gave more or less similar results for both the varieties as far as the available P values are concerned. But, for other treatments, the available P was significantly high for Jyothi than that of Mashoori.

The available P estimates on the 60th day after sowing differed significantly for all the 4 methods tried. As given previously high value (10.27 ppm) of P was obtained by Truog's method and low value by Bray I (6.38 ppm). Though the estimates by Bray II and Olsen's extractants differed significantly.

When treatments are compared, T_6 gave the highest available P value (12.92 ppm) while T_1, the lowest value (4.48 ppm) and the P estimate by T_6 was significantly superior to the estimates given by other treatments. It was found to increase with the increase in the level of applied P.

When method of extraction and treatment interactions are compared, no significant difference could be noted either for available P estimated by Bray II and Olsen or for any of the treatments except T_6. For T_6, Bray II was found to be superior to other methods of extraction. The P estimate was significantly high for T_1, T_2 and T_3 when estimated by Truog's method. Except Bray I, all other methods give almost similar estimates for T_4. The available P was high for T_6 by Bray II (16.22 ppm) and low for T_1 by Bray I (2.04 ppm) and for T_5, Bray I and Truog were on par. Samples taken from soils grown with Mashoori recorded a significantly lower (7.52 ppm) available P status than the same soil grown with Jyothi (9.42 ppm).

For both the varieties, Bray I gave the least estimate of P while Truog, the highest. Bray II and Olsen estimated P more or less at the same level in soils grown with Jyothi while the estimate made by Olsen method was significantly low with that of Bray II for this variety. Also no significant difference in P estimates was obtained for Bray II and Truog's methods for Mashoori. No significant interaction was seen for variety and treatments at this stage.

During the harvest stage also significant differences in P estimates were observed by various methods of estimation and for various treatments. As in the previous case, the highest estimate was given by Truog (20.01 ppm) and the lowest by Bray I (4.74 ppm). No significant difference in P estimate was shown by Bray II and Olsen.

When treatments are compared, the highest P estimate was obtained for the highest level of applied P but the lowest for T_2. But no significant difference in the estimate of P was obtained between T_1 and T_2, T_3 and T_4 and T_5 and T_6.

Significant interactions were noted for treatments with methods of extraction. Bray II and Olsen gave more or less similar estimates at all the applied doses of P. The highest was recorded for Truog and lowest for Bray I for all treatments. The highest P estimate was recorded by Truog for T_5 (21.34 ppm) which was not significantly different from other estimates obtained for the treatment under Truog except for T_2. The estimate obtained for T_2 by Truog was significantly low with the other estimates for various treatments by Truog.

Samples taken from soils grown to Jyothi and Mashoori did not show any significant difference in the estimate of

P at this stage. No significant interaction was noted for variety x treatment and variety x method of extraction. However, higher estimates were obtained for both the variety by the Truog's method.

5.2. <u>Inorganic P fractions at various growth stages</u>

The abstracts of ANOVA for inorganic P fractions at various growth stages are given in Appendix X. Significant influence on all the inorganic P fractions of soil was recorded due to the treatments at 30th day after sowing. The effects due to variety, and the interaction between variety and treatments were not significant.

At 60th day after sowing, significant variation in all the P fractions except reductant P was noted due to treatments. Varietal influence on Al-P and the interaction influence on Fe-P, Ca-P and sum of inorganic P were also significant.

The effects of variety and treatments were significant on saloid P, Al-P, occluded P and sum of inorganic P at harvest stage. Varietal variation on reductant P and treatment variation on Fe-P were also observed. The V x T interaction was significant on Al-P and occluded P contents at this stage.

Table 65. Mean inorganic P fractions (ppm) at 30th day after sowing.

(i) Saloid P / (ii) Al-P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	2.15	3.65	4.20	4.80	5.25	5.15	4.20	25.00	29.95	33.15	38.80	41.60	51.05	36.50
V_2	2.15	3.45	4.25	4.70	5.16	5.50	4.20	24.95	29.35	32.75	38.75	42.10	51.10	36.50
Mean	2.15	3.55	4.23	4.75	5.20	5.33	-	24.98	29.65	32.95	38.78	41.85	51.08	-

C.D. for comparison between		Saloid P	Al-P
(0.05)	Varieties (V)	= 0.15	0.52
"	Treatments (T)	= 0.23	0.90
"	V x T	= 0.38	1.27

(iii) Fe-P / (iv) Ca-P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	31.05	74.20	85.90	93.35	119.45	129.85	88.97	6.15	10.55	12.75	15.15	17.30	20.90	13.80
V_2	30.85	75.10	89.00	93.10	111.35	124.70	87.35	6.75	9.95	13.45	15.45	17.45	21.35	14.07
Mean	30.95	74.65	87.45	93.23	115.40	127.28	-	6.45	10.25	13.10	15.30	17.38	21.12	-

C.D. for comparison between		Fe-P	Ca-P
(0.05)	Varieties (V)	= 3.45	0.29
"	Treatments (T)	= 5.98	0.51
"	V x T	= 8.46	0.72

Contd..........

(v) Reductant P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	7.80	9.00	9.70	10.15	10.35	10.85	9.64
V_2	7.90	8.40	9.75	10.40	10.35	11.10	9.65
Mean	7.85	8.70	9.73	10.28	10.35	10.98	-

(vi) Occluded P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	2.80	3.05	4.15	4.15	4.95	4.95	4.01
V_2	2.85	3.20	4.15	4.25	4.95	5.20	4.10
Mean	2.83	3.13	4.15	4.20	4.95	5.08	-

		(v)	(vi)
C.D. for comparison between Varieties (0.05)	(V)	= 0.31	0.20
"	Treatments (T)	= 0.04	0.34
"	V x T	= 0.77	0.48

(vii) Sum of inorganic P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	74.95	130.40	149.85	166.40	193.90	222.85	156.38
V_2	75.45	129.45	153.35	166.65	191.40	218.65	155.83
Mean	75.20	129.93	151.60	166.53	192.65	220.70	-

C.D. for comparis-on between Varieties (V) = 2.52
(0.05) " Treatments (T) = 4.36
" V x T = 6.17

The means of P fractions in soil at various growth stages are given in Table 65 to 67.

At 30th day after sowing the mean saloid P, Al-P, Fe-P, Ca-P, reductant P, occluded P and sum of inorganic P in soils grown with Jyothi and Mashoori varieties of paddy were 4.20 and 4.20, 36.59 and 36.50, 88.97 and 87.35, 13.80 and 14.07, 9.64 and 9.65, 4.01 and 4.10, and 156.36 and 155.83 ppm respectively. The differences between the mean values for all the P fractions obtained for the two varieties were not significant.

With regard to treatments on P fractions, the control pots recorded lowest values and those pots received highest dose, the highest values. The values for the control pots and the pots with highest dose were 2.15 and 5.33, 24.98 and 51.08, 30.95 and 127.28, 6.45 and 21.12, 7.85 and 10.98, 2.83 and 5.08, and 75.20 and 220.70 ppm for saloid P, Al-P, Fe-P, Ca-P, reductant P, occluded P and sum of inorganic P respectively. Significant differences in P fractions due to treatments were observed in all combinations except T_6 and T_5 for saloid P, T_4 and T_3 for Fe-P and T_6 and T_5, T_4 and T_3, and T_2 and T_1 for occluded P.

Among the interactions V_1T_1 and V_2T_1 recorded the lowest mean saloid P and V_2T_6, the highest. The Al-P was lowest for V_2T_1 and highest for V_2T_6. In the case of Fe-P, V_2T_1 and V_1T_6 showed the lowest and highest mean values respectively. The interactions V_1T_1 and V_2T_6 respectively recorded the lowest and highest mean values both for Ca-P and reductant P. The sum of inorganic P was lowest for V_1T_1 and highest for V_1T_6.

The mean saloid P, Al-P, Fe-P, Ca-P, reductant P, occluded P and sum of inorganic P at 60th day after sowing Jyothi and Mashoori varieties of paddy were 2.77 and 3.17, 37.48 and 36.42, 93.37 and 94.35, 13.85 and 14.03, 8.10 and 8.53, 3.17 and 3.07, and 159.90 and 159.57 ppm respectively. Excepting for Al-P, the differences between the mean values obtained for all the P fractions due to varieties were not significant.

With regard to the influence of treatments on P fractions, the mean values for saloid P, Al-P, Fe-P, Ca-P, reductant P, occluded P and sum of inorganic P recorded by the soil samples from the pots with zero P fertilization and highest dose of P were 1.35 and 4.15, 25.30 and 51.45, 34.00 and 134.10, 6.20 and 21.60, 6.65 and 10.05, 1.80 and 4.00, and 75.30 and 225.35 ppm respectively. Significant differences could not be obtained between T_5 and T_6 for saloid P, T_3 and T_4 for Fe-P, T_5 and T_6, and T_3 and T_4 for occluded P. The other combinations showed significant

Table 66. Mean inorganic P fractions (ppm) at 60th day after sowing.

(i) Saloid P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	1.30	1.50	3.20	2.30	4.10	4.20	2.77
V_2	1.40	2.40	3.10	3.90	4.10	4.10	3.17
Mean	1.35	1.95	3.15	3.10	4.10	4.15	-

(ii) Al-P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	25.20	30.60	33.80	39.30	43.50	52.50	37.48
V_2	25.40	29.50	33.00	39.00	41.20	50.40	36.42
Mean	25.30	30.05	33.40	39.15	42.35	51.45	-

C.D. for comparison between Varieties

C.D. (0.05)		Saloid P	Al-P
for comparison between Varieties	(V)	= 0.67	0.53
" Treatments	(T)	= 1.16	0.92
" V x T		= 1.64	1.30

(iii) Fe-P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	33.10	83.50	91.50	97.00	118.10	137.00	93.37
V_2	34.90	82.80	94.80	107.40	115.00	131.20	94.35
Mean	34.00	83.15	93.15	102.20	116.55	134.10	-

(iv) Ca-P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	6.00	10.60	13.00	15.40	17.10	21.00	13.85
V_2	6.40	9.70	13.10	15.30	17.50	22.20	14.03
Mean	6.20	10.15	13.05	15.35	17.30	21.60	-

C.D. for comparison between Varieties

C.D. (0.05)		Fe-P	Ca-P
for comparison between Varieties	(V)	= 2.40	0.31
" Treatments	(T)	= 4.16	0.53
" V x T		= 5.88	0.76

Contd..........

(v) Reductant P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	6.50	8.30	9.00	4.70	9.70	10.40	8.10
V_2	6.80	7.70	8.10	9.30	9.60	9.70	8.53
Mean	6.65	8.00	8.55	7.00	9.65	10.05	-

(vi) Occluded P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	1.80	2.80	3.20	3.40	3.70	4.10	3.17
V_2	1.80	2.60	2.90	3.40	3.80	3.90	3.07
Mean	1.80	2.70	3.05	3.40	3.75	4.00	-

C.D. (0.05) for comparison between		Reductant P	Occluded P
Varieties	(V)	= 1.64	0.14
" Treatments	(T)	= 2.86	0.24
" V x T		= 4.04	0.33

(vii) Sum of inorganic P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	73.90	138.30	153.70	168.10	196.20	229.20	159.90
V_2	76.70	134.70	155.00	178.30	191.20	221.50	159.57
Mean	75.30	136.50	154.35	173.20	193.70	225.35	-

C.D. for comparison between Varieties (V) = 2.14
(0.05) " Treatments (T) = 3.71
" V x T = 5.25

differences in P fractions due to treatments.

Among the interactions, V_1T_1 and V_1T_6 respectively recorded the lowest and highest mean values for saloid P, Al-P, Fe-P, reductant P and sum of inorganic P. The lowest mean values of Ca-P was obtained for V_1T_1 and highest for V_2T_6. The occluded P obtained for V_1T_1 was lowest and the one for V_2T_1, the highest.

In the harvest stage, the mean saloid P, Al-P, Fe-P, Ca-P, reductant P, occluded P and sum of inorganic P in pots with Jyothi and Mashoori paddy varieties were 2.77 and 1.88, 31.98 and 26.07, 87.98 and 86.01, 13.26 and 12.66, 7.92 and 6.03, 1.78 and 0.77, and 146.77 and 134.67 ppm respectively.

As far as the influence of treatments on P fractions, the values for the control pots and the pots with highest dose were 0.95 and 3.45, 20.03 and 37.48, 29.32 and 127.78 5.90 and 20.70, 5.53 and 8.95, 0.43 and 1.80, and 62.20 and 200.15 ppm for saloid P, Al-P, Fe-P, Ca-P, reductant P, occluded P and sum of inorganic P respectively.

With regards to the interaction effects, excepting for Ca-P, the lowest and highest values for all the P fractions were recorded for V_2T_1 and V_1T_6 respectively.

Table 67. Mean inorganic P fractions (ppm) at harvest stage.

(i) Saloid P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	1.05	2.35	3.10	3.65	2.45	4.00	2.77
V_2	0.85	1.35	1.40	2.15	2.65	2.90	1.88
Mean	0.95	1.85	2.25	2.90	2.55	3.45	-

(ii) Al-P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	22.05	29.35	30.85	32.65	37.10	39.85	31.98
V_2	18.00	20.50	25.15	26.80	30.85	35.10	26.07
Mean	20.03	24.93	28.00	29.73	33.98	37.48	-

C.D. for comparison between Varieties (0.05)

		(i)	(ii)
(V)	=	0.61	0.42
" Treatments (T)	=	1.06	0.03
" V x T	=	1.50	1.60

(iii) Fe-P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	30.70	75.60	86.95	94.55	111.05	129.05	87.90
V_2	27.95	71.90	86.15	97.15	106.40	126.50	86.01
Mean	29.32	73.75	86.55	95.85	108.73	127.78	-

(iv) Ca-P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	6.05	11.05	13.85	15.90	12.10	20.60	13.26
V_2	5.75	8.95	10.90	13.40	16.15	20.80	12.66
Mean	5.90	10.00	12.38	14.65	14.13	20.70	-

C.D. for comparison between Varieties (0.05)

		(iii)	(iv)
(V)	=	2.42	1.85
" Treatments (T)	=	4.19	3.20
V x T	=	5.93	4.52

Contd.........

(v) Reductant P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	5.85	7.65	7.85	8.25	8.55	9.35	7.92
V_2	5.20	6.40	3.55	4.15	8.35	8.55	6.03
Mean	5.53	7.03	5.70	6.20	8.45	8.95	-

(vi) Occluded P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	0.70	1.40	1.90	2.00	2.30	2.40	1.78
V_2	0.25	0.55	0.70	0.85	1.05	1.20	0.77
Mean	0.48	0.98	1.30	1.43	1.68	1.80	-

C.D. (0.05)		Reductant P	Occluded P
for comparison between Varieties	(V) =	1.86	0.13
" Treatments	(T) =	3.22	0.23
" V x T	=	4.55	0.32

(vii) Sum of inorganic P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	66.40	127.40	144.50	157.00	180.05	205.25	146.77
V_2	58.00	109.65	131.85	148.00	165.45	195.05	134.67
Mean	62.20	118.53	138.18	152.50	172.75	200.15	-

C.D. for comparison between Varieties (0.05) (V) = 2.77
" Treatments (T) = 4.80
" V x T = 6.79

In the case of Ca-P, V_2T_1 showed the lowest value and V_2T_6, the highest.

5.3. Biometric and yield characteristics at various growth stages

The abstracts of ANOVA for the biometric characteristics at 30th day and 60th day after sowing for height of plant, number of tillers per hill, total number of roots per hill, maximum length of roots, average length of roots and total dry matter per hill and the biometric and yield characteristics such as height of plant, number of productive tillers, weight of roots, weight of grain, weight of straw and total dry matter per hill at harvest stage of the crop are given in Appendix XI.

Significant influences due to variety, treatments and their interaction on height of plant, weight of roots per hill and total dry matter per hill were recorded at all the stages of observation. The influences due to variety, treatments and their interactions on the total number of roots per hill were significant on the 30th day after sowing. On the 60th day, the influence due to treatment alone was significant on the total number of roots per hill. The maximum length of roots was significantly influenced by variety, treatments and their interactions on the 30th and 60th day after sowing. The effect of treatments alone was significant on the average length of roots both at

30th and 60th day after sowing. The influence due to variety and the interaction between variety and treatments were not significant.

Significant influence on grain and straw yields per hill by variety, treatments and their interaction was also observed.

The mean height of plant, number of tillers per hill, weight of roots per hill, total number of roots per hill, maximum length of roots, average length of roots and total dry matter per hill at 30th day and 60th day after sowing are presented in Tables 68 and 69 respectively. The Table 70 shows the average values of height of plant, number of productive tillers per hill, weight of roots per hill, weight of grain per hill, weight of straw per hill and total dry matter per hill at harvest stage.

5.3.1. Height of plant (cm)

The mean height of plant for Jyothi and Mashoori varieties at 30th day, 60th day and at harvest stage were 67.3 and 65.1, 74.5 and 106.5, and 86.7 and 120.3 respectively. The height of plant increased substantially by 60th day after sowing. The lowest and highest mean values on 30th, 60th day and at harvest stages were 45.4 and 76.4, 72.0 and 102.5, and 92.0 and 107.5 respectively for the control treatment and the treatment with the highest dose of phosphorus. Among the interactions V_1T_1 and V_2T_6 showed the lowest and highest mean height of plant respectively at all stages of observation.

5.3.2. Number of tillers per hill

Jyothi produced lesser number of tillers compared to Mashoori, the mean values being 6.5, 8.8 and 9.8 for Jyothi at 30th day, 60th day and at harvest stages respectively, and 6.8, 12.7 and 14.2 for Mashoori respectively at the above three stages. The lowest (0.75) and highest (11.5) number of tillers at 30th day after sowing were obtained for the control pots and the pots with highest dose of P (120 Kg P_2O_5/ha) respectively. At 60th day and at harvest stage the lowest and highest mean number of tillers were recorded for the control pots and 60 Kg P_2O_5/ha, the values being 7.0 and 13.0, and 8.0 and 14.0 respectively. There was a reduction in the number of tillers/hill for 90 and 120 Kg P_2O_5/ha. But the treatments T_4, T_5 and T_6 were at par. As regards to the interactions, V_2T_1 and V_2T_6 produced the lowest (0.5) and highest (12.0) mean number of tillers/hill at 30th day after sowing. On the 60th day after sowing V_1T_1 and V_1T_2 recorded the lowest (6.0) mean number of tillers, the highest (15.0) by V_2T_5 and V_2T_6. The lowest (7.0) mean number of tillers was obtained for V_1T_1 and the highest (17.0) for the interactions V_2T_5 and V_2T_6 at harvest stage.

5.3.3. Weight of roots (g/hill)

The mean weight of roots for Jyothi and Mashoori at 30th day, 60th day and at harvest stages were 3.66 and 4.84, 7.58 and 13.55, and 8.60 and 14.16 respectively. The varieties differed significantly with respect to this character. The control pots recorded the lowest weight of roots where as the highest value by the highest P dose (120 kg/ha); the mean weight of roots for the control and the highest P dose at 30th day, 60th day and at harvest stage being 0.28 and 8.95, 1.85 and 16.38, and 2.30 and 18.19 respectively. Among the interactions V_1T_1 and V_2T_6 respectively produced the lowest (0.10) and highest (10.50) quantity of roots at 30th day after sowing. On the 60th day, V_2T_1 and V_2T_6 showed the lowest (1.45) and highest (22.45) quantity of roots respectively. The interactions V_2T_1 and V_2T_6 respectively recorded the lowest (1.68) and highest (23.05) quantity of roots at harvest stage.

5.3.4. Total number of roots/hill

The mean total number of roots/hill for Jyothi and Mashoori at 30th day and 60th day after sowing were 112.83 and 144.00, and 333.50 and 360.00 respectively. Due to superimposition of treatment viz., phosphorus, the lowest and highest values obtained for control and highest dose of P at 30th day and 60th day after sowing were respectively 43.50 and 234.00, and 153.00 and 481.00. V_1T_1 and V_2T_6 recorded the lowest and highest total number of roots/hill at 30th and 60th day after sowing, the values being 41 and 255 at 30th day, and 116 and 533 at 60th day after sowing.

5.3.5. Maximum length of roots (cm)

The mean maximum length attained by roots of Jyothi and Mashoori at 30th day and 60th day after sowing were 23.32 and 27.87, and 29.60 and 36.50 respectively. With regards to the effect of treatments, the plants in the control pots and the one with the highest dose of P (120 kg P_2O_5/ha) at 30th and 60th day after sowing recorded the minimum and maximum length of roots (11.15 and 34.85, and 30.5 and 35.5) respectively. V_1T_1 and V_2T_6 were the variety x treatment combinations with the lowest and highest values for root length at 30th and 60th day after sowing. The values were 10.80 and 36.70 cm respectively for V_1T_1 and V_2T_6 at the 30th day. At 60th day V_1T_1 obtained the lowest (30.0) value for the length of roots and V_2T_5 and V_2T_6 the highest (41.0).

5.3.6. <u>Average length of roots</u> (cm)

The average length of roots by Jyothi and Mashoori at 30th and 60th day after sowing were 17.93 and 16.85, and 16.83 and 21.17 respectively. Due to the influence of treatments, the values for control pots and the one with highest dose of P at 30th and 60th day after sowing were 10.95 and 22.55, and 11.50 and 27.00 respectively. The interactions V_2T_2 and V_2T_6 obtained the lowest (8.90) and highest (22.60) values respectively for this character at 30th day and V_1T_1 and V_2T_6 respectively showed the lowest (11.00) and highest (33.00) values at 60th day after sowing.

5.3.7. <u>Total dry matter</u> (g/hill)

The mean quantity of total dry matter produced by Jyothi and Mashoori at 30th day, 60th day and at harvest stage were 5.06 and 7.61, 32.22 and 37.58, and 50.22 and 84.01 respectively. The differences between the mean values were significant. The average values of this character due to treatments were lowest for the control pots at all stages of observation, the values being 0.68, 13.20 and 31.20 at 30th day, 60th day and at harvest stage respectively. The highest quantity of dry matter was produced by T_6 at 30th day, T_4 at 60th day and T_6 at harvest stage, the quantity being 12.70, 46.50 and

86.95 respectively. The differences between the means due to treatments were significant. Among the interactions V_1T_1 recorded the lowest quantity of dry matter both at 30th day (0.50) and at harvest stage (24.22), while V_2T_1 obtained the lowest quantity (10.30) at 60th day after sowing. The highest quantities (14.20, 54.00 and 113.55) of dry matter were produced respectively for the 30th day, 60th day and harvest stages by the treatment combination V_2T_6.

5.3.8. Grain yield (g/hill)

Mashoori out yielded Jyothi by 5.15. Jyothi recorded grain yield of 20.07 whereas Mashoori 25.22. The difference between the means was significant. The lowest yield (11.25) obtained for the control pot and the highest (27.50) by the treatment receiving the highest dose of P. The treatments T_5 and T_6 were, however at par. Substantial increase in grain yield was not obtained after the third dose of P (45 kg P_2O_5/ha). With regard to interactions, V_1T_1 recorded the lowest grain yield (10.10) and V_2T_6, the highest (32.40).

5.3.9. Straw yield (g/hill)

The mean straw yield by Jyothi and Mashoori varieties were 21.55 and 44.63. The superiority of Mashoori over

Table 68. Influence of phosphorus on the biometric charecteristics at 30th day after sowing.

(i) Height of plant (cm)

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	44.50	65.50	69.50	73.50	75.00	76.00	67.33
V_2	46.20	62.50	65.20	68.00	71.90	76.80	65.10
Mean	45.35	64.00	67.35	70.75	73.45	76.40	-

(ii) Number of tillers/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	1.0	3.0	5.5	8.5	10.0	11.0	6.5
V_2	0.5	3.0	5.0	9.5	11.0	12.0	6.8
Mean	0.7	3.0	5.3	9.0	10.5	11.5	-

C.D. (0.05) for comparison between		(i)	(ii)
"	Varieties (V)	1.28	0.63
"	Treatments (T)	2.22	0.63
"	V x T	3.14	0.89

(iii) Weight of roots (g)/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	0.10	0.45	1.50	5.90	6.60	7.40	3.66
V_2	0.45	1.30	2.50	6.50	7.80	10.50	4.84
Mean	0.28	0.88	2.00	6.20	7.20	8.95	-

(iv) Total number of roots/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	41.0	76.0	89.0	116.0	142.0	213.0	112.8
V_2	46.0	71.0	87.0	180.0	225.0	255.0	144.0
Mean	43.5	73.5	88.0	148.0	183.5	234.0	-

C.D. (0.05) for comparison between		(iii)	(iv)
"	Varieties (V)	0.22	8.75
"	Treatments (T)	0.37	5.56
"	V x T	0.53	21.44

Contd..........

(v) Maximum length of roots (cm)

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	10.80	20.90	24.10	25.10	26.00	33.00	23.32
V_2	11.50	24.10	28.70	31.90	34.30	36.70	27.87
Mean	11.15	22.50	26.40	28.50	30.15	34.85	-

(vi) Average length of roots (cm)

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	10.30	15.20	18.20	20.30	21.10	22.50	17.93
V_2	11.60	8.90	17.40	19.40	21.20	22.60	16.85
Mean	10.95	12.05	17.80	19.85	31.15	22.55	-

C.D. for comparison between		(v)	(vi)
(0.05) Varieties	(V)	= 0.84	1.83
" Treatments	(T)	= 1.45	3.18
" V x T		= 2.05	4.49

(vii) Total dry matter (g)/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	0.50	0.75	2.20	7.55	8.15	11.20	5.06
V_2	0.85	2.55	8.30	9.15	10.60	14.20	7.61
Mean	0.68	1.65	5.25	8.35	9.38	12.70	-

C.D. for comparison between Varieties (V) = 0.08
(0.05) " Treatments (T) = 0.13
" V x T = 0.19

Table 69. Influence of phosphorus on the biometric characteristics at 60th day after sowing.

(i) Height of plant (cm)

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	65.00	69.00	82.00	84.00	73.00	74.00	74.50
V_2	79.00	87.00	102.00	117.00	123.00	131.00	106.50
Mean	72.00	78.00	92.00	100.50	98.00	102.50	-

(ii) Number of tillers/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	6.0	6.0	11.0	12.0	9.0	9.0	8.8
V_2	8.0	10.0	14.0	14.0	15.0	15.0	12.7
Mean	7.0	8.0	12.5	13.0	12.0	12.0	-

C.D. (0.05) for comparison between		(i)	(ii)
Varieties	(V)	= 1.62	1.36
" Treatments	(T)	= 2.81	2.35
" V x T		= 3.98	-

(iii) Weight of roots (g)/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	2.25	3.31	9.11	10.09	10.44	10.30	7.58
V_2	1.45	7.04	12.70	16.60	21.05	22.45	13.55
Mean	1.85	5.18	10.91	13.35	15.75	16.38	-

(iv) Total number of roots/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	116.0	220.0	390.0	422.0	424.0	429.0	333.5
V_2	190.0	280.0	239.0	431.0	487.0	533.0	360.0
Mean	153.0	250.0	314.0	426.0	455.0	481.0	-

C.D. (0.05) for comparison between		(iii)	(iv)
Varieties	(V)	= 0.16	56.30
" Treatments	(T)	= 0.23	97.51
" V x T		= 0.40	137.90

Contd.........

(v) Maximum length of roots (cm)

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	30.0	28.0	32.0	31.0	28.0	30.0	29.6
V_2	31.0	33.0	35.0	38.0	41.0	41.0	36.5
Mean	30.5	30.5	33.5	34.5	34.5	35.5	-

(vi) Average length of roots (cm)

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	11.0	14.0	11.0	24.0	20.0	21.0	16.8
V_2	12.0	18.0	14.0	19.0	31.0	33.0	21.2
Mean	11.5	16.0	12.5	21.5	25.5	27.0	-

C.D. for comparison between Varieties (0.05)

		(v)	(vi)
Varieties	(V)	=1.15	6.21
" Treatments	(T)	=2.00	10.75
" V x T		=2.81	15.20

(vii) Total dry matter (g)/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	16.10	18.10	41.10	45.10	36.20	36.70	32.22
V_2	10.30	19.00	45.20	47.90	49.10	54.00	37.58
Mean	13.20	18.55	43.15	46.50	42.60	45.35	-

C.D. for comparison between Varieties (0.05)

Varieties	(V)	= 0.50
" Treatments	(T)	= 0.86
" V x T		= 1.22

Table 70. Influence of phosphorus on the biometric and yield characteristics at harvest stage.

(i) Height of plant (cm)

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	78.0	86.0	92.0	95.0	84.0	85.0	86.7
V_2	106.0	111.2	121.1	125.2	128.3	130.0	120.3
Mean	92.0	98.6	106.6	110.1	106.2	107.5	-

(ii) Number of productive tillers/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	7.0	8.0	12.0	12.0	10.0	10.0	9.8
V_2	9.0	11.0	15.0	16.0	17.0	17.0	14.2
Mean	8.0	9.5	13.5	14.0	13.5	13.5	-

C.D. for comparison between (0.05)		(i)	(ii)
Varieties	(V)	0.92	1.59
" Treatments	(T)	1.59	2.76

(iii) Weight of roots (g)/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	2.72	3.69	9.65	10.77	11.53	13.25	8.60
V_2	1.88	7.60	13.49	17.45	21.50	23.05	14.16
Mean	2.30	5.65	11.57	14.11	16.52	18.15	-

(iv) Weight of grain (g)/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	10.10	17.30	23.60	24.50	22.30	22.60	20.07
V_2	12.40	19.50	26.40	28.40	32.20	32.40	25.22
Mean	11.25	18.40	25.00	26.45	27.25	27.50	-

C.D. for comparison between (0.05)		(iii)	(iv)
Varieties	(V)	0.11	0.28
" Treatments	(T)	0.19	0.48
"	V x T	0.27	0.68

Contd..........

(iv) Weight of straw (g)/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	11.40	16.40	26.10	26.40	24.50	24.50	21.55
V_2	23.90	32.00	45.00	51.70	57.10	58.10	44.63
Mean	17.65	24.20	35.50	39.05	40.80	41.30	-

(v) Total dry matter (g)/hill

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	24.22	37.39	59.35	61.67	58.33	60.35	50.22
V_2	38.18	59.10	84.89	97.55	110.80	113.55	84.01
Mean	31.20	48.25	72.12	79.61	84.57	86.95	-

C.D. for comparison between Varieties

C.D. (0.05)		(iv)	(v)
for comparison between Varieties	(V) =	0.30	0.48
" Treatments	(T) =	0.53	0.83
"	V x T =	0.77	1.17

Jyothi was observed. With regards to the influence of treatments on this character, the control pots recorded the lowest straw yield (17.65) and the highest dose of P, the highest yield (41.40). The increase in straw yield was not prominent after the 4th dose of P (60 kg P_2O_5/ha). There was no significant difference between the means for T_5 and T_6. Among the interactions V_1T_1 and V_2T_6 recorded the lowest (11.40) and highest (58.10) straw yield respectively.

5.4. P uptake (mg P_2O_5/pot)

The abstract of ANOVA for P uptake at various growth stages of the crop are given in Appendix XII. The total P uptake was highly influenced by variety, treatments and the interaction between variety and treatments at 30th day, 60th day and at harvest stage of the crop.

The data on mean P uptake at various growth stages of the crop are presented in Table 71.

The mean P uptake by Jyothi and Mashoori varieties at 30th day, 60th day and at harvest stage were respectively 33.32 and 42.57, 38.30 and 49.86, and 34.31 and 44.66. The maximum uptake by these two varieties was observed at the 60th day after sowing.

Table 71. Influence of phosphorus on the P uptake (mg P_2O_5/pot) by rice at various growth stages.

(i) 30th day after sowing

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	22.25	29.60	33.05	36.75	38.80	39.49	33.32
V_2	30.66	37.65	40.13	46.30	49.48	51.20	42.57
Mean	26.46	33.63	36.59	41.53	44.14	45.35	-

C.D. (0.05) for comparison between Varieties (V) = 0.35
C.D. (0.05) for comparison between Treatments(T) = 0.61
C.D. (0.05) for comparison between V x T = 0.86

(ii) 60th day after sowing

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	27.55	35.65	37.89	41.08	43.35	44.30	38.30
V_2	38.69	44.30	47.17	53.97	56.40	58.61	49.86
Mean	33.12	39.98	42.53	47.53	49.88	51.46	-

C.D. (0.05) for comparison between Varieties (V) = 0.54
C.D. (0.05) for comparison between Treatments(T) = 0.93
C.D. (0.05) for comparison between V x T = 1.32

(iii) Harvest stage

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	24.20	30.34	33.47	37.60	39.23	41.00	34.31
V_2	32.60	38.39	42.41	49.05	52.13	53.40	44.66
Mean	28.40	34.37	37.94	43.33	45.68	47.20	-

C.D. (0.05) for comparison between Varieties (V) = 0.21
C.D. (0.05) for comparison between Treatments(T) = 0.37
C.D. (0.05) for comparison between V x T = 0.52

With regard to the influence of treatments on P uptake, the lowest and highest values at 30th day, 60th day and at harvest stage were 26.46 and 45.35, 33.12 and 51.46 and 28.40 and 47.20 respectively. Increase in P uptake was recorded as the dose of P was increased at all stages of observation. The percentage uptake was highest for T_2 (30 kg P_2O_5/ha) and the increase in dose decreased the percentage uptake of P.

Among the interactions, V_1T_1 and V_2T_6 recorded the lowest and highest mean P uptake at all stages, the values being 22.25 and 51.20, 27.55 and 51.46, and 24.20 and 53.40 respectively.

5.5. Relation between available P estimated by different extractants and inorganic P fractions

Correlation coefficients and the stepwise regression analysis between available P estimated by four different methods (Bray I, Bray II, Olsen and Truog) and inorganic P fractions at various growth stages of the crop were worked out and presented in Table 72 and 73 respectively.

The available P estimated by all the four methods except by Truog, was positively and significantly correlated with all the inorganic P fractions at all

Table 72. Correlation coefficients between inorganic P fractions and available P by different extractants at various growth stages of the crop.

Inorganic P fractions	30th day after sowing				60th day after sowing				Harvest stage			
	Bray 1	Bray 2	Olsen	Truog	Bray 1	Bray 2	Olsen	Truog	Bray 1	Bray 2	Olsen	Truog
Saloid P	0.88**	0.88**	0.78**	0.44*	0.87**	0.89**	0.86**	-0.07	0.89**	0.88**	0.87**	-0.23
Al-P	0.90**	0.90**	0.69**	0.72**	0.98**	0.98**	0.85**	0.02	0.92**	0.91**	0.90**	-0.22
Fe-P	0.91**	0.91**	0.72**	0.50*	0.90**	0.90**	0.82**	-0.05	0.92**	0.92**	0.94**	0.10
Ca-P	0.90**	0.89**	0.71**	0.63**	0.96**	0.96**	0.85**	-0.02	0.95**	0.95**	0.97**	-0.03
Reductant-P	0.86**	0.85**	0.71**	0.52**	0.90**	0.92**	0.87**	0.04	0.91**	0.91**	0.91**	-0.15
Occluded-P	0.87**	0.86**	0.66**	0.50*	0.91**	0.93**	0.86**	0.03	0.73**	0.73**	0.70**	-0.36
Sum of inorganic-P	0.91**	0.91**	0.73**	0.56**	0.93**	0.94**	0.85**	-0.03	0.94**	0.94**	0.95**	0.02

* Significant at 0.05 level

** Significant at 0.01 level.

Table 73. Summary results of the stepwise regression analysis for available P by Bray 1 (Y_1), Bray 2 (Y_2), Olsen (Y_3) and Truog's (Y_4) methods and the inorganic {Saloid-P (X_5), Al-P (X_6), Fe-P (X_7), Red-P (X_8), Ca-P (X_9) and Occluded-P (X_{10})} P fractions at various growth stages of the crop.

Equation	R^2
I. 30th day after sowing	
(i) $Y_1 = -2.1423 + \underset{(0.0120)}{0.1209^{**}}X_7$	0.907
(ii) $Y_1 = -4.7299 + \underset{(0.0308)}{0.0730^{**}}X_7 + \underset{(0.1111)}{0.1860}X_6$	0.914
(i) $Y_2 = -2.8960 + \underset{(0.1111)}{0.1682^{**}}X_7$	0.903
(ii) $Y_2 = 5.5549 + \underset{(0.0454)}{0.1190^{*}}X_7 + \underset{(0.1637)}{0.1911}X_6$	0.904
(i) $Y_3 = -1.9394 + \underset{(0.5185)}{3.0261^{**}}X_5$	0.779
(ii) $Y_3 = 1.8424 + \underset{(1.4306)}{5.3839^{**}}X_5 + \underset{(1.9036)}{3.1911}X_{10}$	0.801
(i) $Y_4 = -4.0990 + \underset{(0.1401)}{0.5203^{**}}X_6$	0.621
(ii) $Y_4 = -27.9453 + \underset{(0.6237)}{2.6688^{**}}X_6 - \underset{(1.1199)}{3.9238^{**}}X_9$	0.771
(iii) $Y_4 = -33.4850 + 2.0993^{**}X_6 - \underset{(1.4502)}{5.0836^{*}}X_9 + \underset{(2.7096)}{3.4500}X_8$	0.778
(iv) $Y_4 = -44.6154 + \underset{(0.6967)}{2.6566^{**}}X_6 - \underset{(1.8103)}{4.0342^{*}}X_9 + \underset{(2.8005)}{3.5175}X_8 - \underset{(3.8307)}{3.5634}X_{10}$	0.777
II. 60th day after sowing	
(i) $Y_1 = -8.1246 + \underset{(0.0177)}{0.3947}X_6$	0.979
(i) $Y_2 = -10.6076 + \underset{(0.0224)}{0.5287^{**}}X_6$	0.981
(i) $Y_3 = -16.6840 + \underset{(0.3733)}{3.1044^{**}}X_8$	0.871
(ii) $Y_3 = -15.3375 + \underset{(0.9451)}{2.0529^{*}}X_8 + \underset{(0.1297)}{0.1566}X_6$	0.874
(iii) $Y_3 = -17.5194 + \underset{(2.0457)}{2.5066^{*}}X_8 + \underset{(0.1301)}{0.1680}X_6 - \underset{(0.7071)}{0.7153}X_5$	0.875

* Significant at 0.05 level

** Significant at 0.01 level.

contd

(i)	$Y_4 = 10.8643 - \underset{(0.3616)}{0.1957}X_5$	0.115
(ii)	$Y_4 = 9.3611 - \underset{(0.6825)}{0.3682}X_5 + \underset{(0.9838)}{1.1397^{*}}X_{10}$	0.174
(iii)	$Y_4 = 6.9968 - \underset{(0.6625)}{0.9511}X_5 + \underset{(2.0865)}{4.0355}X_{10} - \underset{(0.0488)}{0.0608}X_7$	0.307

III. <u>Harvest stage</u>

(i)	$Y_1 = 2.4479 + \underset{(0.0375)}{0.5407^{**}}X_9$	0.951
(ii)	$Y_1 = -2.4234 + \underset{(0.0762)}{0.4315^{**}}X_9 + \underset{(0.3542)}{0.5761}X_5$	0.955
(i)	$Y_2 = -3.3822 + \underset{(0.0537)}{0.7510^{**}}X_9$	0.948
(i)	$Y_3 = -2.6219 + \underset{(0.0362)}{0.6664^{**}}X_9$	0.969
(i)	$Y_4 = 22.2014 - \underset{(0.6326)}{1.1318}X_{10}$	0.356
(ii)	$Y_4 = 20.2193 - \underset{(0.7513)}{2.3055^{*}}X_{10} + \underset{(0.0170)}{0.0409^{*}}X_7$	0.534
(iii)	$Y_4 = 40.7204 + \underset{(0.9189)}{0.2687}X_{10} + \underset{(0.0376)}{0.1702^{**}}X_7 - \underset{(1.2610)}{4.0342^{**}}X_8$	0.744

* Significant at 0.05 level

** Significant at 0.01 level.

growth stages of the crop. The Truog's-P was observed to be significantly correlated with inorganic P fractions only at 30th day after sowing.

In the regressions, it has been observed that Fe-P accounted for about 90 per cent of the total variation in the available P estimated by both Bray I and Bray II, Saloid P by 78 per cent for Olsen and Al-P by 62 per cent by Truog's method at 30th day after sowing. At 60th day of the crop, about 98 per cent in the total variation of the available P estimated by Bray I and Bray II methods was explained by Al-P, reductant P by 87 per cent for Olsen and saloid P by 12 per cent for Truog's method. The Ca-P fraction was observed to be responsible for about 95 per cent of the total variation in available P estimated by Bray I and Bray II while it was about 97 per cent by this fraction for Olsen's P and 36 per cent by occluded P for the P estimated by Truog's method at the harvest stage.

5.6. Relation between the available P estimated by different extractants and biometric or yield characteristics.

The relationship between biometric and yield characteristics with the available P estimated by Bray I, Bray II, Olsen and Truog methods were worked out and the corresponding correlation coefficients are given in Table 74. The summary results of the stepwise regression for total dry matter, grain and straw yield with the P estimated by the four extractants are presented in Table 75 and 76.

At 30th day after sowing, significant positive correlations were obtained between the available P estimated by all the four methods and various characters of the crop except the correlations for the available P estimated by Truog's method with the maximum length of roots and with total P uptake.

The relationships between all the characters and the P estimated by Bray I, Bray II and Olsen methods were positive but with the Truog's P it was negative at 60th day after sowing. No significant correlation was observed between total dry matter and Truog's P. At harvest stage, the correlations between available P by Bray I, Bray II and Olsen's methods and grain yield were significant but no significant correlation was observed for Truog's P and grain yield. Significant correlations were obtained between available P estimated by the four different methods with total dry matter and with total P uptake but the relationship for the Truog's P with these characters was significant only at 0.05 level.

Table 74. Correlation coefficients between biometric or yield characteristics with available P by various methods at different growth stages of U'c crop.

Biometric or yield characteristics	Available P by different methods											
	30th day after sowing				60th day after sowing				Harvest stage			
	Bray 1	Bray 2	Olsen	Truog	Bray 1	Bray 2	Olsen	Truog	Bray 1	Bray 2	Olsen	Truog
Ht. of plant	0.87**	0.87**	0.77**	0.42*	0.35	0.34	0.23	-0.60*	0.12	0.12	0.16	0.54**
No. of tillers/hill	0.88**	0.87**	0.74**	0.55**	0.45*	0.45*	0.40	-0.52*	0.48*	0.49*	0.51*	0.44*
Wt. of roots/pot	0.79**	0.78*	0.65**	0.68**	0.67**	0.67**	0.57**	-0.37	0.75**	0.75**	0.77**	0.35
Total No. of roots/hill	0.74**	0.72**	0.53**	0.61**	0.83*	0.84	0.77*	-0.19	-	-	-	-
Max. length of roots	0.73**	0.72**	0.61**	0.39	0.28	0.26	0.09	-0.56**	-	-	-	-
Average length of roots	0.92**	0.91**	0.76**	0.52**	0.65**	0.65**	0.56**	-0.36	-	-	-	-
Total drymatter (g/hill)	0.75**	0.75**	0.57**	0.61**	0.71**	0.73**	0.71**	-0.16	0.58**	0.59**	0.61**	0.43*
Grain yield (g/pot)	-	-	-	-	-	-	-	-	0.72**	0.72**	0.74**	0.27
Straw yield (g/pot)	-	-	-	-	-	-	-	-	0.42*	0.42*	0.46*	0.52*
Total P uptake (mg/pot)	0.55*	0.55**	0.48*	0.36	0.57**	0.57**	0.46*	-0.60**	0.64**	0.65**	0.68**	0.46*

* Significant at 0.05 level

** Significant at 0.01 level

Table 75. Summary results of the stepwise regression analysis for total drymatter (Y) and the available P estimated by Bray 1 (X_1), Bray 2 (X_2), Olsen (X_3) and Truog's (X_4) methods at various growth stages of the crop.

	$\bar{R}^2$
I. <u>30th day after sowing</u>	
(i) $Y = 1.7310 + \underset{(0.2665)}{0.6522^{*}}X_1$	0.463
II. <u>60th day after sowing</u>	
(i) $Y = 14.7130 + \underset{(0.4526)}{2.2599^{**}}X_2$	0.729
(ii) $Y = 32.1080 + \underset{(0.4401)}{2.3191^{**}}X_2 - \underset{(1.1169)}{1.7457}X_4$	0.749
(iii) $Y = 31.2540 + \underset{(1.0086)}{1.4857}X_2 - \underset{(1.1212)}{1.7634}X_4 + \underset{(1.1114)}{1.0216}X_3$	0.747
III. Harvest stage	
(i) $Y = 34.9769 + \underset{(1.3966)}{5.1060^{**}}X_3$	0.615
(ii) $Y = -56.5696 + \underset{(1.2819)}{4.7483^{**}}X_3 + \underset{(1.9210)}{4.5018^{*}}X_4$	0.696

* Significant at 0.05 level

** Significant at 0.01 level

Table 76. Summary results of the stepwise regression analysis for grain yield (Y_1) and straw yield (Y_2) with the available P estimated by Bray 1 (X_1), Bray 2 (X_2), Olsen (X_3) and Truog's (X_4) methods at harvest stage.

		$\bar{R}^2$
(i)	$Y_1 = 13.2702 + \underset{(0.2901)}{1.4895^{**}} X_3$	0.738
(ii)	$Y_1 = 2.1507 + \underset{(0.2883)}{1.4456^{**}} X_3 + \underset{(0.4321)}{0.5468} X_4$	0.747
(i)	$Y_2 = -39.7013 + 3.4912^{*} X_3$	0.512
(ii)	$Y_2 = 44.3413 + \underset{(1.1418)}{3.1640^{*}} X_3 + \underset{(0.7617)}{1.8183^{**}} X_4$	0.627

* Significant at 0.05 level

** Significant at 0.01 level

The regressions for available P by the above four methods and total dry matter indicate that about 46 per cent of the total variation in dry matter produced at 30th day of the crop was accounted by Bray 1-P, 73 per cent of the total variation in dry matter at 60th day by Bray 2-P and about 62 per cent of the total variation in dry matter by Olsen's P at the harvest stage of the crop.

When the P estimated by all the four methods was regressed with grain as well as straw yield, it was observed that about 74 and 51 per cent of the total variation respectively in grain and straw yields have been observed to be explained by Olsen's P.

In the regressions for total P uptake and the available P estimated by the four methods (Table 77) it has been observed that about 55 per cent of the total variation in the P uptake was explained by Bray 1-P at 30th day after sowing, about 60 per cent of the total variation in P uptake was due to Truog's-P at 60th day after sowing and about 68 per cent of the total variation in P uptake was explained by Olsen's P at harvest stage of the crop.

5.7. Relation between biometric and yield characteristics with inorganic P fractions

The correlation coefficients between biometric as well as yield characteristics with the inorganic P

Table 77. Summary results of the stepwise regression analysis for P uptake (Y) and available P estimated by Bray 1 (X_1), Bray 2 (X_2), Olsen (X_3) and Truog's (X_4) methods at different growth stages of the crop.

	R^{-2}
I. <u>30th day after sowing</u>	
(i) $Y = 28.7591 + 1.0828^{**}X_1$ $(0.3490)_1$	0.552
(ii) $Y = 30.2654 + 1.3341X_1 - 0.2439X_4$ $(0.4327)_1 \; (0.2479)_4$	0.552
II. <u>60th day after sowing</u>	
(i) $Y = 73.2177 - 2.8379^{**}X_4$ $(0.8047)_4$	0.601
(ii) $Y = 65.8848 - 3.1075^{**}X_4 + 1.5716^{**}X_1$ $(0.5099)_4 \; (65.8348)_1$	0.864
III. <u>Harvest stage</u>	
(i) $Y = 28.6380 + 1.7240^{**}X_3$ $(0.4006)_3$	0.676
(ii) $Y = -1.6053 + 1.6052^{**}X_3 + 1.4872^{**}X_4$ $(0.3516)_3 \; (0.5269)_4$	0.767

* Significant at 0.05 level

** Significant at 0.01 level

fractions at various growth stages of the crop are presented in Table 78 and the summary results of the stepwise regression for total dry matter produced with inorganic P fractions and total P uptake in Table 79.

At 30th day after sowing significant positive correlations were obtained between the inorganic P fractions and all the characters studied. Similar is the case with respect to the relationship obtained on 60th day after sowing except the correlation between maximum length of roots with Al-P, Fe-P, reductant P, occlded P and sum of inorganic P. At harvest stage, the grain yield was well correlated with all the P fractions except occluded P and the relationships between straw yield with Fe-P, Ca-P and sum of inorganic P were alone significant; the total P uptake was significantly correlated with Fe-P, reductant P and sum of inorganic P at this stage of the crop.

The regressions for total dry matter with all the inorganic P fractions and total P uptake at various growth stages indicate that about 68 per cent of the total variation in the dry matter produced was explained by P uptake followed by Fe-P at 30th day after sowing and about 82 per cent of the total variation in dry matter produced was explained by Ca-P and then Al-P, both accounting for about 90 per cent in the total variation on the dry matter produced at 60th day after sowing.

Table . 78 Correlation Coefficients between biometric or yield characteristics with inorganic P fractions at Various growth stages of the crop

Sl. No.	Biometric/yield characteristics	Inorganic P fractions																				
		30th day after sowing							60th day after sowing							Harvest stage						
		Saloid P	Al-P	Fe-P	Ca-P	Red-P	Occluded P	Sum of inorganic P	Saloid P	Al-P	Fe-P	Ca-P	Red-P	Occl-P	Sum of inorganic P	Saloid P	Al P	Fe-P	Ca-P	Red-P	Occluded P	Sum of inorganic P
1.	Height of Plant (Cm)	.96**	.85**	.96**	.91**	.90**	0.85**	.94**	.51*	.42*	.49*	.53**	.38	.46*	.48*	-.22	-.17	.20	.15	.15	-.50*	.16
2.	No. of tillers/hill	.95**	.90**	.93**	.97**	.93**	0.94**	.95**	.65**	.48*	.58**	.60**	.50*	.57**	.57**	.18	.22	.58**	.49*	.39	-.11	.51*
3.	Weight of roots (g/pot)	.87**	.94**	.65**	.93**	.87**	0.89**	.89**	.79**	.71**	.77**	.81**	.70**	.76**	.77**	.46**	.54**	.81**	.76**	.67**	.19	.76**
4.	Total No. of roots/hill	.84**	.94**	.85**	.92**	.87**	0.87**	.89**	.94**	.85**	.90**	.92**	.88**	.91**	.91**	-	-	-	-	-	-	-
5.	Max. length of roots (cm)	.92**	.86**	.91**	.91**	.88**	0.87**	.92**	.41*	.33	.38	.43*	.27	.36	.38	-	-	-	-	-	-	-
6.	Average length of roots (cm)	.98**	.94**	.96**	.97**	.96**	0.94**	.97**	.80**	.69**	.77**	.80**	.69**	.77*	.77**	-	-	-	-	-	-	-
7.	Total drymatter (g)/hill	.87**	.92**	.86**	.93**	.88**	0.90*	.89**	.86**	.72**	.78**	.82**	.76**	.80**	.79**	.27	.34	.68**	.60**	.50*	-.02	.62**
8.	Grain yield (g/pot)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.51*	.54**	.82**	.75**	.60**	.24	.77**
9.	Straw yield (g/pot)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.07	.14	.53**	.45*	.31	-.23	.45*
10.	Total P uptake (mg/pot)	.61*	.76	.77	.81**	.76**	.79**	.79**	.71*	.65**	.72	.75**	.6[illegible]	.6[illegible]	.71*	.[illegible]	.40	.74*	.[illegible]	.54*	.0[illegible]	.67**

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 79. Summary results of the regression analysis for total drymatter (Y) and inorganic P fractions { Saloid-P (X_5), Al-P (X_6), Fe-P (X_7), Red-P (X_8), Ca-P (X_9) and Occluded-P (X_{10})} and total P uptake (X_{11}) at various growth stages.

	R^2
I. <u>30th day after sowing</u>	
(i) $Y = -11.3464 + \underset{(0.1119)}{0.4906^{**}}X_{11}$	0.683
(ii) $Y = -10.5125 + \underset{(0.1795)}{0.3904^{*}}X_{11} + \underset{(0.0470)}{0.0338}X_7$	0.675
(iii) $Y = -5.5820 + \underset{(0.1798)}{0.5030^{*}}X_{11} + \underset{(0.1135)}{0.2301}X_7 - \underset{(3.3589)}{6.3138}X_5$	0.718
(iv) $Y = -6.4189 + \underset{(0.1898)}{0.5510^{**}}X_{11} + \underset{(0.1466)}{0.3078^{*}}X_7 - \underset{(3.4128)}{5.9319}X_5 - \underset{(0.7943)}{0.6728}X_9$	0.714
(v) $Y = -28.7500 + \underset{(0.1684)}{0.6580^{**}}X_{11} + \underset{(0.1457)}{0.3924^{**}}X_7 - \underset{(3.6002)}{2.9308}X_5 - \underset{(2.2218)}{4.5071}X_9 + \underset{(0.7712)}{1.4136}X_6$	0.752
(vi) $Y = -40.4556 + \underset{(0.1812)}{0.6823^{**}}X_{11} + \underset{(0.1401)}{0.4100}X_7 - \underset{(3.5231)}{4.0031}X_5 - \underset{(2.2628)}{5.7337^{*}}X_9 + \underset{(0.7584)}{1.6850^{*}}X_6 + \underset{(3.1810)}{5.1107}X_{10}$	0.776
II. <u>60th day after sowing</u>	
(i) $Y = 1.8562 + \underset{(0.3547)}{2.3096^{**}}X_9$	0.818
(ii) $Y = 43.7375 + \underset{(1.3347)}{7.7096^{**}}X_9 - \underset{(0.7705)}{3.1483^{**}}X_6$	0.899
(iii) $Y = 37.1779 + \underset{(1.4240)}{6.4890^{**}}X_9 - \underset{(0.7489)}{2.8326^{**}}X_6 + \underset{(2.1035)}{3.9055}X_5$	0.910
(iv) $Y = 42.2793 + \underset{(1.7830)}{8.1062^{**}}X_9 - \underset{(0.7510)}{3.0912^{**}}X_6 + \underset{(2.0630)}{4.2543^{*}}X_5 - \underset{(0.1414)}{0.2041}X_7$	0.915

* Significant at 0.05 level

** Significant at 0.01 level

5.8. Relation between total P uptake with biometric, yield characteristics and inorganic P fractions.

The correlations between total P uptake and the various characteristics of the plant are given in Table 80 and the summary results of stepwise regressions for P uptake with inorganic P fractions at different growth stages of the crop in Table 81.

Significant positive correlations were obtained between P uptake and all the characteristics of the crop viz., height of plant, number of tillers, weight of root, total number of roots, maximum length of roots, average length of roots, total dry matter, grain and straw yield.

In the regressions between P uptake and various inorganic P fractions, it has been observed that about 81 per cent of the total variation in P uptake could be explained by Fe-P followed by Al-P at 30th day after sowing and about 73 per cent of the total variation in P uptake was accounted by Fe-P both at 60th day after sowing and at harvest stage of the crop.

6. Comparative evaluation of two sources of phosphorus on rice in the acid soils of Kerala.

The abstracts of ANOVA for all the characteristics at the panicle initiation stage of the rice crop are given

Table 80. Correlation coefficients between biometric or yield characteristics with total P uptake at various growth stages of the crop.

Sl. No.	Biometric or yield characteristics	Total P uptake (mg/pot)		
		30th day after sowing	60th day after sowing	Harvest stage
1.	Height of plant	0.71**	0.92**	0.82**
2.	No. of tillers/hill	0.83**	0.80**	0.92**
3.	Weight of roots/pot	0.85**	0.92**	0.95**
4.	Total No. of roots/hill	0.86**	0.83**	-
5.	Max. length of roots/(cm)	0.91**	0.83**	-
6.	Average length of roots (cm)	0.79**	0.91**	-
7.	Total drymatter (g/pot)	0.88**	0.76**	0.97**
8.	Grain yield (g/pot)	-	-	0.92**
9.	Straw yield (g/pot)	-	-	0.94**

* Significant at 0.05 level

** Significant at 0.01 level

Table 81. Summary results of the stepwise regression analysis for P uptake (Y) and inorganic P fractions {Saloid-P (X_5), Al-P (X_6), Fe-P (X_7), Red-P ($X_{[illegible]}$), Ca-P (X_9) and Occluded-P (X_{10})} at various growth stages.

		$\bar{R}^2$
I. 30^{th} day after sowing		
(i)	$Y = 18.9067 + 1.3665^{**}X_7$ $(0.2131)^7$	0.807
(ii)	$Y = 30.1576 + 3.0288^{*}X_7 - 0.9416X_6$ $(1.1352)^7 (0.6322)^6$	0.819
(iii)	$Y = 36.4755 + 5.1452^{*}X_7 - 1.4613X_6 - 0.1912X_9$ $(2.0422)^7 (0.7519)^6 (0.1542)^9$	0.824
II. 60^{th} day after sowing		
(i)	$Y = 26.4429 + 1.2651^{**}X_7$ $(26.4429)^7$	0.728
(ii)	$Y = 40.1563 + 4.0336^{**}X_7 - 1.6323^{*}X_6$ $(1.1216)^7 (0.6476)^6$	0.789
(iii)	$Y = 65.0088 + 4.6249^{**}X_7 - 1.5665^{*}X_6 - 3.1671X_8$ $(1.2165)^7 (0.6436)^6 (2.6577)^8$	0.794
(iv)	$Y = 66.3006 + 4.1178^{**}X_7 - 1.3716^{*}X_6 - 4.0945X_8 + 2.1765X_5$ $(1.2893)^7 (0.6620)^6 (2.7640)^8 (1.9237)^5$	0.798
III. Harvest stage		
(i)	$Y = 21.9342 + 0.2017^{**}X_7$ $(0.0394)^7$	0.737
(ii)	$Y = 21.9841 + 0.3300^{**}X_7 - 9.3354^{**}X_6$ $(0.0263)^7 (1.1663)^6$	0.939
(iii)	$Y = 21.5569 + 0.2523^{**}X_7 - 16.2793^{**}X_6 + 6.7164^{*}X_5$ $(0.0457)^7 (3.3201)^6 (3.0398)^5$	0.949

* Significant at 0.05 level

** Significant at 0.01 level

in Appendix XIV and XV and the data relating to the influence of two sources of phosphorus in different soil types on the biometric and other characteristics of the rice crop at panicle initiation stage in Table 82 to 94.

6.1.1. Height of plant

While a significant increase in plant height was observed with the application of P, the different sources of P have no significant effect on this character. A quadratic response was observed for this character with the application of three levels of P. When the dosage was increased from 30 to 60 kg P_2O_5/ha, about 8 per cent increase in the height was noted. A significant interaction was noted for the two sources of P with the various levels. At lower dose (30 kg P_2O_5/ha) MCP (Monocalcium monophosphate) was found to be more effective than the TCP (Tricalcium phosphate) while for higher doses TCP was found to be superior to MCP. A significant interaction was observed for soils under different treatments. Varied response to application of MCP at different doses was also noted. Thus, lateritic alluvium, Kari and Kayal soils showed a quadratic; Kole soils, a positive linear and Karapadam, coastal sandy and Pokkali soils produced a negative response. But a differential response was observed for

TCP with the dosages. Plant height was found to increase with an increase in dose in lateritic alluvium, Kari, Kayal, coastal sandy alluvium and Pokkali soils. A quadratic response was observed in Karapadam and Kole soils

6.1.2. Number of productive tillers

P application increased productive tillers by 16 percent. The different sources of P showed varying responses in the number of productive tillers. Plants grown in soils treated with TCP produced 3 per cent more tillers than the one grown with MCP. The increase in dose is found to increase the number of tillers in general. However the rate of increase was found to decrease with an increase in dose from 60 to 90 kg P_2O_5/ha of TCP.

Significant differences in the production of tillers were observed with varying soil types. The maximum number of tillers was observed for plants grown in Kole soils while minimum for the one in Pokkali soils. Kayal and Karapadam soils were found to be superior to all the other soils except Kole soils in terms of tillering habit for rice plants. Lateritic alluvium, Kayal, Pokkali and Kole soils produced a quadratic response for productive tillers with an increase in dose of P while a negative response was observed for Karapadam and coastal sandy alluvial soils and a positive response for Kari soils with

Table 82. Influence of MCP and TCP in different soils on height of plant (cm) at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	36.5	39.5	49.3	46.2	38.7	46.5	46.7	43.3
Kari	52.3	55.1	61.3	54.1	56.6	65.1	67.4	58.8
Karapadam	51.3	58.4	56.6	55.5	54.7	58.6	56.8	56.0
Kayal	52.1	54.7	56.1	57.4	54.7	59.5	60.7	56.5
Pokkali	52.2	53.7	52.1	48.4	47.7	50.4	53.6	51.2
Coastal sandy alluvium	46.6	53.7	50.3	50.8	51.2	51.7	51.8	50.9
Kole	53.5	64.1	66.8	68.4	50.6	66.5	65.4	62.2
Mean (T)	49.2	54.2	56.1	54.4	50.6	56.9	57.5	-

C.D. (0.05) S = 0.12
" T = 0.12
" S x T = 0.32

Table 83. Influence of MCP and TCP in different soils on productive tillers/hill at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	6.0	7.0	10.5	10.0	5.0	7.0	8.0	7.6
Kari	6.0	7.0	9.0	10.0	7.0	9.5	10.5	8.4
Karapadam	9.0	11.0	9.5	8.7	8.6	10.0	10.0	9.5
Kayal	7.0	8.0	10.0	10.0	6.0	11.0	12.0	9.1
Pokkali	5.0	4.5	5.0	4.5	6.5	7.4	8.5	5.9
Coastal sandy alluvium	9.0	7.5	5.0	4.5	5.5	6.4	6.2	6.3
Kole	9.0	10.0	12.0	12.0	10.0	12.0	14.0	11.3
Mean (T)	7.3	7.9	8.7	8.5	6.9	9.0	9.9	-

C.D. (0.05) S = 0.08
" T = 0.08
" S x T = 0.21

an increase in levels of P as MCP. When TCP was applied, productive tillers was found to increase with an increase in P in lateritic alluvium, Kari, Kayal, Pokkali and Kole soils. It was found to decrease with highest dose of P as TCP in Karapadam and coastal sandy alluvium.

6.1.3. Weight of roots

The root weight of P treated plants increased by 49 per cent over those of control. Different sources of P did not produce any significant difference in root weight. However, an increase in dose had a significant effect in increasing the root weight. Thus the weight of roots was found to increase by 22 per cent for the first incremental increase of 30 kg P_2O_5/ha from 30 to 60 kg/ha and then to 41 per cent for the subsequent incremental increase of 30 kg P_2O_5/ha from 60 kg to 90 kg P_2O_5/ha. Weight of roots markedly differed depending on soil type. The root weight was more for plants grown in Kari soils and least for Pokkali soils. Kole soils were nearer to Kari soils in this respect. Significant interaction was observed between soils and different treatments. In general, all the plants grown in all soil types gave more weight of roots with an increase in dose except a negative response observed in coastal sandy alluvium and Pokkali soils treated with MCP, where in the root weight was found to decrease with an increase in dose.

6.1.4. Weight of straw

The straw yield increased upto 30 per cent with P application as compared to control. The weight of straw was found to be affected by various sources of P. Plants treated with TCP produced about 10 per cent more straw than those grown with MCP. The first incremental increase of 30 kg/ha from 30 to 60 kg/ha and the second incremental increase from 60 to 90 kg enhanced straw yields by 11 and 12 per cent respectively.

Straw yield was significantly different with varying soil types. Maximum yield was recorded with Kole soil and minimum with Pokkali. Significant interaction was noted for soil types under treatment. Lateritic alluvium, Kayal, Karapadam, coastal sandy alluvium and Kole soils treated with MCP produced quadratic response with the dosage and linear increase in response with Kari and Pokkali soils. While lateritic alluvial and Kayal soils treated with TCP produced quadratic response and Kari, Karapadam, coastal sandy alluvium, Pokkali and Kole soils, a linear response.

6.1.5. Total drymatter

The drymatter yield was found to increase (32 per cent) with P application. When TCP was applied, the drymatter was found to be 14 per cent more than that obtained with MCP

Table 84. Influence of MCP and TCP in different soils on weight of roots (g)/hill) at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	1.1	1.3	1.7	2.2	0.9	1.1	1.3	1.4
Kari	1.1	1.8	2.1	2.4	2.3	2.7	2.8	2.2
Karapadam	1.1	1.4	1.7	2.0	2.1	2.2	2.8	1.9
Kayal	1.2	1.5	1.9	2.2	0.9	1.3	1.5	1.5
Pokkali	0.8	0.7	0.5	0.4	0.8	1.0	1.4	0.8
Coastal sandy alluvium	1.1	0.9	0.8	0.6	1.1	1.3	1.9	1.1
Kole	1.3	2.1	2.5	2.5	1.1	2.3	3.3	2.0
Mean (T)	1.1	1.4	1.6	1.8	1.3	1.7	2.0	-

C.D. (0.05) S = 0.09
" T = 0.09
" S x T = 0.25

Table 85. Influence of MCP and TCP in different soils on weight of straw (g/hill) at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	7.9	8.9	10.4	9.0	7.7	9.3	9.2	8.9
Kari	7.7	9.2	10.0	11.4	9.3	9.7	10.7	9.7
Karapadam	9.2	12.0	10.7	10.3	13.4	16.2	16.4	12.6
Kayal	9.8	10.9	11.2	11.1	11.5	12.3	12.1	11.3
Pokkali	4.6	4.2	2.4	2.7	4.1	5.5	5.8	4.2
Coastal sandy alluvium	5.4	10.3	6.0	3.5	9.6	7.5	7.9	7.2
Kole	13.6	14.6	21.8	19.4	14.7	22.4	26.5	19.0
Mean (T)	8.3	10.0	10.4	9.6	10.0	11.8	12.7	-

C.D. (0.05) S = 0.13
" T = 0.13
" S x T = 0.35

But no significant difference in dry matter was observed at this stage with an increase in levels of P. Also no interaction was obtained for the forms viz., MCP and TCP with doses. However, the different soils responded in varied manner. Maximum dry matter (21 g/hill) obtained for Kole soils while the minimum (5 g/hill) for Pokkali soil. Lateritic alluvium, Karapadam, coastal sandy alluvium and Kole soils produced quadratic response in dry matter yield with an increase in dose while a linear response in Kari, Kayal and Pokkali soil when MCP was applied. A linear positive response was obtained with P levels for all soils applied with TCP.

6.1.6. P (ppm) in root

P application increased the root P by about 30 per cent. However at the same level of P, two different sources had no significant difference in this effect. But with an increase of 30 kg P_2O_5 from a dose of 30 to 60 kg P_2O_5/ha. an increase of root P to the extent of 13 per cent has been observed. Another incidental increase of 30 kg P_2O_5/ha. has resulted in a root P increase of about 23 per cent. A significant interaction was noted for the two sources with various doses. When MCP was applied at 60 kg P_2O_5/ha, 6 per cent increase in root P was noted when compared to 30 kg P_2O_5 application and

Table 86. Influence of MCP and TCP in different soils on total dry matter (g/hill) at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	9.0	10.2	12.1	11.2	8.6	10.4	10.5	10.3
Kari	8.8	11.0	12.1	13.8	11.6	12.4	13.5	11.9
Karapadam	10.3	13.4	12.4	12.3	15.5	18.4	19.2	14.5
Kayal	11.0	12.4	13.1	13.3	12.4	13.6	13.6	13.0
Pokkali	5.4	4.9	2.9	3.1	4.9	6.5	7.2	5.0
Coastal sandy alluvium	6.5	11.2	6.8	4.1	10.7	8.8	9.8	8.3
Kole	14.9	16.7	24.3	21.8	15.8	24.7	28.8	21.0
Mean (T)	9.4	11.4	12.0	11.4	11.4	13.5	14.7	-

C.D. (0.05) S = 0.12
" T = 0.12
" S x T = 0.31

Table 87. Influence of MCP and TCP in different soils on P (ppm) in root at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	250	290	320	520	210	300	510	343
Kari	200	280	300	430	320	450	550	361
Karapadam	150	190	240	270	120	140	180	184
Kayal	90	120	140	150	120	130	140	127
Pokkali	190	190	150	180	180	170	210	181
Coastal sandy alluvium	260	270	280	300	290	310	260	281
Kole	260	260	270	300	250	300	300	277
Mean (T)	200	229	243	307	213	257	307	-

C.D. (0.05) S = 2.96
" T = 2.96
" S x T = 7.84

34 per cent increase was observed with 90 kg P_2O_5/ha as MCP, the per centage increase between the higher two doses being 26. But with TCP, the root P increased by 21 per cent when P increased from 30 to 60 kg P_2O_5/ha and 44 per cent with 90 kg P_2O_5, the increase in root P for a P increase from 60 to 90 kg P_2O_5/ha being 19 per cent. The root P was significantly different with varying soil types, the highest (361 ppm) in Kari soils and lowest (127 ppm) in Kayal, about one third of that in the roots grown in Kari soils. Significant interaction was observed between soil types and varying doses. In lateritic alluvium and Kari soils, a significant increase in root P was observed with an increase in dose for both sources of P. Though root P was increased with higher doses in Kayal, Karapadom and Kole soils, the rate of change in increase was diminishing with 90 kg P_2O_5/ha. A differential type of response was observed for Pokkali soils with MCP, while a linear response with TCP. When a quadratic response in coastal sandy alluvium for TCP application, a linear response with MCP has been observed.

6.1.7. P (ppm) in straw.

The P application increased the P content in straw by 65 per cent. No significant difference in this character was observed with two sources of P. But the increase in dose was found to increase the P in straw. When P was increased from 30 to 60 kg P_2O_5/ha the P content in straw increased by 31 per cent and with an increase of P dose from 60 to 90 kg P_2O_5/ha it increased by 38 per cent. When MCP was used, the straw P was found to increase with a decrease in rate of increase while TCP recorded a low content of P in straw with 90 kg P_2O_5/ha as compared to 60 kg P_2O_5/ha. The P was significantly low in straw of plants grown in Kole soil and high in Kayal soil. A significant interaction was observed for various soils with P application. The straw P was found to increase with P doses in all soils except Karapadam soil for MCP, and Karapadam and Pokkali soils for TCP application.

6.1.8. <u>Total P (ppm) in soil</u>

The total P in soil was increased by about 49 per cent with P application. It was significantly increased when TCP was applied (21 per cent). With an increase in level also a corresponding increase in soil P was observed. When the dose of P was increased from 30 to 60 kg P_2O_5/ha the soil P was increased by 21 per cent and then increased upto 40 per cent with 90 kg P_2O_5/ha, the rate of increase from 60 to 90 kg P_2O_5/ha being 16 per cent. A significant interaction was noted for MCP and TCP with

Table 88. Influence of MCP and TCP in different soils on P (ppm) in straw at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	500	670	830	950	580	820	850	743
Kari	420	540	710	760	620	950	1100	729
Karapadam	400	430	680	450	530	730	450	524
Kayal	500	800	1020	1400	850	1080	1130	969
Pokkali	210	220	250	270	80	160	180	196
Coastal sandy alluvium	110	190	130	220	260	220	180	187
Kole	90	140	160	170	70	120	160	130
Mean (T)	319	427	540	603	427	583	579	-

C.D. (0.05) S = 3.42
" T = 3.42
" S x T = 9.04

Table 89. Influence of MCP and TCP on total P (ppm) in different soils at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	480	530	650	980	450	860	1100	721
Kari	300	450	660	950	610	1050	1250	753
Karapadam	430	560	560	410	560	380	490	484
Kayal	700	750	760	930	860	1300	1350	950
Pokkali	630	760	700	640	770	780	810	727
Coastal sandy alluvium	600	630	730	480	530	650	650	610
Kole	490	650	690	1160	850	1080	1320	894
Mean (T)	519	619	679	796	661	871	996	-

C.D. (0.05) S = 3.32
" T = 3.32
" S x T = 8.78

varying doses. When MCP, 60 kg P_2O_5/ha was applied, the soil P was increased by 10 per cent only while with the same dosage of TCP, the soil P increased by 32 per cent However, the increase in soil P with an additional dose of 30 kg resulted only 17 per cent increase in soil P with MCP and 14 per cent increase in soil P with TCP. The soil P was significantly different for various soil types. The soil P was highest in Kayal and lowest in Karapadam soils. A significant interaction was observed for various soil types with treatments. The soil P was found to increase with increase in dose in lateritic alluvium, Kari, Kayal and Kole soils when P through both the sources was applied. In Karapadam, coastal sandy alluvium and Pokkali soils, with an increase in P dose, a decrease in soil P was observed for MCP application. While a differential response was noted for these soils when TCP was applied.

6.1.9. Percentage derived from fertilizer (PDFF) - Root

The PDFF in root was not significantly different with respect to the two sources of P. But, increased doses of P produced an increased PDFF value, the rate of change showing a diminishing trend with higher doses. When the level of P was increased from 30 to 60 kg P_2O_5/ha, 8 per cent increase in PDFF was observed but for a further increase to 90 kg P_2O_5/ha only 2.5 per cent increase in PDFF was observed. No interaction was obtained for the various levels of P with the two sources. The PDFF was significantly different among various soil types, the highest was recorded for coastal sandy alluvium and the lowest for Kayal soils. This finds a ready explanation based on the total P status of the coastal sandy alluvial soils and Kayal soils which have rended the lowest and highest levels of total P (Table 3). Further, root proliferation rate had an inverse relationship to the concentration of P observed, which indicates a dilution effect (Table 84). The PDFF (root) was found to increase with an increase in dose for all soil types except Pokkali soil which produced a quadratic trend in PDFF with an increase in dose.

6.1.10. <u>Percentage derived from fertilizer (PDFF) - Straw</u>

No significant difference in PDFF in straw was observed with the two sources of P. But the PDFF was found to increase with an increase in dose. When the P dose was increased from 30 to 60 kg P_2O_5/ha, 2.4 per cent increase in PDFF was recorded, this increase was 4.5 per cent with a further increase in P dosage to 90 kg P_2O_5/ha. Significant differences in PDFF was observed with various soil types. The highest PDFF value was record

Table 90. Influence of MCP and TCP in different soils on PDFF (Root) at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	0.0	21.3	23.3	24.5	14.3	15.0	16.3	16.4
Kari	0.0	18.0	19.5	20.3	19.5	20.0	21.3	16.9
Karapadam	0.0	15.5	17.0	17.5	16.3	18.0	20.0	14.9
Kayal	0.0	15.5	16.3	16.8	15.8	17.5	18.3	14.3
Pokkali	0.0	15.8	18.0	17.8	15.5	21.8	16.5	15.0
Coastal sandy alluvium	0.0	24.0	23.8	24.5	26.0	25.8	26.3	21.5
Kole	0.0	20.7	22.5	23.5	20.5	21.8	23.5	18.9
Mean (T)	0.0	18.7	20.0	20.7	18.3	20.0	20.3	-

C.D. (0.05) S = 0.31
" T = 0.31
" S x T = 0.81

Table 91. Influence of MCP and TCP in different soils on PDFF (straw) at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	0.0	25.5	26.8	28.3	24.8	26.0	27.5	22.7
Kari	0.0	24.8	24.3	25.3	27.5	28.5	30.0	22.9
Karapadam	0.0	22.8	24.3	24.5	23.5	21.8	19.5	19.5
Kayal	0.0	12.5	13.0	13.0	12.0	14.3	20.0	12.1
Pokkali	0.0	16.0	16.8	15.3	19.3	20.0	21.0	15.5
Coastal sandy alluvium	0.0	21.3	17.8	18.3	13.3	14.8	16.3	14.5
Kole	0.0	21.3	22.8	23.8	22.5	23.3	24.5	19.7
Mean (T)	0.0	20.6	20.8	21.2	20.4	21.2	22.7	-

C.D. (0.05) S = 0.29
" T = 0.29
" S x T = 0.77

for Kari followed by lateritic alluvium and lowest for Kayal soil. A significant interaction was observed for soils and the two sources of P at different dosages. The PDFF was found to increase with all soil types except Pokkali when MCP was applied. A similar result was obtained for all soil types except Kayal, Karapadam and Pokkali soils when TCP was applied. It was found to decrease with highest dose in Pokkali for MCP and in Kayal soil for TCP application. In Karapadam soil, application of TCP decreased the PDFF with an increase in dose and in Pokkali soil, the PDFF was found to increase with an increase in dose.

6.1.11. A-value (ppm)

The A-value was not significantly different when P is applied through different sources. It significantly increased with the increased dose. When the P level increased from 30 to 60 kg P_2O_5/ha, the available P increased by about 98 per cent and 203 per cent at 90 kg P_2O_5/ha though the increase for 60 to 90 kg P_2O_5/ha was 53 per cent. In lateritic alluvium with MCP and 60 kg P_2O_5/ha, the available P increased by 94 per cent from the initial dose of 30 kg P_2O_5/ha, but with TCP, it increased by about 102 per cent. The corresponding increases at 90 kg P_2O_5/ha were 200 and 206 percentages respectively for MCP and TCP. The available P was significantly different in all soil types except Karapadam and Pokkali soils which were found to be on par. The highest available P was recorded by Kayal soils and lowest by coastal sandy alluvial soils. A significant interaction was observed with the soil types for the treatments applied. Though an increase in available P was observed with an increase in doses of P for both the sources, the magnitude of increase was significantly different.

6.1.12. <u>Percentage utilization of P</u>

The percentage utilization of P was significantly different when different sources of P were applied. The utilization increased by 7 per cent for TCP application when compared to MCP. The percentage utilization significantly decreased when the levels of P were increased. For an increase in P dosage from 30 to 60 kg P_2O_5/ha, the per centage utilization decreased by 26 and to 42 per centage at 90 kg P_2O_5/ha. When MCP was applied, at 60 and 90 kg P_2O_5/ha, the P utilization decreased respectively by 32 and 47 per cent while with TCP this decrease was respectively 19 and 37 per cent.

With various soil types a remarkable change in P utilization was observed. When P was tried in Kari soil,

Table 92. Influence of MCP and TCP in different soils on A-value (ppm) at panicle initiation stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	0.0	5.6	10.7	20.0	5.4	10.8	17.1	9.9
Kari	0.0	5.2	10.1	16.0	5.2	11.3	16.2	9.1
Karapadam	0.0	5.1	10.2	15.5	5.1	9.5	15.1	8.6
Kayal	0.0	5.8	11.4	17.8	5.7	11.9	17.6	10.0
Pokkali	0.0	5.0	10.1	15.3	5.1	9.9	14.9	8.6
Coastal sandy alluvium	0.0	5.5	9.3	11.7	4.8	10.4	15.1	8.1
Kole	0.0	5.9	11.6	16.9	5.7	11.6	17.1	9.8
Mean (T)	0.0	5.4	10.5	16.2	5.3	10.7	16.2	-

C.D. (0.05) S = 0.04
" T = 0.04
" S x T = 0.11

Table 93. Influence of MCP and TCP in different soils on percentage utilization of P at panicle initiation state.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	0.0	9.2	7.0	5.7	5.3	4.8	4.2	5.2
Kari	0.0	7.7	5.4	5.0	10.3	8.4	7.6	6.3
Karapadam	0.0	6.4	4.7	2.5	8.0	6.4	3.2	4.4
Kayal	0.0	6.4	4.4	4.1	6.7	5.2	4.4	4.5
Pokkali	0.0	1.3	0.4	0.3	0.9	0.9	0.7	0.6
Coastal sandy alluvium	0.0	4.7	1.2	0.6	4.6	1.9	1.2	2.0
Kole	0.0	5.6	4.7	3.2	4.4	4.7	4.2	3.8
Mean (T)	0.0	5.9	4.0	3.1	5.7	4.6	3.6	-

C.D. (0.05) S = 0.08
" T = 0.08
" S x T = 0.20

Table 94. Mean values for various characters at the panicle initiation stage of the crop over sources x doses of phosphorus in different soil types.

(i) Height of plant (cm)

	D_1	D_2	D_3	Mean
S_1	54.2	56.1	54.4	54.9
S_2	50.6	56.9	57.5	55.0
Mean	52.4	56.5	56.0	-

C.D. (0.05) for doses = 0.02

" for S x D = 0.03

(ii) No. of productive tillers/hill

	D_1	D_2	D_3	Mean
S_1	7.9	8.7	8.5	8.4
S_2	6.9	9.0	9.9	8.6
Mean	7.4	8.9	9.2	-

C.D. (0.05) for doses = 0.008

" for S x D = 0.012

(iii) Weight of roots (g/hill)

	D_1	D_2	D_3	Mean
S_1	1.4	1.6	1.8	1.6
S_2	1.3	1.7	2.0	1.7
Mean	1.4	1.7	1.9	-

C.D. (0.05) for doses = 0.012

" S x D = 0.017

(iv) Weight of straw (g/hill)

	D_1	D_2	D_3	Mean
S_1	10.0	10.4	9.6	10.0
S_2	10.0	11.8	12.7	11.5
Mean	10.0	11.1	11.2	-

C.D. (0.05) for doses = 0.024

" S x D = 0.033

(v) Total dry matter (g/hill)

	D_1	D_2	D_3	Mean
S_1	11.4	12.0	11.4	11.6
S_2	11.4	13.5	14.7	13.2
Mean	11.4	12.8	13.1	-

C.D. (0.05) for doses = 1.76

" S x D = 2.49

(vi) P content (ppm) in root

	D_1	D_2	D_3	Mean
S_1	228.6	242.9	307.1	259.5
S_2	212.9	257.1	307.1	259.0
Mean	220.8	250.0	307.1	-

C.D. (0.05) for doses = 11.56

" S x D = 16.35

Contd........

(vii) P content (ppm) in straw

	D_1	D_2	D_3	Mean
S_1	427.1	540.0	602.9	523.3
S_2	427.1	582.9	578.6	529.3
Mean	427.1	561.5	590.8	-

C.D. for doses (0.05) = 15.38

" S x D = 21.76

(viii) Total P (ppm) in soil

	D_1	D_2	D_3	Mean
S_1	618.6	678.6	795.7	697.6
S_2	661.4	871.4	995.7	842.8
Mean	640.0	775.0	895.7	-

C.D. for doses (0.05) = 14.51

" S x D = 20.52

(ix) PDFF (Root)

	D_1	D_2	D_3	Mean
S_1	18.7	20.0	20.7	19.8
S_2	18.3	20.0	20.3	19.5
Mean	18.5	20.0	20.5	-

C.D. for doses (0.05) = 0.12

" S x D = 0.17

(x) PDFF (Straw)

	D_1	D_2	D_3	Mean
S_1	20.6	20.8	21.2	20.9
S_2	20.4	21.2	22.7	21.4
Mean	20.5	21.0	22.0	-

C.D. for doses (0.05) = 0.11

" S x D = 0.16

(xi) A-value (ppm)

	D_1	D_2	D_3	Mean
S_1	5.4	10.5	16.2	10.7
S_2	5.3	10.7	16.2	10.7
Mean	5.4	10.6	16.2	-

C.D. for doses (0.05) = 0.002

" S x D = 0.003

(xii) Percentage utilization of P

	D_1	D_2	D_3	Mean
S_1	5.9	4.0	3.1	4.3
S_2	5.7	4.6	3.6	4.6
Mean	5.8	4.3	3.4	-

C.D. for doses (0.05) = 0.008

" S x D = 0.001

the percentage utilization was 6.3 while in Pokkali soil, it was only 0.6. The utilization of P decreased with soil types in the following order - Kari (6.3), lateritic alluvium (5.2), Kayal (4.5), Karapadam (4.4), Kole (3.8), coastal sandy alluvium (2.0) and Pokkali (0.6). A significant interaction was observed for these soil types with the levels of P applied either as MCP or TCP.

The abstracts of ANOVA for all the characteristics at the harvest stage are presented in Appendix XVI and XVII and the data relating to the influence of two sources of P in various soil types on all the characteristics of the crop at this stage in Table 95 to 108.

6.2.1. Grain yield

The grain yield was not significantly different with the application either as MCP or TCP. When P was increased from 30 to 60 kg P_2O_5/ha, the yield increased by 20 per cent and then decreased by 8 per cent for 90 kg P_2O_5/ha A significant interaction was observed for MCP and TCP at various dosages. With MCP at 60 kg P_2O_5/ha, the yield increased by 13 per cent while with TCP at the same dosage a 27 per cent increase in yield was observed. With an increase from 30 to 90 kg P_2O_5/ha, the yield increased by 1 per cent for MCP and 15 per cent for TCP. From 60 to

90 kg P_2O_5/ha, the decrease was 10 per cent for both MCP and TCP. Significant difference in yield was observed with varying soil types. The highest yield was recorded for Kole soils and lowest for coastal sandy alluvial soils. A significant interaction was observed for soil types with P application. The yield was found to increase with an increase in the doses tried for Kari soil with both the sources of P. While similar type of response was obtained for lateritic alluvium with MCP and Karapadam with TCP. On an average 37 per cent increase in grain yield was recorded with P application. The maximum yield (25.2 g/pot) was recorded from plants treated with MCP at 60 kg P_2O_5/ha and grown in Kole soil and the minimum yield (4.2 g/pot) from coastal sandy alluvium without P, among the treated ones, the lowest was for lateritic alluvium at 30 kg P_2O_5/ha applied as MCP.

6.2.2. Straw yield

The straw yield was found to be significantly different when P was applied as MCP or TCP. Application of P as TCP increased the straw yield by 7 per cent when compared to MCP. Highest doses gave negative response in straw yield. The straw yield increased by 20 per cent when P dose increased from 30 to 60 kg P_2O_5/ha and

Table 95. Influence of MCP and TCP in different soils on grain yield (g/pot).

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	5.1	6.7	7.2	9.4	7.6	14.1	12.9	9.0
Kari	7.1	10.9	11.1	12.1	12.0	13.5	13.9	11.5
Karapadam	13.4	16.6	16.7	14.0	12.0	15.6	16.8	15.1
Kayal	9.7	19.3	16.9	15.1	18.4	19.7	16.6	16.5
Pokkali	10.4	13.4	20.7	16.1	16.2	19.8	12.6	15.6
Coastal sandy alluvium	4.2	12.5	10.3	9.6	8.5	8.0	7.2	8.6
Kole	13.4	15.9	25.2	19.6	13.5	21.4	21.6	18.7
Mean (T)	9.0	13.6	15.4	13.8	12.6	16.0	14.5	-

C.D. (0.05) S = 0.12
" T = 0.12
" S x T = 0.32

Table 96. Influence of MCP and TCP in different soils on straw yield (g/pot).

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	19.5	22.6	27.4	32.5	18.0	25.6	29.4	25.0
Kari	25.3	26.2	29.3	34.0	27.2	34.1	39.0	30.7
Karapadam	37.7	40.4	49.8	38.5	37.0	37.5	45.2	40.9
Kayal	22.1	42.9	39.5	35.5	42.0	47.7	29.2	37.0
Pokkali	10.6	27.6	44.3	35.2	38.7	54.0	31.5	34.6
Coastal sandy alluvium	14.1	24.2	15.6	15.0	21.1	32.5	28.3	21.5
Kole	29.7	43.8	49.9	44.1	40.0	51.3	58.0	45.3
Mean (T)	22.7	32.5	36.5	33.5	32.0	40.6	37.2	-

C.D. (0.05) S = 0.36
" T = 0.36
" S x T = 0.95

decreased by 8 per cent when P increased from 60 to 90 kg P_2O_5/ha. The straw yield increased by 12 and 27 per cent at 60 kg P_2O_5/ha as MCP and TCP respectively and then decreased (8 per cent) at the same magnitude. The maximum straw yield was recorded for Kole soils (45.3 g/pot) followed by Karapadam soil (40.9 g/pot) and the minimum for coastal sandy alluvial soil (21.5 g/pot). In lateritic alluvium and Kari soils, the straw yield was found to increase with the application of P either as MCP or TCP. But a similar type of response was observed for Karapadam and Kole soils treated TCP. In all the other cases, straw yield was found to decrease with the highest dose tried. Application of P increased the straw yield by 56 per cent. The highest straw yield was recorded from Kole soil (58 g/pot) treated with TCP at the rate of 90 kg P_2O_5/ha and the lowest from coastal sandy alluvium (15.0 g/pot) treated with MCP at the rate of 90 kg P_2O_5/ha apart from control.

6.2.3. Weight of roots

The weight of roots was significantly different with respect to the two sources of P. Plants treated with TCP gave 9 per cent more root weight than those treated with MCP. Significant increase in root weight was observed

Table 97. Influence of MCP and TCP in different soils on weight of roots (g/pot) at harvest stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	3.2	4.2	4.3	9.0	3.6	5.8	5.4	5.1
Kari	4.2	4.3	4.8	11.3	9.8	11.0	11.4	8.1
Karapadam	3.7	5.3	7.9	10.3	4.7	7.0	11.6	7.2
Kayal	4.3	4.6	4.6	4.6	5.3	9.6	8.6	5.9
Pokkali	3.5	5.0	10.9	4.0	6.0	7.2	3.8	5.8
Coastal sandy alluvium	2.8	4.5	3.2	3.0	5.3	3.9	3.2	3.7
Kole	3.9	5.5	8.2	6.5	4.1	4.6	6.5	5.6
Mean (T)	3.7	4.8	6.3	7.0	5.5	7.0	7.2	-

C.D. (0.05) S = 0.12
" T = 0.12
" S x T = 0.31

Table 98. Influence of MCP and TCP in different soils on total dry matter (g/pot) at harvest stage.

Soil Type (S)	Treatments (T)							Mean (S
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	27.8	33.5	38.9	50.9	29.2	45.5	47.7	39.1
Kari	36.6	41.4	45.2	57.4	49.0	58.6	64.3	50.4
Karapadam	54.8	62.3	74.4	63.7	53.7	60.1	73.6	63.1
Kayal	36.1	66.8	61.0	55.2	65.7	77.0	54.4	59.5
Pokkali	24.5	46.0	75.9	55.3	60.9	81.0	47.9	55.9
Coastal sandy alluvium	21.1	41.2	29.1	27.6	34.9	44.4	38.7	33.9
Kole	47.0	65.2	83.3	70.2	57.6	77.3	86.1	69.5
Mean (T)	35.4	50.9	58.3	54.3	50.1	63.4	59.0	-

C.D. (0.05) S = 0.41
" T = 0.41
" S x T = 1.08

with increasing dose. Root weight increased by 29 per cent when the dosage was increased from 30 to 60 kg P_2O_5/ha and then increased by 9 per cent when the P increased from 60 to 90 kg P_2O_5/ha. The same type of trend was observed when P was applied as MCP or TCP. Root weight was significantly different with the soil types. Maximum root weight was recorded for plants grown in Kari soil (8.1 g/pot) and minimum from coastal sandy alluvium (3.7 g/pot). In Kari and Karapadam soils, when P was applied either as MCP or TCP, root weight was found to increase with increasing dose. It was found to decrease in coastal sandy alluvial soil. The root weight was found to decrease at the highest dose in lateritic alluvium, Kayal and Pokkali soils treated with TCP and in Pokkali and Kole soils treated with MCP. The Kayal soil treated with MCP did not show any change in root weight and the treatments recorded a root weight of 4.6 g/pot. Lateritic alluvium treated with MCP and Kole with TCP also showed an increase in root weight with an increase in dose. The root weight increased by 70 per cent on an average for P treated plants compared to control.

6.2.4. Total dry matter

A significant increase in dry matter production was observed for plants treated with TCP. The dry matter production increased from 51 to 61 g (about 20 per cent) when P increased from 30 to 60 kg P_2O_5/ha, a further increase of P to 90 kg P_2O_5/ha resulted in a reduction in dry matter to 57 g (about 7 per cent). The same amount of decrease of about 7 per cent was observed for both MCP and TCP, but the increase in dose from 30 to 60 kg P_2O_5/ha resulted about 14 per cent increase in dry matter for MCP and 27 per cent increase with TCP. Significant difference in dry matter was observed with various soil types. Highest quantity of dry matter was produced by plants grown in Kole soil (69.5 g/pot) and lowest from coastal sandy alluvium (33.9 g/pot). Application of P resulted to increase the dry matter production by 58 per cent when compared to control.

6.2.5. P (ppm) in root

The phosphorus content of root was more when treated with MCP (220 ppm) than with TCP (200 ppm). The root P content increased with increase in applied P either as MCP or TCP, but the magnitude of increase was not similar. When MCP increased from 30 to 60 kg P_2O_5/ha the root P increased by 11 per cent and when the P increase was from 60 to 90 kg P_2O_5/ha it increased by 17 per cent. The corresponding increases with TCP were 21 and 33 per cent respectively.

The root P content was observed to be highest for Kari soil (310 ppm) followed by lateritic alluvium (295.7 ppm) and lowest for Kayal soils (110 ppm). The root P content was found to increase with added P in all soil types treated with two sources of P except Kayal and Kole soils treated with TCP. Application of P increased the P content in root by 257 percent.

6.2.6. P (ppm) in straw

The P content in straw was more when P was applied as MCP (494 ppm). It was 457 ppm when TCP was applied. The straw P content was found to increase with an increase in dose. When the dosage was increased from 30 to 60 kg P_2O_5/ha, the straw P increased by 33 and 39 percent respectively for MCP and TCP and then increased by 31 and 15 percent respectively for the two sources of P with an increase from 60 to 90 kg P_2O_5/ha. The straw P content was high from plants grown in Karapadam soil (775 ppm) and low in Kole soil (111 ppm). With increase in dose, the straw P content increased in all soil types treated with P except in coastal sandy alluvium treated with TCP and Kole treated with MCP. A very significant decrease in straw P content recorded with 90 kg P_2O_5/ha as TCP applied in coastal sandy alluvial soil while no change in total P was observed in Kole soil treated with 60 and 90 kg P_2O_5/ha as MCP. The straw P content increased by 53 per cent with P application.

Table 99. Influence of MCP and TCP in different soils on P (ppm) in root at harvest stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	210	270	300	420	190	280	400	296
Kari	180	250	280	310	280	320	550	310
Karapadam	140	160	200	250	100	110	150	159
Kayal	80	110	120	140	100	110	110	110
Pokkali	90	200	210	220	140	130	190	169
Coastal sandy alluvium	130	200	210	260	140	170	180	184
Kole	110	150	170	200	180	200	180	170
Mean (T)	134	191	213	257	161	189	251	-

C.D. (0.05) S = 2.48
" T = 2.48
" S x T = 6.57

Table 100. Influence of MCP and TCP in different soils on P (ppm) in straw at harvest stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	460	620	780	860	510	770	800	686
Kari	390	480	650	700	580	850	1000	664
Karapadam	800	905	1020	1200	100	550	850	775
Kayal	130	140	450	1150	950	700	800	617
Pokkali	200	210	240	250	80	140	150	181
Coastal sandy alluvium	110	70	100	120	130	230	120	126
Kole	80	120	150	150	50	100	130	111
Mean (T)	310	364	484	633	343	477	550	-

C.D. (0.05) S = 3.82
" T = 3.82
" S x T = 10.11

6.2.7. Grain P (ppm)

The grain P content was more (5 per cent) when treated with MCP than TCP. Increase in dosage resulted in an increase in grain P content. When MCP was increased from 30 to 60 kg P_2O_5/ha the grain P increased by 40 per cent and then increased by 7 per cent with an additional dose of 30 kg P_2O_5/ha. A differential response was observed with TCP. The grain P decreased by 2 per cent when TCP increased from 30 to 60 kg P_2O_5/ha. However a further increase of 30 kg P_2O_5/ha increased grain P by 13 per cent. The grain P was high from plants grown in Kole soil (4847 ppm) followed by Kayal (4756 ppm) and low in Kari soil (2567 ppm). An increase in grain P was observed in all soil types treated with either MCP or TCP with the following exceptions. When TCP was applied in lateritic alluvium at 90 kg P_2O_5/ha a decrease in grain P was obtained. In Karapadam soil, the grain P increased from 1600 to 1650 ppm and then to 2600 ppm at the three levels tried, the rate of change in increase being low at 60 kg P_2O_5/ha. as TCP. In Kayal soil, the grain P decreased from 6800 to 5400 ppm at doses 30 and 60 kg P_2O_5/ha, respectively and then increased to 6050 ppm at 90 kg P_2O_5/ha. The grain P increased by 63 per cent with P application.

6.2.8. Total P (ppm) in soil

Application of TCP significantly improved soil P at harvest stage, the increase being 16 per cent. An increase in dosage of P also increased the soil P. On an average, when P increased from 30 to 60 kg P_2O_5/ha, the soil P increased by 21 per cent and a further increase of 30 kg helped to increase soil P by 13 per cent. A significant interaction was observed between the two sources of P applied at three doses. When MCP increased from 30 to 60 kg P_2O_5/ha, the soil P increased by 12 per cent. While at the same rate of TCP, the soil P increased by 29 per cent. Similarly, when the dosage increased from 60 to 90 kg P_2O_5/ha, the soil P increased by 9 and 17 per cent respectively for MCP and TCP. Different soil types showed significant variations in soil P. The maximum soil P recorded in Kayal (807 ppm) and a minimum in coastal sandy alluvium (341 ppm). In lateritic alluvium, Kari, Kayal and Kole soils, the soil P was found to increase with an increase in dose. In Karapadam, coastal sandy alluvium and Pokkali soils, application of MCP at 90 kg P_2O_5/ha showed a diminishing effect in soil P. The Karapadam soil, applied with TCP, did not show any definite trend while Pokkali soil produced a linear positive trend and coastal sandy alluvium, a quadratic type of response. The maximum soil P was recorde

Table 101. Influence of MCP and TCP in different soils on P (ppm) in grain.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	1650	2150	3050	3140	3350	3550	2950	2834
Kari	1440	1980	2520	3450	2250	2650	3680	2567
Karapadam	2100	2620	5250	5400	1600	1650	2600	3031
Kayal	1850	2300	5300	5800	6800	5400	6050	4786
Pokkali	3750	4050	4750	4000	3500	4000	4100	4021
Coastal sandy alluvium	2300	4250	4350	5000	4000	4500	5040	4206
Kole	4000	4550	5500	6000	5010	4120	4750	4847
Mean (T)	2441	3129	4389	4684	3787	3696	4167	-

C.D. (0.05) S = 5.03
" T = 5.03
" S x T = 13.30

Table 102. Influence of MCP and TCP in different soils on Total P (ppm) in soil at harvest stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	430	500	580	690	430	580	900	587
Kari	250	350	456	648	450	838	1020	573
Karapadam	310	430	445	390	490	230	360	379
Kayal	650	700	750	850	720	950	1030	807
Pokkali	570	660	680	630	750	770	790	684
Coastal sandy alluvium	220	370	410	380	120	450	440	341
Kole	350	370	460	530	420	550	580	466
Mean (T)	389	483	540	588	483	624	731	-

C.D. (0.05) S = 3.10
" T = 3.10
" S x T = 8.21

in Kayal soil treated with TCP at 90 kg P_2O_5/ha (1030 ppm) and minimum in coastal sandy alluvium treated with TCP at 30 kg P_2O_5/ha (120 ppm) which was significantly low as compared to even untreated soils. However, treated soils recorded a significant increase (48 per cent) in soil P.

6.2.9. Percentage derived from fertilizer (PDFF) - Root

The PDFF in root was significantly different in plants treated with either MCP or TCP. But the increase in their doses produced an increase in PDFF also. No interaction was observed between the sources of P and their levels. Significant differences in PDFF were observed among various soil types, highest was found in coastal sandy alluvium (17.6) and lowest in lateritic alluvium (12.4). PDFF was found to increase in all soil types treated with MCP or TCP except in coastal sandy alluvium and Pokkali soils.

6.2.10. Percentage derived from fertilizer (PDFF) - Straw

The PDFF in straw also showed no significant difference with the application of MCP or TCP but the increase in dose again helped to increase the PDFF values. Same type of trend was obtained for both the sources at the various levels of P tried. Varying soil types showed varying amount of PDFF in straw. Highest was seen in Kari (18.9) and the lowest in Kayal soil (10.8). In general, PDFF was found to increase with all soil types for an increase in dose except for chance deviations.

Table 103. Influence of MCP and TCP in different soils on PDFF (Root) at harvest stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	0.0	15.8	17.3	18.0	11.2	12.0	12.5	12.4
Kari	0.0	15.5	16.3	17.5	14.5	16.3	19.3	14.2
Karapadam	0.0	13.5	14.5	15.5	13.8	15.8	18.3	13.0
Kayal	0.0	14.0	14.5	15.0	14.3	16.3	16.5	12.9
Pokkali	0.0	13.8	15.0	15.8	15.0	17.5	16.3	13.3
Coastal sandy alluvium	0.0	13.7	20.3	20.8	21.3	21.0	21.5	17.6
Kole	0.0	17.8	18.5	20.0	18.0	18.8	19.5	16.1
Mean (T)	0.0	15.6	16.6	17.5	15.4	16.8	17.7	-

C.D. (0.05) S = 0.32

" T = 0.32

" S x T = 0.85

Table 104. Influence of MRP and TCP in different soils on PDFF (straw) at harvest stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	0.0	21.3	21.8	23.0	20.5	21.3	22.0	18.5
Kari	0.0	20.3	20.0	21.3	22.8	23.7	24.5	18.9
Karapadom	0.0	19.9	19.8	20.3	20.3	19.5	19.0	16.9
Kayal	0.0	12.0	12.3	12.5	11.3	10.3	14.5	10.8
Pokkali	0.0	13.0	13.8	13.3	15.0	15.5	16.8	12.5
Coastal sandy alluvium	0.0	16.5	14.5	15.3	12.0	13.0	13.8	12.1
Kole	0.0	17.8	19.0	19.8	18.8	19.0	20.3	16.4
Mean (T)	0.0	17.2	17.3	17.9	17.2	17.9	18.7	-

C.D. (0.05) S = 0.32

" T = 0.32

" S x T = 0.84

6.2.11. Percentage derived from fertilizer (PDFF) - Grain

No significant difference in PDFF was observed with the application of MCP and TCP. Also the various levels of P did not influence the PDFF in grain. But the PDFF was significantly different in various soil types. It was high in Karapadam soil (2.1) and low in Kole soil (0.9). No significant difference in PDFF was noted between lateritic alluvium and Kari soils. In all soil types except Kayal and Kole the PDFF in grain was high at the highest dose. In coastal sandy alluvium and Kole soils with MCP and Kayal soil with TCP, the PDFF was 1.0 at all the levels tried.

6.2.12. A-value (ppm)

The A-value was not significantly different for MCP and TCP. But the A-value was increased with an increase in levels of P. The available P increased by 100 per cent when the applied P increased from 30 to 60 kg P_2O_5/ha. and to 192 per cent at 90 kg P_2O_5/ha. The increase in available P was only 46 per cent when P increased from 60 to 90 kg P_2O_5/ha. Both MCP and TCP responded similarly to the available P. The A-value was significantly different in various soils, the highest being shown in Kayal soil (9.8 ppm), the lowest in coastal sandy alluvium (7.5 ppm). In all the soil types, the per centage increas

Table 105. Influence of MCP and TCP in different soils on PDFF in grain.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	0.0	1.5	1.8	1.8	1.8	1.8	2.0	1.5
Kari	0.0	1.3	1.0	1.8	1.3	1.5	2.3	1.4
Karapadam	0.0	1.3	1.0	1.8	3.0	4.5	3.0	2.1
Kayal	0.0	1.5	1.0	1.3	1.0	1.0	1.0	1.0
Pokkali	0.0	1.5	1.3	1.0	1.3	1.3	1.8	1.1
Coastal sandy alluvium	0.0	1.0	1.0	1.0	1.5	1.5	2.3	1.2
Kole	0.0	1.0	1.0	1.0	0.8	1.3	1.0	0.9
Mean (T)	0.0	1.3	1.2	1.4	1.5	1.8	1.9	-

C.D. (0.05) S = 0.25
" T = 0.25
" S x T = 0.66

Table 106. Influence of MCP and TCP in different soils on A-value (ppm) at harvest stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	0.0	5.4	10.5	14.0	5.0	10.4	16.2	8.8
Kari	0.0	4.9	9.9	15.3	5.2	10.7	16.2	8.9
Karapadam	0.0	5.1	9.8	14.4	5.1	9.3	14.4	8.3
Kayal	0.0	5.6	11.4	17.6	5.6	11.2	17.1	9.8
Pokkali	0.0	4.8	9.9	15.1	5.0	9.9	14.2	8.4
Coastal sandy alluvium	0.0	4.7	8.4	11.3	4.5	9.5	14.0	7.5
Kole	0.0	5.4	10.5	15.1	5.3	11.1	13.5	8.7
Mean (T)	0.0	5.1	10.1	14.7	5.1	10.3	15.1	-

C.D. (0.05) S = 0.31
" T = 0.31
" S x T = 0.82

in available P was almost similar when P increased from 30 to 60 kg P_2O_5/ha and from 60 to 90 kg P_2O_5/ha either as MCP or TCP.

6.2.13. <u>Per centage P utilization</u>

At harvest, P utilization was different for MCP and TCP. It was observed to be more (13 per cent) when P was applied as MCP. Increase in P was found to decrease the P utilization capacity by 20 per cent when P increased from 30 to 60 kg P_2O_5/ha, and to 40 per cent for an additional increase of 30 kg P_2O_5/ha. Whereas the decrease in P utilisation capacity was 25 per cent from 60 to 90 kg P_2O_5/ha. Significant interaction was observed for soils treated with MCP and TCP at various doses. When P increased from 30 to 60 kg P_2O_5/ha, the utilization decreased respectively by 14, 29, 64 and 19 per cent for lateritic alluvium, Kari, coastal sandy alluvium and Kole soils. While a slight increase in P utilization was observed for Karapadam soil (8 per cent), Kayal (6 per cent and Pokkali (2 per cent) when treated with MCP. But with TCP, all the soils showed a decrease in P utilization, the values being 7, 21, 23, 47, 17, 35 and 41 per cent for lateritic alluvium, Kari, Karapadam, Kayal, coastal sandy alluvium, Pokkali and Kole soils respectively.

Table 107. Influence of MCP and TCP in different soils on percentage utilization of P at harvest stage.

Soil Type (S)	Treatments (T)							Mean (S)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
Lateritic alluvium	0.0	17.4	14.6	14.2	17.6	16.3	10.7	13.0
Kari	0.0	18.5	13.1	15.4	26.1	20.7	22.9	16.7
Karapadam	0.0	35.0	37.7	24.2	15.9	12.3	15.8	20.1
Kayal	0.0	20.9	22.1	16.7	20.3	10.8	9.0	14.2
Pokkali	0.0	25.8	26.3	11.0	31.5	26.3	11.0	18.8
Coastal sandy alluvium	0.0	30.0	10.8	8.1	23.0	17.2	11.5	14.4
Kole	0.0	17.0	13.8	9.0	16.8	9.9	8.8	10.7
Mean (T)	0.0	23.5	19.8	14.1	21.6	16.2	12.8	-

C.D. (0.05) for S = 0.39

C.D. (0.05) for T = 0.39

C.D. (0.05) for S x T = 1.02

Table 108. Mean values for various characters at the harvest stage of the crop over sources x doses of phosphorus in different soil types.

(i) Grain yield (g/pot)

	D_1	D_2	D_3	Mean
S_1	13.6	15.4	13.8	14.3
S_2	12.6	16.0	14.5	14.4
Mean	13.1	15.7	14.2	-

C.D. (0.05) for doses = 0.02

C.D. (0.05) for S x D = 0.03

(ii) Straw yield (g/pot)

	D_1	D_2	D_3	Mean
S_1	32.5	36.5	33.5	34.2
S_2	32.0	40.6	37.2	36.6
Mean	32.3	38.6	35.4	-

C.D. (0.05) for doses = 0.02

C.D. (0.05) for S x D = 0.24

(iii) Weight of root (g/pot)

	D_1	D_2	D_3	Mean
S_1	4.8	6.3	7.0	6.0
S_2	5.5	7.0	7.2	6.6
Mean	5.2	6.7	7.1	-

C.D. (0.05) for doses = 0.02

C.D. (0.05) for S x D = 0.03

(iv) Total dry matter (g/pot)

	D_1	D_2	D_3	Mean
S_1	50.9	58.3	54.3	54.5
S_2	50.1	63.4	59.0	57.5
Mean	50.5	60.9	56.7	-

C.D. (0.05) for doses = 0.22

C.D. (0.05) for S x D = 0.31

(v) P (ppm) in root

	D_1	D_2	D_3	Mean
S_1	191.4	212.9	257.1	220.5
S_2	161.4	188.6	251.4	200.5
Mean	176.4	200.8	254.3	-

C.D. (0.05) for doses = 8.11

C.D. (0.05) for S x D = 11.46

(vi) P (ppm) in straw

	D_1	D_2	D_3	Mean
S_1	363.6	484.3	632.9	493.6
S_2	342.9	477.1	550.0	456.7
Mean	353.3	480.7	591.5	-

C.D. (0.05) for doses = 19.23

C.D. (0.05) for S x D = 27.19

Contd........

(vii) P (ppm) in grain

	D_1	D_2	D_3	Mean
S_1	3128.6	4388.6	4684.3	4067.2
S_2	3787.1	3685.7	4167.1	3883.3
Mean	3457.9	4042.2	4425.7	-

C.D. (0.05) for doses = 33.28

" S x D = 47.06

(viii) Total P (ppm) soil

	D_1	D_2	D_3	Mean
S_1	482.9	540.1	588.3	537.1
S_2	482.9	624.0	731.4	612.8
Mean	482.9	582.1	659.9	-

C.D. (0.05) for doses = 12.68

" S x D = 17.93

(ix) PDFF (root)

	D_1	D_2	D_3	Mean
S_1	15.6	16.6	17.5	16.6
S_2	15.4	16.8	17.7	16.6
Mean	15.5	16.7	17.6	-

C.D. (0.05) for doses = 0.14

" S x D = 0.19

(x) PDFF (Straw)

	D_1	D_2	D_3	Mean
S_1	17.2	17.3	17.9	17.5
S_2	17.2	17.9	18.7	17.9
Mean	17.2	17.6	18.3	-

C.D. (0.05) for doses = 0.13

" S x D = 0.18

(xi) PDFF (grain)

	D_1	D_2	D_3	Mean
S_1	1.3	1.2	1.4	1.3
S_2	1.5	1.8	1.9	1.7
Mean	1.4	1.5	1.7	-

C.D. (0.05) for doses = 0.04

" S x D = 0.08

(xii) A-value

	D_1	D_2	D_3	Mean
S_1	5.1	10.1	14.7	10.0
S_2	5.1	10.3	15.1	10.2
Mean	5.1	10.2	14.9	-

C.D. (0.05) for doses = 0.13

" S x D = 0.18

(xiii) Percentage P utilization

	D_1	D_2	D_3	Mean
S_1	23.5	19.8	14.1	19.1
S_2	21.6	16.2	12.8	16.9
Mean	22.5	18.0	13.5	-

C.D. (0.05) for doses = 0.20

" S x D = 0.28

With an increase from 60 to 90 kg P_2O_5/ha of MCP, a decrease in P utilization was noticed in all soil types except Kari soil (18 per cent). All soils, except Kari (11 per cent) and Karapadam (28 per cent) showed an increase in P utilization when TCP increased from 60 to 90 kg P_2O_5/ha. These increases or decreases were significantly different.

6.3. Path Analysis

The direct and indirect effects of total P (root, grain and soil), PDFF (root, straw and grain), available P by A-value technique and percentage P utilization on grain and straw yield was investigated by path analysis and the details are presented in Tables 109 and 110.

6.3.1. Grain yield

No significant correlation was observed between grain yield and P content in root. The correlation coefficient between grain yield and root P was found to be -0.20 though its direct effect was -0.60. The P content in root positively influenced grain yield via. soil P, PDFF (straw) available P in soil and percentage P utilization by about 53 per cent and negatively influenced by 14 per cent via. grain P, PDFF (root) and PDFF (grain). The high negative direct effect and negative indirect effects of P (root) resulted in a negative correlation.

The grain P was significantly correlated with grain yield (0.48) though its direct effect was small (0.16). The positive indirect effects via. all factors except PDFF (root) contributed by 0.42 towards the correlation and 0.10 was nullified by the negative indirect effect.

The soil total P was found to be significantly correlated with grain yield (0.37) which is the sum total of the direct effect of soil total P (0.20), positive indirect effect via. P (grain), PDFF (straw), available P (A-value), and percentage P utilization (0.38) and negative indirect effects (-0.21) via. P (root), PDFF (root) and PDFF (grain).

The direct effect of PDFF (root) was negative (-0.22) though its correlation with the yield was positive (0.33). This positive correlation is due to the positive indirect effect of PDFF (root) via. P (grain), soil total P, PDFF (straw), available P (A-value) and percentage P utilization (0.85) which was nullified by the negative indirect effect (-0.29) via. P (root) and PDFF (grain).

The correlation coefficient (0.27) between PDFF (straw) and grain yield was not significant but the direct effect of PDFF (straw) was high (0.55). The low correlation is mainly due to the indirect effect via. P content in root (-0.34).

Table 109. Path analysis 1. Grain yield (Y) Vs. Root P (X_1), Grain P (X_2), Soil total P (X_3), Root PDFF (X_4), Straw PDFF (X_5), Grain PDFF (X_6), A-value (X_7) and Percentage P utilization (X_8).

	(X_1)	(X_2)	(X_3)	(X_4)	(X_5)	(X_6)	(X_7)	(X_8)	Total Correlation
X_1	-0.5953	-0.0220	0.0506	-0.0658	0.3137	-0.0489	0.1384	0.0253	-0.2040
X_2	0.0833	0.1576	0.0622	-0.1036	0.0662	0.0229	0.1558	0.0315	0.4760**
X_3	-0.1512	0.0492	0.1992	-0.0414	0.1328	-0.0148	0.1718	0.0223	0.3679**
X_4	-0.1740	0.0726	0.0366	-0.2249	0.4295	-0.1146	0.2243	0.0825	0.3320*
X_5	-0.3379	0.0189	0.0479	-0.1749	0.5525	-0.1347	0.2042	0.0893	0.2652
X_6	-0.1431	-0.0177	0.0145	-0.1267	0.3659	-0.2034	0.1619	0.0566	0.1081
X_7	-0.2537	0.0756	0.1054	-0.1554	0.3474	-0.1015	0.3247	0.0313	0.3739**
X_8	-0.0985	0.0324	0.0290	-0.1211	0.3220	-0.0752	0.0664	0.1532	0.3082*

Residual effect = 0.71538

* Significant at 0.05 level

** Significant at 0.01 level

The direct effect of PDFF (grain) was negative (-20) and its correlation with grain yield was less (0.11) and not significant. The negative indirect effect via. root P, grain P and PDFF in root and positive indirect effects via. soil total P, PDFF in straw, available P (A-value) and percentage P utilization as well as the direct effect of PDFF in grain together contributed for the low correlation. It may be noted that the positive indirect effect of PDFF (grain) via. PDFF (straw) was high (0.37) compared to the other effects.

The correlation coefficient between available P (A-value) and the grain yield was significant (0.37) which is mainly due to the direct effect (0.32) via. available P (A-value). Though the indirect effect of available P via. PDFF (straw) was high (0.35), the negative indirect effects via. P content in root, PDFF (root) and PDFF (grain) reduced the correlation.

The correlation between percentage P utilization and grain yield was 0.31 out of which 0.15 was contributed by its direct effect. The indirect effects of percentage P utilization via. PDFF (straw) was more than the correlation coefficient, but the negative indirect effects via root P PDFF (root and grain) contributed for the reduction in correlation.

6.3.2. Straw yield

The straw yield was not significantly correlated with the P content in root, the correlation coefficient being -0.10 though its direct effect was -0.52. The root P positively influenced (0.51) straw yield via. P in grain, soil total P, PDFF in straw, available P (A-value) and percentage P utilization, and negatively influenced (-0.09) through PDFF (root and grain). The high negative direct effect and negative indirect effects of P in root resulted in a negative correlation.

The P content in grain was significantly correlated with straw yield (0.34) though its direct effect was small (-0.04). Indirect positive influence (0.44) via. all factors except PDFF in root was also observed.

The soil total P was not significantly correlated with straw yield (0.28) and the direct effect of which was only 0.07. When PDFF (straw), available P (A-value) and percentage P utilization influenced straw yield positively and indirectly through soil total P, the P (root and grain), PDFF (root and grain) indirectly and negatively influenced the effect of soil total P on straw yield.

The direct effect of PDFF in root (-0.15) was negative though its correlation with straw yield was positive and significant (0.38). This positive correlation is due to the positive indirect effects (0.80) of P in grain, soil total P, PDFF in straw, available P (A-value) and percentage P utilization which was nullified by the negative indirect effect (-0.28) via. P (root and grain) and PDFF in grain.

The correlation coefficient (0.34) between PDFF in straw and yield of straw was positive and significant only at 0.05 level. The direct effect of PDFF in straw was 0.43. The soil total P, available P and percentage P utilization influenced positively and indirectly (0.46) through PDFF in straw on the straw yield.

The direct effect of PDFF in grain was negative (-0.19) and its correlation with straw yield was less (0.22). The negative indirect effects via. root P, PDFF (root and grain), and positive indirect effects via. P in grain, soil total P, PDFF in straw, available P (A-value) and percentage P utilization, and the negative direct effect of PDFF in grain together contributed for the low correlation.

The correlation coefficient between available P (A-value) and straw yield was significant (0.40) and its direct effect was positive and comparatively high (0.48).

Table 110. Path analysis 2. Straw yield (Y) Vs. Root P (X_1), Grain P (X_2), Soil total P (X_3), Root PDFF (X_4), Straw PDFF (X_5), Grain PDFF (X_6), A-value (X_7) and percentage P utilization (X_8).

	(X_1)	(X_2)	(X_3)	(X_4)	(X_5)	(X_6)	(X_7)	(X_8)	Total Correlation
X_1	-0.5184	0.0054	0.0186	-0.0437	0.2424	-0.0467	0.2033	0.0408	-0.0984
X_2	0.0726	-0.0383	0.0229	-0.0689	0.0512	0.0219	0.2288	0.0506	0.3408*
X_3	-0.1317	-0.0120	0.0733	-0.0275	0.1026	-0.0141	0.2524	0.0359	0.2788
X_4	-0.1515	-0.0176	0.0135	-0.1496	0.3319	-0.1094	0.3294	0.1328	0.3794**
X_5	-0.2943	-0.0046	0.0176	-0.1163	0.4269	-0.1287	0.2997	0.1438	0.3442*
X_6	-0.1246	0.0043	0.0053	-0.0842	0.2827	-0.1943	0.2378	0.0912	0.2183
X_7	-0.2209	-0.0184	0.0388	-0.1033	0.2684	-0.0969	0.4769	0.0504	0.3950**
X_8	-0.0857	-0.0079	0.0107	-0.0805	0.2488	-0.0718	0.0975	0.2467	0.3577*

Residual effect = 0.7856

* Significant at 0.05 level

** Significant at 0.01 level.

When soil total P, PDFF in straw and percentage P utilization influenced positively and indirectly through available P (A-value), P (root and grain) and PDFF (root and grain) influenced the available P on straw yield negatively and indirectly.

The correlation coefficient between percentage P utilization and strau yield was positve and significant. Out of the total correlation (0.36), 0.25 was contributed by its direct effect. The indirect effects of percentage P utilization via.soil total P, PDFF in straw and av·ilable P (A-value) was 0.36 and the negative indirect effects of percentage P utilization via. P (root and grain) and PDFF (root and grain) was -0.25.

6.4. Standardisation of P response for various soils

The response of rice for monocalcium monophosphate (MCP) and tricalcium phosphate (TCP) was independently investigated to determine the optimum dose of P for maximum yield. The response functions for grain yield and phosphorus doses for various soil types are given in Table 111 along with the estimate of optimum P.

In lateritic alluvium, with the applied dose of MCP the relationship between grain yield and P was found to be

Table 111. Response functions for grain yield and P doses for monocalcium monophosphate (MCP) and tricalcium phosphate for different soil types.

Soil Type	Monocalcium monophosphate (MCP)	
	Regression model	Optimum P_2O_5 (kg/ha)
1. Lateritic alluvium	$Y = 5.1925+0.0314P$	-
2. Kari	$Y = 7.3212+0.1205P-0.0010P^2$	60
3. Karapadam	$Y = 10.0162+0.4847P-0.0052P^2$	46
4. Kayal	$Y = 10.3333+0.3307P-0.0032P^2$	52
5. Pokkali	$Y = 9.5927+0.2711P-0.0024P^2$	56
6. Coastal sandy alluvium	$Y = 4.8027+0.2734P-0.0025P^2$	54
7. Kole	$Y = 12.3180+0.2952P-0.0025P^2$	59

Soil Type	Tricalcium phosphate (TCP)	
	Regression model	Optimum P_2O_5 (kg/ha^2)
1. Lateritic alluvium	$Y = 4.4693+0.1937P-0.0012P^2$	81
2. Kari	$Y = 5.8916+0.1853P-0.0014P^2$	67
3. Karapadam	$Y = 13.0298-0.1190P+0.0010P^2$	59
4. Kayal	$Y = 9.8537+0.3680P-0.0033P^2$	56
5. Pokkali	$Y = 9.9736+0.3586P-0.0036P^2$	50
6. Coastal sandy alluvium	$Y = 4.4266+0.1557P-0.0014P^2$	55
7. Kole	$Y = 12.6260+0.1057P$	-

linear and hence no optimum dose could be determined. Similarly in Kole soil also with the applied dose of TCP no optimum could be determined. In all other soils, the relationship between yield and dose of P was parabolic and the optimum dose of P as MCP worked out were 60, 46, 52, 56, 54 and 59 kg P_2O_5/ha for Kari, Karapadam, Kayal, Pokkali, coastal sandy alluvium and Kole soils respectively As TCP, the optimum dose of P for lateritic alluvium, Kari, Karapadam, Kayal, Pokkali and coastal sandy alluvium were 81, 67, 59, 56, 50 and 55 kg P_2O_5/ha respectively. The optimum P was found to vary from soil to soil for both the sources tried. It varied from 46 kg P_2O_5/ha for Karapadam soils to 60 kg P_2O_5/ha for Kari soils when MCP was applied. The range of variation for the optimum P was from 50 to 81 kg P_2O_5/ha respectively for Pokkali and lateritic alluvium in the case of TCP application.

DISCUSSION

Reports on lack of response to phosphorus especially in the rice soils of Kerala are often being brought forward from various locations and sporadically by field officers. Disjointed attempts have been made in studying the lack of response of rice to phosphorus. Some of them attribute the lack of response as due to release of fixed native phosphorus consequent to continuous submergence (Padmanabhan Nair and Aiyer, 1966), as due to varietal tolerance (Mahendran, 1979), fixation of added soluble phosphatic fertilizers and there by of being no consequence to meet the requirements of the growing crops (Koshy and Brito-mutunayagom, 1961) etc. However, no systematic integrated attempt to investigate this problem of lack of response to phosphorus in rice soils in nearly all its aspects has been attempted so far especially in Kerala. The results embodied in this thesis can claim itself to be one in this direction in view of the varied nature of the approaches that have been attempted towards the solution of the central theme of explaining lack of response of rice to phosphorus under Kerala situations.

From the objectives already enunciated in the introduction and type of methodology adopted, the approaches attempted can be abstracted and listed as:-

(i) A study of various soil parameters, at times, critically contributing towards increased availability and in contrast parameters contributing towards greater fixation. A balance between these obviously interacting soil parameters which will ultimately decide whether P will be fixed or made available probably is to be hypothesised as defining the capacity of a soil to respond to application of phosphorus. From among various such soil parameters studied, nine important parameters have been taken into consideration as defining the behaviour of rice soils of Kerala in respect of their native P vis-a-vis added phosphates. On this basis the soils have been categorised into six categories or clusters which progressively indicate their pattern of native P and projected behaviour towards added P.

(ii) Detailed studies were conducted on soil P fractions both organic and inorganic and their inter-relationships with total P in particular besides working out their relationships with major soil parameters in general. This study which has thus brought out the major P fractions in different rice soil types helps to explain the chemical nature of phosphorus in the soil and the conditions under which the P will be available to plants.

(iii) Elaborate studies on phosphorus fixing capacity of rice soils as one of the important parameters in preventing responsiveness to added P particularly soluble phosphatic fertilizers have been carried out.

(iv) The studies on the pattern of transformation of P upon submergence help to explain changes in available P due to waterlogging and the shifting of a soil from one which is tested and rated as low in available P to one that is medium or high. The nature of this detailed study enabled how such a generalisation cannot easily be made and exceptions either way i.e., which decrease the available P or do not increase or decrease the available P on submergence exist.

(v) Two rice varieties, a short and medium duration, highly popular in the Virippu and Mundakan seasons, two among the three rice seasons in Kerala, have been tested under pot culture condition with graded levels of P in a soil low in total and available P i.e., soil conditions suitable for response. The response behaviour, pattern of uptake of P, peak periods of utilization of P etc., as worked out suggest further approaches of considerable practical significance in the management of P fertilization of rice.

(vi) In a paradoxical situation of fixation of high amounts of applied soluble phosphatic fertilizers but in the same soils release of minute quantities of available forms of P especially from applied rock phosphates the controversy continues to rage as to which form viz., rock phosphate or soluble phosphatic fertilizer is better. The only method of getting an answer to this vexing problem is to use ^{32}P labelled phosphatic fertilizers in both soluble and insoluble forms. Conducting response and uptake studies in one and the same experiment to bring out the relationship and proving unequivocally the equality or otherwise of the two forms leaving further choice to economic judicious resource utilisation and other considerations, is probably the only recourse. Optimum P requirement for maximum yield, contribution of native and added P to its uptake and consequently residual effects of different forms of P have also been worked out.

The results brought out by the series of experiments are in short, an attempt to describe the phosphate status of the rice soils and to explain lack of response of rice to phosphorus under Kerala situations. These are discussed to update the state of our knowledge in the light of the present study.

from which the soils are developed. It has to be realised that these soils are continuously in a state of being formed by alluviation and developed by pedogenic processes. Such a dynamic situation exists on account of their being situated in the flood plains of rivers, in ribbon valleys of the midlands or in low lying areas below sea level near the coast or on the fringes of the backwaters into which some of the rivers empty themselves. The variations in the major physico-chemical characteristics of the rice soils in Kerala were well brought out by a number of workers viz., Subramoney (1947), Janardhanan Nair et al. (1966), Venugopal (1969), Koshy (1970), Kurup and Aiyer (1973), Subramoney and Gopalaswamy (1973), Sreedevi Amma and Aiyer (1974), Panda and Koshy (1982), Aiyer et al. (1984) and others. The wide variations in physico-chemical characteristics of the soil, the complexity of natural conditions and the intensity of human activities may be responsible for the wide variations in the total P content.

This grouping has enabled us to predict the behaviour pattern of a rice soil from its total P content which will enable to locate the group to which it belongs. In fact there is considerable scope for furthering this work in terms of response studies based on the inclusion of a soil in a category and the general pattern of response of members of a category. It is significant to note that this clustering of soils for purpose of studies on P fixation and availability has broken the conventional classification of soils into various soil types such as lateritic alluvium (Inceptisol), coastal sandy alluvium (Entisol), Pokkali (Inceptisol), Kole (Entisol) etc. based on certain characteristic features or based on local names since in many of the clusters, soils belonging to more than one type are found to occur. The maximum number of soils (26.49 per cent) belong to the second category and the minimum (1.32 per cent) in the sixth category. Tentatively, if a further classification is made into low, medium or high based on total P, it could be observed that 37.09 per cent of the total soils (groups 1 and 2) come under low (a total P content less than 450 ppm), 47.02 per cent (groups 3 and 4) under medium (a total P content ranging from 451 to 900 ppm) and 15.89 per cent (groups 5 and 6) under high (a total P content more than 900 ppm) category. The soil recording a total P content less than 400 ppm was classified under low category for tropical soils (Kawaguchi and Kyuma, 1977). Thus the majority of the rice soils in Kerala can be categorised under medium group with respect to their P status.

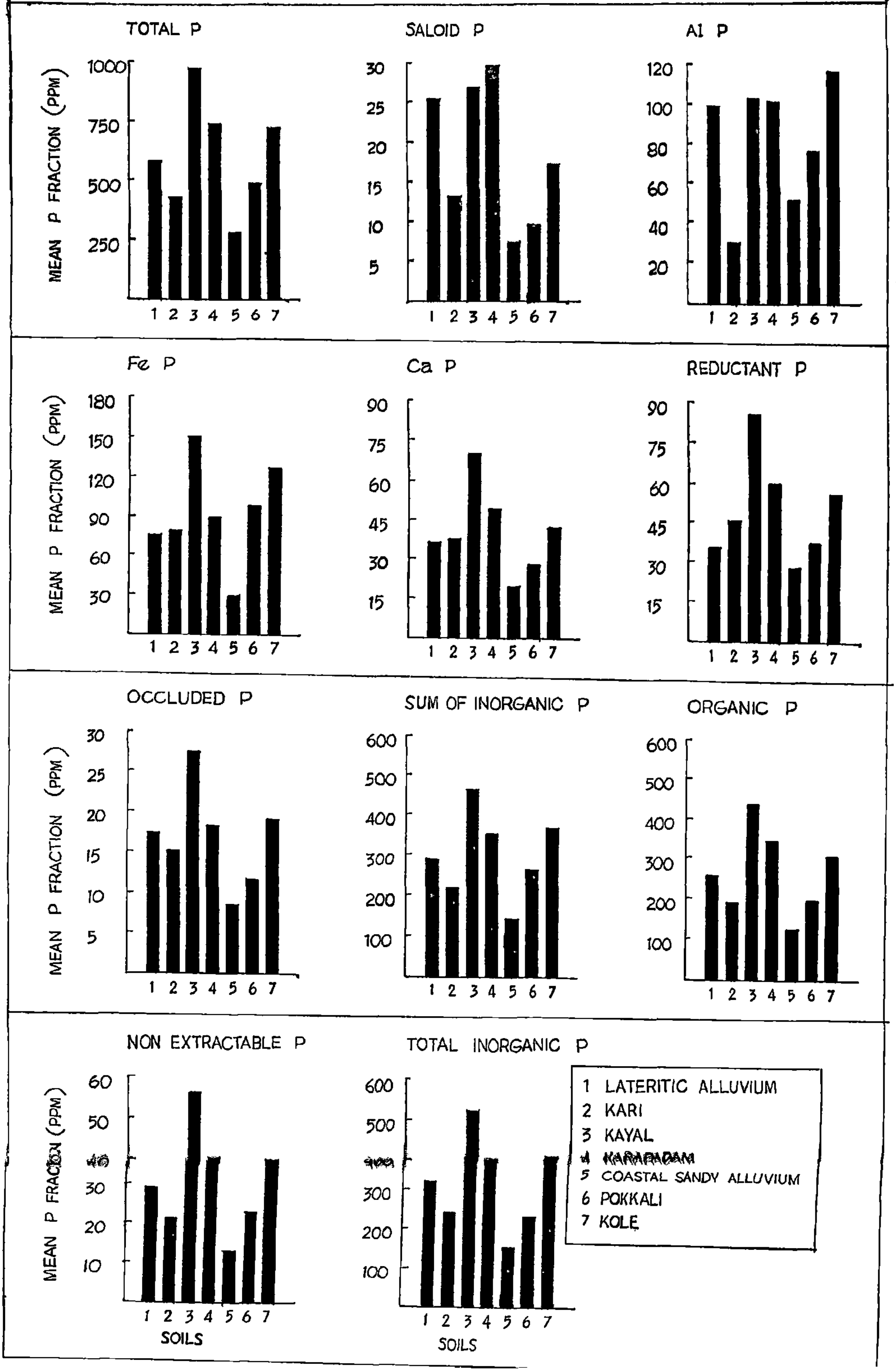
Based on this classification it has been observed that majority of the lateritic alluvium fall under medium (49.09 per cent) or low total P (38.18 per cent). None of the Kari soils have a high total P. The entire Kayal soils studied belong to either medium (53.33 per cent) or high P (46.67 per cent). A large number of Karapadam soils have either medium (52.94 per cent) or high P (35.30 per cent). None of the coastal sandy alluvium and Pokkali soils show a high P content. A maximum number of Kole soils have a medium P status (55.00 per cent). The highly leached coastal sandy alluvium and the Pokkali soils with sandy characteristics have poor P status.

An attempt has been made to use the statistical tool of classificatory analysis and index score method (Singh and Chowdhury, 1979) contrast to the principal component analysis discussed earlier. This is mainly with the intention to classify soils since it offered a greater possibility of testing the significance if they could be categorised. However, since no grouping could be obtained, this had to be given up. In classifying the soils using Classificatory analysis and index score method, the Bray 1-P has also been considered as a parameter among the nine included for the study. The Bray 1-P has been the most variable among all the parameters, the coefficient of variation being 95 per cent (Table 2). It indicates that profound variation exists between various soils with respect to the available P content. But the available P as estimated by Bray 1 method has not shown any definite pattern of increase or decrease with an increase or decrease in total P content. Thus total P itself may not be a single factor governing P availability. There may be factors like PFC, R_2O_3, pH, clay, silt, organic matter, CEC etc., which are as important to characterise the soils and define the P availability. The probability of obtaining a profitable response to P application exists since the majority of Indian soils (98 per cent) and also Kerala soils (more than 84 per cent) have either low or medium total P.

2. <u>Phosphorus fractions of rice soils</u>

A knowledge on the amount and chemical nature of various fractions of phosphorus in the soil and the conditions under which they become available to plants is a pre-requisite since the availability of P to growing crops depends on the solubility of P fractions in the soil. It is well known that the marked variation in the different forms of phosphorus is a function of genetic differences among soils (Chang and Jackson, 1958) organic matter, calcium carbonate and sesqui-oxide content in addition to the cropping system appear to be guiding factors in determining the distribution of different forms of phosphorus.

FIG 2 MEAN P FRACTIONS OF RICE SOILS



The observations on various fractions of phosphorus and the relationship between each form of P with important soil characteristics are discussed below. (Tables 3 to 24 and Fig. 2)

2.1. <u>Total phosphorus</u>

Appendix III indicates significant variation in total P content (108 to 1763 ppm) for various soil types. It may possible be due to the differential characteristics of the parent material from which the soils were developed and also the profound and varied influence of human activities. A reference to Table 3 indicates that coastal sandy alluvium have the lowest mean total P content (280.8 ppm) and Kayal soils, the highest (962.5 ppm). The low total P recorded by the coastal sandy alluvium is in conformity with the observation made by Yadav and Pathak (1963) for the Indian coastal sands. The coarse textured and intensively leached soils have poor reserve of phosphorus. But Aiyer et al. (1984) observed the high content of P in coastal sandy littoral soils of Kerala. The maximum variation in total P has been observed for lateritic alluvium and the minimum for Kayal soils.

2.1.1. <u>Saloid - P</u>

As in the case of total P, the coastal sandy alluvium has recorded the lowest content of saloid-P (Table 4), the reason may be that these soils do not contain appreciable amounts of sorbing or binding sites for phosphorus. The high content of clay or sesqui-oxides in Karapadam soils may possibly increase the sorption of P by these soils. The Table 14 indicates a comparatively low contribution by this fraction (1.92 to 4.75 per cent with an average of 3.22 per cent for all the soils taken together) to total P which further defines the sorbing capacity of these soils for P. Major quantity of the phosphorus may either be converted into Fe-P, Al-P or similar compounds other than loosely bound form indicating the high phosphate fixing capacity of these acid soils.

2.1.2. Al-P

The mean Al-P (Table 5) has been observed to be lowest for Kari soils (30.4 ppm) and highest for Kole soils (116.2 ppm) indicating a wide variation between soil types. It contributes 13.81 per cent to the total P, the second most dominant factor next to Fe-P in the total pool of phosphorus. The high R_2O_3 content in the soils and also the low pH may decide upon the dominance of this fraction and the presence of Al-P in soils is mostly dependent upon the pH and Fe-P or soil iron content. The results of the present investigation are in agreement with the findings of earlier workers such as Mathan, (1964) and Vijayachandran (1966) for Tamil Nadu soils and Aiyer and Nair (1979) for Kerala soils.

2.1.3. Fe-P

The highly leached coastal sandy alluvial soils with low R_2O_3 and comparatively moderate and only pH near neutrality have recorded a low Fe-P content of 28.1 ppm (Table 6). The Kayal soils have recorded a comparatively high Fe-P content of 151.3 ppm among the seven soils under study. The acid nature of Kerala soils may possibly be one of the reasons for the dominance of Fe-P over all other fractions contributing to total P and the average proportion of Fe-P to total P being 15.49 per cent. The low pH and high content of sesqui-oxides may be responsible for the predominance of Fe-P in the laterite and other acid soils. The percentage contribution of Fe-P to total P has however been lowest (10.00) for coastal sandy alluvium and highest (20.31) for Pokkali soils, the latter having a very low pH compared to a pH slightly on the acid side or neutral for the coastal sandy alluvium.

2.1.4. Ca-P

The mean Ca-P fraction has also been lowest for coastal sandy alluvium and highest for Kayal soils (Table 7). The acid nature of soils may be the reason for the low contribution of Ca-P (6.79 per cent) to total P. The differences between the percentage contribution of Ca-P to total P in various soils is not very high. Chang and Jackson (1958) opined that in calcareous soils or soils that had not much weathered, most of the inorganic P was present as Ca-P. The highly weathered riverine alluvium, very often may contain lesser quantities of Ca-P. Jose (1973) observed that in neutral and alkali soils of South India, Ca-P dominated over Fe-P and Al-P, and Ca-P increased with increase in pH which lends support to the observations made in the acid soils of Kerala.

2.1.5. Reductant-P

The reductant-P is observed to be the third abundant fraction of phosphorus. As in the case of other fractions, reductant P has also been low for coastal sandy alluvium and high for Kayal soils (Table 8). Highly weathered soils according to Chang and Jackson (1958) always contained appreciable amounts of reductant-P. They further observed that the reductant soluble P was due to an iron oxide precipitate formed on the surface of iron and aluminium particles during weathering by hydrolysis of ferric iron. The fact that the acid soils of Kerala contained reasonably a good proportion of reductant-P over total P (8.25 per cent on an average for all soils) confirms that these soils are developed on recent alluvial deposits (Aiyer and Nair, 1979).

2.1.6. Occluded-P

Table 9 indicates that the lowest conc. of occluded P of 8.5 ppm has been recorded by coastal sandy alluvium and the highest conc. of 27.6 ppm by Kayal soils. The average per cent contribution of this fraction to total P for all soil types has been 2.82 (Table 14), comparatively a low value when Fe-P, Al-P, reductant-P and Ca-P fractions are compared. Significant difference in occluded-P could not be observed between lateritic alluvium, Kari, Karapadam and Kole soils and is in conformity to the earlier findings of Aiyer and Nair (1979) for rice soils of Kerala and Jose (1973) for the neutral and alkali soils of South India.

2.1.7. Sum of inorganic-P

The sum of inorganic P is found to be lowest for the coastal sandy alluvium (Table 10) since majority of the inorganic P fractions in these soils are low due to a low sesqui-oxide content and also low content of other parameters of the soils viz., organic matter, silt, clay etc., responsible for the P sorbing capacity of the soils. The Kayal soils has registered the highest quantity of sum of inorganic P. Unlike coastal sandy alluvium and Pokkali soils, other soil types viz., lateritic alluvium, Kari, Kayal, Karapadam and Kole have a comparatively high conc. of P sorbing parameters. About 50 per cent of the total extractable P can be accounted by the sum of inorganic P and the remaining 50 per cent by the organic and non-extractable form of phosphorus for all the soils taken together.

The present observation of the dominance of Fe-P, followed by Al-P in the acid soils is in conformity with the findings of Chai Moo Cho and Caldwell (1959) in Minnesota soils; Janardhanan Nair (1961), Vijayachandran (1963, 1966), Nambiar (1962), Bhat (1964), Rajaram (1964), Aiyer and Nair (1979) and Sundaresan Nair and Aiyer (1983) in Kerala soils; Kanwar and Tripathi (1977) in acid soils, and Mathan (1964) in the high level latosols of Nilgiris hills in Tamil Nadu and Cholitkul and Tyner (1971) in low land soils of Thailand.

2.1.8. Organic P

The low organic P levels in coastal sandy alluvium and their higher content in Kayal soils (Table 11) may be due to either low or high organic matter content in these soils when compared to other soils under study as observed by Jackman (1955) and Mehta et al. (1971). The acid soils of Kerala showed a wide variation in organic P ranging from 0.8 to 42.4 per cent to total P as reported by Koshy and Brito-mutunayagom (1961). For all the soil types on an average, the organic P accounted 44.3 per cent on the total P. One third of the total P was observed to be in the organic form by Fuller and Mc George (1951) for calcareous soils where as only 10 to 20 per cent of the total P was the contribution by organic P for Kanpur soils as recorded by Goel and Agarwal (1959).

2.1.9. Non-extractable P

The coastal sandy alluvium which contained a low total P has recorded a low quantity of non-extractable P and Kayal soils with highest total P have showed a high conc. of this fraction (Table 12). About 5.34 per cent of the total P could not be extracted by the fractionation procedure as outlined by Chang and Jackson (1956), a defect pointed out earlier by Aiyer et al. (1984) for coastal sandy littoral soils of Kerala. They attributed this to residual accumulation of Thorium phosphate of monozitic minerals present in the littoral coastal sandy soil during the Chang and Jackson fractionation. The sesqui-oxide conc. may decide upon the quantity of non-extractable P in the Chang and Jackson method of fractionation and the high value of non-extractable P observed in the laterite and acid soils may be associated with the hydrated sesqui-oxides.

2.1.10. Total inorganic P

The coastal sandy alluvium and Kayal soils have been observed to contain a low and high content of total inorganic P respectively. This may be due to the fact that total P itself has been respectively low and high for these soils. There is not much variation between various soil types for the percentage contribution of the total inorgani P to the total P, the average being 55.6 per cent.

In correlation studies between various P fractions and soil properties (Tables 15 to 24) significant positive relationships have been observed between all the P fractions except saloid P in Kari, Kayal, Karapadam, coastal sandy alluvium and Kole with total P as well as with sum of inorganic P indicating the presence of a close equilibrium between them for all the soils in general. Same is the case with the relations between various P fractions except Saloid P and Al-P with non-extractable P. It is interesting to note that the P fractions increase substantially as the total P increases. The correlation coefficients between total P and the various P fractions for all the soils considered together have ranged between 0.73 to 0.99.

3. Phosphorus fixing capacity of rice soils

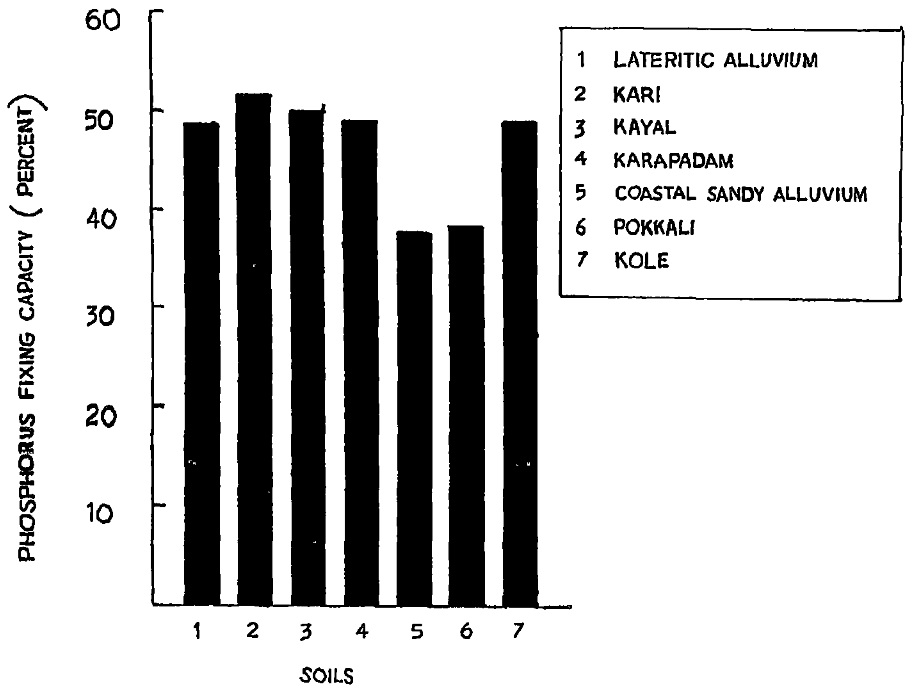
The fixation of native and applied phosphates is generally considered to be the main cause of its low availability. Research on soil phosphate is further complicated by the fact that each of the phosphate ion forms a multitude of compounds of low solubility and often of highly variable composition. The term phosphorus fixation is the process whereby readily soluble phosphorus is changed to less soluble forms by reaction with inorganic and organic components of the soil, with the result that the phosphorus becomes restricted in its mobility in the soil and suffers a decrease in its availability to plants.

Among the seven rice soils, the mean phosphorus fixing capacity (Table 25 and Fig. 3) has varied from 36.10 (coastal sandy alluvium) to 52.75 per cent (Kari soil). Significant difference in PFC between the various soil types (Appendix IV) has been noted as observed by Koshy and Brito-mutunayagom (1961) in their studies on P fixation and P availability in Kerala soils and Nad et al. (1975) in various soil groups. Comparatively a low H ion conc., poor R_2O_3 and clay content in coastal sandy alluvium and high conc. of H ions, R_2O_3 and clay content in Kari soils may be responsible for the lowest and highest P fixing capacities respectively for these soils. The differences between the mean PFC of lateritic alluvium, Kari, Kayal, Karapadam and Kole soils are not significant. The similarity of Kuttanad acid soils, lateritic alluvium and Kole with respect to PFC is brought out unlike coastal sandy alluvium and Pokkali soils which have formed a separate group. Since the fixed P is added to the total pool of phosphorus, the coastal sandy alluvium has been observed to be having a low PFC has recorded a low total P status also.

3.1. <u>Factors governing phosphorus fixing capacity</u>

A number of soil factors control and govern P fixation

FIG 3 MEAN PHOSPHORUS FIXING CAPACITY (PERCENT) OF RICE SOILS



which itself is highly variable from soil type to soil type in view of both variation in governing factors as well as interaction and interplay of the factors there of. This is an aspect critical in the study of factors governing patterns of response to applied P by a given soil. In view of this, the PFC has been investigated in relation to various factors in detail. Correlations and linear regressions are computed between PFC and various soil parameters (Table 26 to 42).

The correlations and regression coefficients between PFC and pH are negative and significant for all the soil types. However, the intensity of influence of pH on PFC has been varying with the soil types depending upon the extent of acidity. Parfitt (1978), Freisen et al. (1980) and Hynes (1983) observed the significant negative effect of pH on PFC. At lower pH values, there will be free Fe and Al ions, responsible for precipitating the phosphate anions and thus increasing the PFC of the soils.

Similar to the influence of pH, negative correlations and regressions are obtained between PFC with organic carbon, total CaO, total MgO, CEC, Exch. Ca., Exch. Mg., C/P ratio, active P and sand content for all the soils studied. The negative effect of organic matter on the PFC of the soil was well brought out by the earlier work of Datta and Srivastava (1963) and Kanwar and Grewal (1960).

The organic matter either reduces the intensity of P fixation by the sesqui-oxides or the anionic organic compounds released from organic matter compete with phosphate anion in polar adsorption by soil colloids and thus decreases P fixation.

The total CEC, nature and quantity of exchangeable cations present in the colloidal complex etc. play an important role on PFC. The observations of Kanwar and Grewal (1960) on the effect of degree of base saturation on the PFC of the acid soils of Punjab are in total agreement with the present findings. Since all the soils included for the study are acidic and the total CaO, total MgO, CEC, Exch. Ca., and Exch. Mg. are comparatively less the PFC of the soils has been high depending upon the extent of CEC and percentage base saturation. Though the active P contains both Fe-P and Al-P, the influence by Ca-P has produced a net negative response for actice P on PFC. The negative influence of sand on PFC was well established by Patel and Viswanath (1946) confirming the results obtained in the present study.

The PFC is significantly and positively influenced by the total sesqui-oxides, total Fe_2O_3, total Al_2O_3, silt, clay, C/N ratio and Fe_2O_3/Al_2O_3. The correlation coefficients are narrowest (0.81 to 0.99) between PFC and total sesqui-oxides for all the soils among the various factors. The sesqui-oxides present in the free state and in the hydrated forms are considered the main cause of phosphate fixation in acid soils. The iron and aluminium containing soil minerals including clay minerals are the source of iron and aluminium. The effects of sesqui-oxides, active Fe and Al were widely reported by workers like Raychaudhuri and Mukherjee (1941), Coleman (1942, 1944 a, b) Konwar (1956), Leaver and Russel (1957), Coleman et al. (1960), Hsu (1965), Vijayachandran (1966), Fox et al. (1971) and Jose (1973). The acid soils with high silica: sesqui-oxides have high capacities for P fixation, the observation by Koshy and Brito-mutunayagom (1961) is in conformity with the present finding. Similar results were reported by Raychaudhuri and Mukherjee (1963), Ned et al. (1975) and Danilo Lopez-Hernandez and Burnham (1982). The hydrated sesqui-oxides on their positively charged exchange sites anionically exchange phosphate which later undergoes adsorption plus reactions. These later get more complicated to lead to complex reaction products. The variation in the r values between the different soils may be due to the total content and nature of sesqui-oxides. As a consequence the nature and quantity of the reaction products vary considerably as influenced by other soil factors.

It has been generally accepted that most of the phosphate fixing power of soils lie in its finer mechanical fractions, expecially clay. The differential behaviour of various soils may be due to the amount of clay, silt, Fe_2O_3/Al_2O_3 or nature of clay minerals present. Raychaudhuri and Mukherjee (1963), Koshy and Brito-mutunayagom (1965) and Nad et al. (1975) have expressed similar views on the positive influence of clay, silt, Fe_2O_3/Al_2O_3 on the PFC. In acidic soils, the iron and aluminium containing clay minerals may be more resulting in a high quantity of P getting precipitated or the hydrated oxides of iron and aluminium adsorb the phosphate to form some complex compounds, totally unavailable to the plants.

A stepwise regression analysis carried out to assess the relative influence of selected independent factors such as pH, R_2O_3, CaO, MgO, CEC, Organic matter and clay content on the PFC of different soils are presented in Table 43 to 49. The results show that the sesqui-oxides exert a maximum per cent variation on the PFC of lateritic alluvium (97), Karapadam (90), Pokkali (92) and Kole (97), pH in Kari soil (94) and coastal sandy alluvium (82) while CEC in the case of Kayal soil (40). These results clearly bring out the subtle differences in the contribution of the factors to PFC in different soils and some of their indirect effects as well. Thus in the lateritic alluvium, Karapadam Pokkali and Kole soils, the sesqui-oxides contribute more than 90 per cent towards the total PFC. It is known that the hydrated sesqui-oxides which are abundantly present in the waterlogged situations contribute maximum towards anion exchange capacity in a soil. Further, P fixation is also known as the anion exchange plus reaction. Thus the very initiation and furtherance of anion exchange process and further adsorption and precipitation products of iron and aluminium phosphates are initiated by the presence of the sesqui-oxides in the soil. This ability to initiate the retention of P increases with increasing conc. of iron and aluminium as exemplified by a gradation shown in the PFC of Karapadam, Pokkali, Kole and lateritic alluvium. In Kari soil with very low pH and high amounts of organic matter and in coastal sandy alluvium with moderate pH and with both low organic matter, iron and aluminium, pH is the dominant factor governing P fixation. In both cases, pH and factors decreasing pH will indirectly enhance solubilisation of iron and aluminium enhancing precipitation reaction and P retention. In the Kayal soils saturated with lime shells and having a pH around 6.5 to 7.0, it is natural to expect 90 per cent of the CEC saturated with Ca Under such circumstances it is no wonder that CEC is seen to be the major factor governing P fixation. Though Patel and Viswanath (1946), and Nad et al. (1975) and other researchers studied both PFC and factors governing it, the present critical studies have made it clear that in certai acid soil types (lateritic alluvium, Karapadam, Pokkali and Kole) while sesqui-oxides are the dominant factor in certain others (Kari and coastal sandy alluvium), pH becomes the dominant one relegating sesqui-oxides to the second position. Even a slightly acid or near neutral soil like the Kayal soil of Kuttanad, which is calcareous due to the occurence of lime shells have CEC as the dominating factor. The present study has thus brought out the criticality of the factors in controlling the PFC of acid soils of not too widely varying pH values and all of them on the acid side of neutral.

4. Pattern of transformation of phosphorus due to submergence

Land submergence is known to influence the transformation and availability of both native and applied phosphorus. P fractions in rice soils under natural situations (submerged conditions) in contrast to aerobic non-submerged situations (prevailing usually only at the time of harvest of rice crop) needs to be differentiated and studied soil typewise to interpret variations in the pattern of response of rice in various rice soils of Kerala. The relationship between available P and crop response worked out for upland soils may not hold good for low land rice as P transformation is known to be associated with Eh and pH changes in flooded soils. Except for some early or preliminary studies on the distribution of soil phosphorus and its availability in rice soils of Kerala by Koshy (1952), Koshy and Brito-mutunayagom (1961), Aiyer and Nair (1979) and Aiyer et al. (1984) and others, very little authoritative information is available on the kinetics of inorganic P fractions and the available P due to submergence. In the study, laboratory sampled rice soils were uniformly re-waterlogged for a period of 16 weeks corresponding to the period of harvest of rice crop to study the extent of simulation of field waterlogged situations. In each soil type two samples, one with a low total P and another with a high total P were selected. They belong to the first (Lateritic alluvium, Kari, coastal sandy alluvium and Pokkali soils), second (Karapadam and Kole soils) and fourth categories or clusters (Kayal soil) which registered a low total P and to the third (coastal sandy alluvial soil fourth (Kari and Pokkali soils), fifth (Karapadam soil) and sixth clusters (lateritic alluvium, Kayal and Kole soils) which registered a high total P.

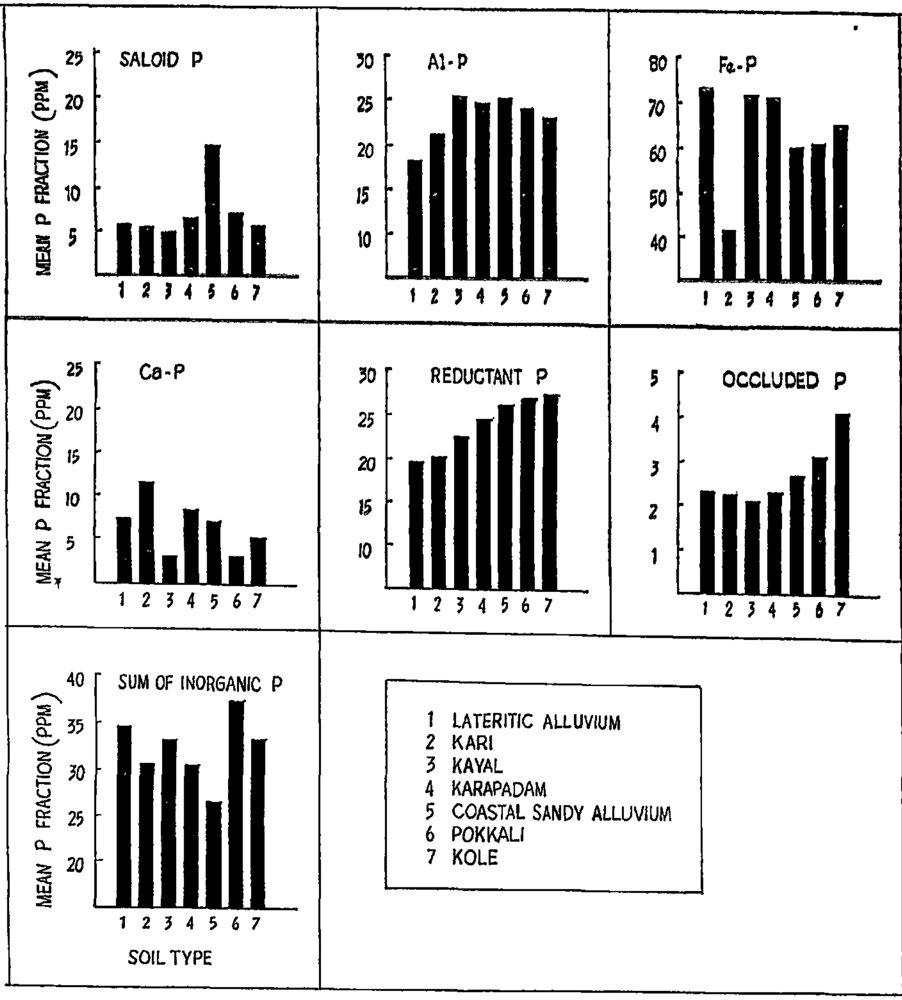
Though the transformation of P due to submergence has been studied in general, the magnitude of its variation especially the inorganic P fractions and available P in different rice soil types with both high and low total P has not been studied earlier. In fact such a detailed scrutiny in the present study has brought out significant differences which are meaningful in explaining differentia behaviour of soils in producing response to applied phosphatic fertilizers. The results on the transformation of inorganic P fractions du to submergence and available as estimated by four different method viz., Bray 1, Bray 2, Olsen and Truog methods are discussed below.

4.1. Inorganic P fractions

Under air dry conditions excepting Al-P all the other inorganic P fractions have been lowest in coastal sandy alluvium and highest in Kayal soils. When the Al-P content is lowest in Kari it is highest in Kole soils. Upon waterlogging all the soils have registered an increase in all the inorganic fractions of phosphorus. (Table 50 to 56 and Appendix V). Excepting the Al-P fraction in Kari soil, the coastal sandy alluvium has recorded the lowest value for all the inorganic fractions of P due to submergenc With the exception of Kole soil which has recorded the highest value for both saloid-P and Al-P, Kayal soils have recorded the highest value for all other fractions of P. Those soils having a low or high content of P fractions in the air dry condition have registered correspondingly a low or high value under submerged situation also. This is in conformity with the findings by Mandal and Chatterjee (1972) that the transformation of P into Al-P and Fe-P appeared to be directly related to the quantity of these inorganic forms of P already present in the soils. The observations by Aiyer and Nair (1979) and Sundaresan Nair and Aiyer (1983) on the increase of Al-P, Fe-P and Ca-P upon submergence in rice soils and the findings of Verma and Tripathi (1982) that native inorganic P fractions increase upon waterlogging agree with the results obtained in the present study.

A reference to Table 57 and Fig. 4 indicates that the percentage increase in P fractions due to submergence has been differing with respect to soil types and the same may be due to the difference in the original status of each P fraction before submergence. The average percentage increase has been lowest for occluded-P (2.7) and highest for Fe-P (63.5). The Al-P and reductant-P have behaved more or less uniformly when all the soils taken together. Similarly with respect to the contribution of each P fraction in the total variation of inorganic P due to submergence (Table 58), occluded-P has been observed to be contributing to 2.2 per cent (lowest) while Fe-P, 48.9 per cent (highest). In the acid rice soils, the dominance of Fe-P fraction and hence the availability of Fe-P will be more due to submergence resulting in a high absorption of P by rice plant. Mahapatra and Patrick Jr. (1969) opined that the dissolution of the coating of hydrated ferric oxide around the soil particles possibly resulted in the release of Fe-P. They (1971) further found that when Al-P increased

FIG. 4 PERCENTAGE INCREASE OF P FRACTIONS IN RICE SOILS DUE TO SUBMERGENCE



by 35 per cent, Fe-P increased by 64 per cent and Ca-P did not undergo much change due to waterlogging. The observations by Mandal and Khan (1975) indicated that continuous waterlogging for 110 days caused an increase in Fe-P in all soils and the work by Verma and Thripathi (1982) found a maximum increase of 70.7 per cent in Fe-P upon submergence. The above views are in total conformity with the results currently obtained.

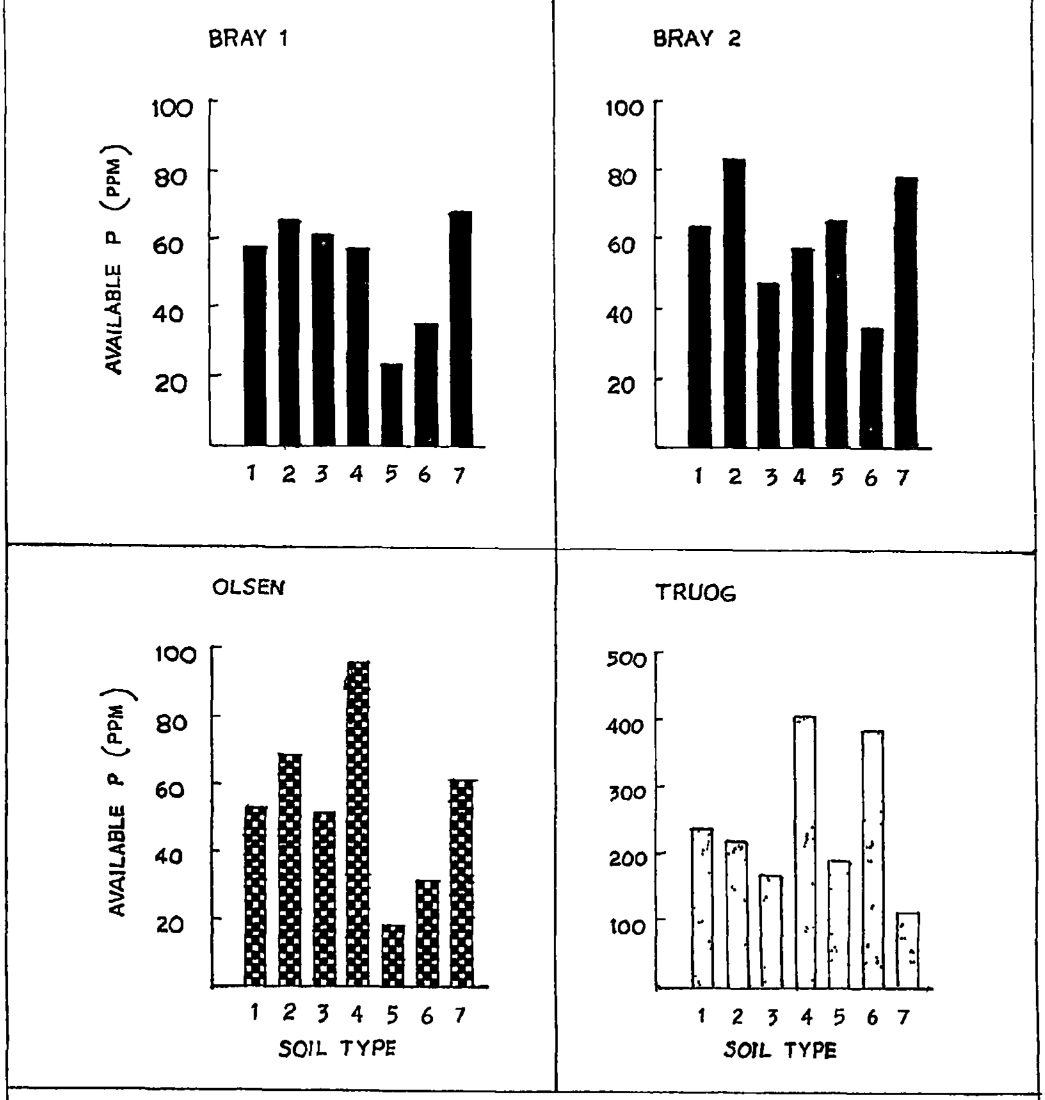
4.2. Available Phosphorus

The mean available P for all the soil types has been lowest (6.1 ppm) under air dry conditions and highest (13.5 ppm) under waterlogged conditions (Table 59). The difference between the mean values of available P estimated by all the four methods in all soil types is found to be significant (Appendix VI). The occurence of a marked increase in the availability of native and added P in flooded soils as compared to well drained soils was well established by Shapiro (1958 a), Ponnamperuma (1964), Padmanabhan Nair and Aiyer (1966), Mahapatra (1968), Basu and Mukherjee (1969), Mahapatra and Patrick Jr. (1971), Mandal and Khan (1975, 1977), Goswami and Banerjee (1978), Verma and Thripathi (1982) Katyal and Venkatramayya (1983) and Sharpley and Smith (1983). Though there is difference between the methods in extracting the available P both under air dry and waterlogged conditions, their suitability has to be judged in relation to plant growth parameters. The soils have differed with respect to the P availability unde air dry and waterlogged conditions.

The average per cent increase in P availability due to submergence is lowest (52.6) by the Bray 1 method and highest (244.1) by the Truog's method (Table 60 and Fig. 5) Basak and Bhattacharya (1962) reported a 64 per cent increase in soil available P from planting to tillering stage of rice plant. The increase in P availability was reported to be either due to the reduction of iron and aluminium (Basak et al. 1960) or due to the dissolution of solid phase Fe-P by the drop in redox potentials (Ponnamperuma, 1964). Ponnamperuma (1972) suggested two ways by which increase in P availability due to submergenc could be achieved. (i) a decrease in the levels of soluble forms of elements such as iron, manganese and aluminium and (ii) a decrease in the sorption and occlusion of P on soil solid phase. Goswami and Banerjee (1978) considered the causes of the increase in available P in soil to be (i) release of P from organic P (ii) increase in solubility of P resulting from decreased soil pH due to the accumulation of Co_2 in calcareous soil (iii) reduction of $FePO_4.2H_2O$ to $Fe_3(PO_4)2.8H_2O$ with higher solubility. (iv) higher solubilities of $FePO_4.2H_2O$ and $AlPO_4.2H_2O$ resulting from hydrolysis due to the increase of soil pH in acid and strongly acid soils. (v) release of phosphate ions from the exchange between organic anions and phosphate ions in iron and aluminium phosphates and (vi) increased diffusion of phosphate under submerged conditions. Katyal and Venkatramayya (1983) attributed high temperature as one of the reasons for the increase in water soluble P.

Since several inorganic P fractions have been investigated both under aerobic and submerged situations and available P has been determined by four different methods from both air dried as well as submerged soils, intercorrelation matrix between the percentage increase in available P estimated by various methods and percentage increase in inorganic P fractions due to submergence has also been worked out and tested for their significance (Table 61). However none of the correlation coefficients has been found to be significant indicating thereby that the inorganic P fractions studied in detail indicate only one side of the picture. It is very much possible that number of other factors are differently acting so as to prevent the intercorrelation matrix from becoming significant. Evidently such factors could be the organic P fractions, transformation of organic P by microbial population, variations in the content of non-extractable P (residual P) and various factors contributing to solubilizing them differentially under submergence. In fact these are aspects which have not been studied in detail and which

FIG 5 PERCENTAGE INCREASE OF AVAILABLE P (PPM) DUE TO SUBMERGENCE BY DIFFERENT METHODS



1 LATERITIC ALLUVIUM
2 KARI
3 KAYAL
4 KARAPADAM
5 COASTAL SANDY ALLUVIUM
6 POKKALI
7 KOLE

do require very intensive further studies. However, Fe-P fraction being the dominant one, might be influencing the estimate of available P by different methods as observed by Verma and Tripathi (1982) who stated that waterlogging increased the P availability indices determined by seven chemical extractants. From their step-wise regression studies also Fe-P has been found to be the most important variable contributing to the total variation in the regression of Olsen, Bray 1, Bray 2, Truog, Peech and Morgan's both in air dry and waterlogged soils.

In rice culture, frequently due to failure of rainfall or delayed monsoon, the field may be alternately flooded or dried. Under these conditions the P transformations may not be exactly similar in nature to those under continuous submergence. Addition of organic or inorganic nutrients may also accelerate the transformation of P. These aspects have also to be taken care of for predicting the behaviour pattern of rice crop to the application of phosphatic fertilizers.

5. Response of rice to graded doses of Phosphorus

Earlier results obtained by Mahendran (1979) based on field experiments conducted in this institution had delineated Mashoori as a medium responder and Jyothi as a low responder to P corresponding to their medium and short duration. The term 'non-responder' used for the variety Jyothi was however to be further tested. The detailed pot culture study with Mashoori and Jyothi including observations on root parameters conducted in the present study are intended to bring out clearly these subtle differences in the varieties in relation to their pattern of response as guided and controlled by the total and available P status of soils. Some of the salient results obtained are itemised and discussed below to bring out the essential points.

5.1. Available phosphorus at various growth stages

The available P has been determined by four common methods from the soils under various P treatments and grown to two different rice varieties, viz., Mashoori and Jyothi and at three stages of growth, 30th and 60th days and at harvest. Since fractionation of soil P at all these stages has also been carried out, considerable data on intercorrelations and stepwise regressions between available P estimated by various methods on the one hand and inorganic P fractions on the other have been generated. The available P estimated by all the four methods have also been correlated with various yield contributing and or biometric factors as well as yield.

The ANOVA (Appendix VIII) and the mean Table (62 to 64) indicate that the available P as estimated by the three methods viz., Bray 1, Bray 2 and Olsen has been influenced by differences in the varieties of rice grown in the soil, doses of phosphatic fertilizers added and the growth stage of the crop. The estimate of available P by Truog's method is seen to be influenced by varieties on 60^{th} day and phosphate treatments on the 30^{th} day of sampling only. Truog's estimate of available P is unaffected by other parameters on the 30^{th} and 60^{th} day, by all the parameters at harvest. These results though apparently pedestrian are really not so. Thus, out of all the four different methods of available P extraction, at least three are seen to be seriously affected by differences in variety of rice grown in them prior to sampling. This may be due to a modification in the total rhizosphere and nature of the root exudates. This is an aspect of study which has not been systematically attempted.

The observed differences in available P estimated by different methods for various levels of P treatment (Superphosphate) have been mainly due to the partitioning of the soluble phosphates into various inorganic and organic forms.

The mean available P in soil at various growth stages as indicated by all the extractants (except Truog at harvest stage) is lower in pots grown with Mashoori. Root studies conducted at various stages show that Mashoori has a more extensive and ramified root system than the variety Jyothi. This only corraborates the faster depletion of available P in the soil grown to Mashoori compared to the soil grown to the variety, Jyothi. Similar attempts at establishing relationships of uptake patterns in relation to root parameters have been made by Kamath and Oza at New Delhi (1979), Mahendran (1979) at Vellayani and Sumio Itoh and Barber (1983).

Excepting Truog's-P on 30th day of sampling, the available P estimated by all the four methods at all stages have been positively and significantly correlated with all the inorganic P fractions (Table 72). The extent of contribution by each fraction on the available P determined by the different methods has been further analysed with stepwise regressions (Table 73). Thus the proportion of available P estimated by both Bray 1 and Bray 2 derived from Fe-P is greater to the extent of 90 per cent. The contributions of saloid P towards available P by Olsen's method and of the Al-P fraction on available P by Truog's method on 30th day are respectively 78 and 62 per cent. When the Al-P has contributed by about 98 per cent towards the available P estimated by Bray 1 and Bray 2, reductant P did so by 87 per cent on Olsen's P and saloid P by 12 per cent on Truog's P, all on the 60th day. At harvest stage, the Ca-P fraction is responsible for about 95 per cen of the Bray 1 and Bray 2 available P while its contribution has been 97 per cent on Olsen's P. Occluded P has accounted for 36 per cent on Truog's-P. The observed non-uniformity in the contribution of P fraction to the various extractant is readily understood. In fact it is significant to note that based on differences in the nature of the extractants, moisture regimes and stage of crop, crop exudates, crop residues etc., in the soil, Bray 1 and Bray 2, the recommended extractants extract maximum available P in the form of Al-P and Fe-P in the waterlogged situation on 30th and 60th day while, at harvest stage when conditions are dry, Ca-P fraction has contributed highest towards available P. On the other hand Olsen's reagent has extracted available P in mostly saloid and reductant P during periods o. waterlogged situation and Ca-P during harvest period of the crop which is an aerobic situation.

The reliability of each method of estimation of available of P nas been further judged with the help of correlations and regres.ions (Table 74 to 77) between the available P estimated by the four methods and biometric and yield characteristics. Significant positive correlations have been observed between available P determined by all the four methods except Truog and biometric and yield characteristics, in general, indicating there by that Bray 1, Bray 2 and Olsen can be suitable extractants for estimating the available P content. Further it has been observed that Olsen's P is responsible for about 74 and 51 per cent respectively among the other three methods on grain and straw yields (Table 76). The P uptake and grain yields are highly correlated ($r=0.92^{**}$). The superiority and reliability of Olsen's method in predicting the available P in the soil have been further emphasised by its contribution (68 per cent) on the estimate of P uptake by the rice crop at its harvest stage though Bray 1 and Truog's-P are mainly responsible (55 and 60 per cent respectively) on total P uptake at 30th and 60th day of sowing. The growth stage of the crop may also play a decisive role in the estimate of available P in the soil, the P uptake and hence the suitability of the extractant in view of the sequence of transformations of P under submerged situations. Further, the P fraction which dominates the available P and gets absorbed by the crop also depends upon t e growth stage as observed by Ramamoorthy and Bisen (1971) and also the moisture regime and other soil conditions.

5.2. Inorganic P fractions at different growth stages

The inorganic forms of phosphorus have been determined at 3 stages in soils treated with different doses of phosphorus where in the two rice varieties (Mashoori and Jyothi) have been grown. The relationship between various inorganic P fractions and biometric as well as yield characteristics have been evaluated by correlations and stepwise regressions. Further, intercorrelations and multiple regressions between P fractions and P uptake have also been worked out to emphasise the influence of each P fraction on the various crop characteristics at all stages of observations.

In general, the influence due to treatment on various inorganic P fractions at all the growth stages of the crop as indicated in the ANOVA (Appendix A) has been observed to be significant unlike the varietal and the interactional effects. The addition of phosphatic fertilizers in the soil produces a change in the different fractions of phosphorus. The mean values of various inorganic fractions of P (Table 65 to 67) indicate that varieties could not make any significant effect on them. The highest dose of P has recorded the highest values for all P fractions. Among the various inorganic P fractions, Fe-P has been found to be the highest at all stages of growth due to varieties, treatments and indirectly due to their interactions. Among the P fractions, occluded-P has recorded lowest values as influenced by varieties both on 30th day and at harvest. Low values of saloid-P have been recorded for soils under the lowest dose of phosphatic fertiliser on 30th and 60th days after sowing and occluded-P at harvest. Similarly low values for occluded P have been observed for the highest dose of P at all growth stages of the crop. Varieties, Jyothi and Mashoori grown in the same soil having identical quantities of different inorganic fractions of P at the beginning of the cropping period, treated with varying quantities of P have been able to bring about a differentiation in the spectrum of inorganic P fractions. Thus Mashoori grown soils progressively have decreased in their content of various inorganic P fractions.

A slight increase has been observed in the sum of inorganic P fractions from the 30th to the 60th day after sowing and thereafter a decline in the concentration of P fractions for both the varieties and treatments at harvest stage.

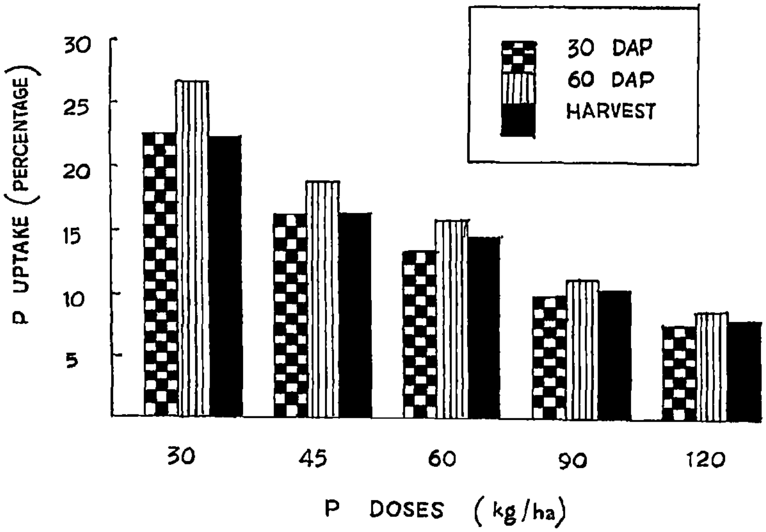
The grain yield has been significantly correlated with all the inorganic P fractions except occluded-P but the correlation coefficients between straw yield with Fe-P, Ca-P and sum of inorganic-P have alone been significant (Table 78). The significant relationships indicate the responsiveness of the rice crop to P fertilization especially when the soil has a comparatively low P content. The P uptake has also been highly correlated with the major P fractions viz., Fe-P and Ca-P. The regression between total dry matter production as dependent variable and P uptake and inorganic P fractions as independent variables (Table 79) indicates that P uptake has accounted for about 68 per cent of the total drymatter production at the 30th day of the crop followed by Fe-P. Thus Fe-P is observed to be one of the most important form of P taken up by the rice crop and it significantly influences P uptake. Higher P uptake results in an increased drymatter yield. On 60th day, Ca-P and Al-P together have accounted for 90 per cent of the total variation in the drymatter production. The observations of Ramamoorthy and Bisen (1971) on the differential uptake of P fraction by the rice crop with progressive maturity of the crop agree with the findings of the present study. With regard to the influence of the P fractions on P uptake (Table 81), Fe-P is found to contribute 81 per cent of the total P uptake by the crop followed by Al-P on the 30th day; and 73 per cent of the P uptake has been accounted by Fe-P both on the 60th day and at harvest stages indicating the significance of Fe-P in the total P uptake by the rice crop in the acid soils of Kerala.

5.3. Biometric and yield characteristics

The response of rice to graded doses of phosphorus has been evaluated on two rice varieties. A reference to the ANOVA (Appendix XI and XII) indicates significant influence due to varieties, treatments and their interactions on almost all the important biometric characteristics such as height of plant, number of tillers, number of roots, weight of roots, total drymatter and total P uptake of the crop at all growth stages of the crop. Varieties, treatments and their interactions have also a significant effect on grain and straw yield indicating the positive response of both the rice varieties to the application of graded doses of P (Appendix XI). These results are thus slightly at variance with those of Mahendran (1979) who had in microplot experiments obtained results indicative of poor responsiveness by Jyothi and moderate responsiveness by Mashoori.

Among the biometric characteristics (Table 68 to 70) the height of plants is found to increase substantially around 60th day after sowing. The lowest and highest values for the height of plant have been recorded by the lowest and highest doses of P respectively. The control treatment on Jyothi has recorded minimum height where as the highest dose on Mashoori has recorded maximum height. With regard to tiller production, Mashoori has been found to be superior to Jyothi. On 30th day, the control pots and the pots with highest dose of P have recorded the minimum and maximum number of tillers respectively. At 60th day and at harvest, the lowest and highest mean

FIG 6 MEAN PERCENTAGE P UPTAKE FOR DIFFERENT P DOSES AT VARIOUS GROWTH STAGES OF RICE



number of tillers have been recorded for control pots and pots receiving 60 Kg P_2O_5/ha respectively. There has been reduction in the number of tillers/hill for 90 and 120 Kg P_2O_5/ha. However 60, 90 and 120 Kg P_2O_5/ha are on par. This shows that application of P at a level beyond 60 Kg tends to decrease the number of tillers which hitherto had been increased by application of P. Thus higher doses of P could not produce significant influence on the tiller production by both the varieties. The findings by earlier workers viz., Tiwari and Singh (1969) on the positive significant response through increased plant height, tiller number et., for P application and the reports by Gopal Rao et al. (1974), Katyal et al. (1975), Ittyavirah et al. (1979) support the positive response of rice to phosphorus.

A differential response in total weight of roots and number of roots has been observed for the two varieties. The control pots and the pots receiving highest dose have produced minimum and maximum weight and number of roots respectively. The control treatment on Jyothi and the highest dose on Mashoori respectively have produced the lowest and highest number of roots and inturn the root weight. The observations are similar with respect to the maximum length of roots at all stages of observation. Rice variety, Mashoori, with 30 and 120 Kg P_2O_5/ha respectively have recorded the lowest and highest average length of roots on 30th day. At 60th day, Jyothi with zero P and Mashoori with the highest dose of P have shown the lowest and highest average length of roots respectively. The significant differences observed in root parameters such as weight, length and number in the present study are indicative of the differential response of rice varieties to the application of phosphorus as observed by Russel (1961), Black (1968), Gabelman (1976), Gerloff (1976), Mahendran (1979), Kamath and Oza (1979) and Sumio Itoh and Barber (1983).

Mashoori has out yielded Jyothi (Table 70) by 5.15 g/hill and the difference between them has been significant. This may be due to its medium duration as compared to Jyothi. Among the treatments, the control pots have recorded the lowest yield and the highest dose, the highest yield. But 90 and 120 Kg P_2O_5/ha have been on par with respect to grain yield. Substantial increase in grain yield could not be obtained after the 4th dose (60 Kg P_2O_5/ha), a barrier beyond which significant increase in yield could not be obtained. Jyothi with zero P and Mashoori with the highest dose of P have produced the lowest and highest grain yield respectively. The superiorit of Mashoori on straw production is much in evidence (Table 70). But the treatments and the interaction influences on straw yield are very similar to the one on grain yield. The varietal variation in drymatter production has been significant. Mashoori being a medium duration crop absorbs more of P (Table 71 and Fig. 6) due to its better root spread (number of roots, length and weight) produces higher grain, straw and drymatter yields. The drymatter production is found to be lowest in the control treatment and highest in treatment under 120 Kg P_2O_5/ha on 30th day and at harvest. But the drymatter yield has been highest for the 4th treatment (60 Kg P_2O_5/ha) at 60th day of sowing. The differences between the means of drymatter due to treatments are significant. Thus the response of these two varieties to the application of phosphorus has been well brought out by the observations on root characteristics, other biometric and yield componen

The response of rice to P application has been further judged with the help of inter-correlations between P uptake and biometric or yield characteristics (Table 80) at all the stages of crop growth. All the biometric and yield characteristics especially grain and straw yields have been significantly and positively correlated with P uptake indicating there by the clear response of these two rice varieties to the application of graded doses of phosphorus under the present experimental conditions. Significant response of rice to P application was observed by a number of researchers viz., Kadam (1945), Ishizuka and Tanaka (1950), Davin (1951), Parthasarathy (1953), Desai et al. (1954), Verma (1960), Venkatachalam et al.

(1969 a), Katyal et al. (1975), Katyal (1978), Upadhyay and Pathak (1981), Fageria et al. (1982), Alam (1983) and others. When Ghosh et al. (1960) observed a positive response to P application in all kinds of soils in India, Sethi et al. (1952) concluded that unlike nitrogenous fertilizers, the response of rice to P was not general, but limited to a few stations. This may be depending upon the predominance of the various reasons for the non-response of rice to P application such as improper method of application, high fixation of P, transformation of native unavailable P to available forms under flooded conditions etc. as observed by a number of researchers or maturity of soil (Goel and Agarwal, 1959), P status in the soil (Rajendran et al. 1971; Ponnamperuma, 1976 and Lu et al. 1982) and the factors as described by Mandal (1979) and the varietal variations in the response behaviour as observed by Mahendran (1979). Singh (1983) opined that the methods of evaluation of soil P may not correctly predict the P response as the determination of nutrient status in this manner may not adequately simulate the conditions under which the crop is grown.

6. Comparative evaluation of two sources of phosphorus on rice

There is a need for continued research on the evaluation of different phosphatic fertilizers for rice crop because of the increasing number and complexity of fertilizers coming into the market and because of their differential behaviour in different soil types. The use of different labelled phosphatic fertilizers both soluble and insoluble forms may pave the way to identify or evaluate different sources of P for their efficiency on rice and also the response pattern of rice to the application of phosphorus in various soil situations. Further we do not know the extent of stimulatory role of different levels of the two sources viz., soluble and insoluble forms of phosphatic fertilizers in releasing native phosphorus in rice soils of high P fixing capacity. The two sources selected viz., monocalcium monophosphate (MCP) and tricalcium phosphate (TCP) for the study have been tried at 4 levels each on rice grown in seven major rice soils of Kerala. The observations on plant and soil at panicle initiation and harvest stages of the crop including final yield are discussed below.

6.1. Panicle initiation stage

A reference to the ANOVA (Appendix XIV) indicates that phosphorus application has significantly influenced the height of plant, number of productive tillers, weight of roots, weight of straw, total drymatter and P content (root, straw and soil). Sources of P however have no significant effect on height of plant, weight of roots and content of P in root and straw unlike its effect on the number of productive tillers, weight of straw and for the drymatter. At a lower dose, MCP and at a higher dose, TCP are found to be more effective. The availability of P in acidic soils increases as the dose of TCP also increases.

Differential response in terms of height of plants to P in two different sources or carriers applied in different soil types (Table 82) has been recorded. A quadratic response in lateritic alluvium, Kari and Kayal soils, a positive linear response in Kole soil and a negative response in Karapadam, coastal sandy alluvium and Pokkali soils have been observed with MCP on height of plant. A positive linear response in lateritic alluvium, Kari, Kayal coastal sandy alluvium and Pokkali soils and a quadratic response in Karapadam and Kole soils have also been observe for TCP. These differences in the response patterns of height could not however manifest in yield except with MCP in lateritic alluvium and TCP in Kole soils which maintained a quadratic response.

The data on the number of productive tillers (Table 83 indicate an increase of this character with an increase in dose of P and the rate of increase has been found to decrease with an increase in dose from 60 to 90 Kg P_2O_5/ha as TCP. In lateritic alluvium, Kayal, Pokkali and Kole soils, with the application of MCP, a quadratic response;

in Karapadam and coastal sandy alluvium, a negative response and in Kari, a positive linear response have been obtained. But with the application of TCP, in lateritic alluvium, Kari, Kayal, Pokkali and Kole, a positive linear response and in Karapadam and coastal sandy alluvium, a negative response have been observed. The response pattern on tiller productions however could not maintain their differences in yield.

A significant increase in root-weight has been observed with application of P (Table 84). However the two sources could not make a significant difference on root yield. The percentage increase in root weight gets doubled as the dose of P increases from 60 to 90 Kg P_2O_5/ha. Though an increase in root weight has been recorded for an increase in dose of P, in coastal sandy alluvium and Pokkali soils as the dose of P is increased for the carrier MCP root weight has been decreased. One of the foremost effects of P on crop growth is its influence on root production. This has also been recorded in the earlier experiments with two different rice varieties, Mashoori and Jyothi.

The two sources of P on various soils have produced a significant difference on straw yield (Table 85). The rate of increase in straw yield with dose has not been commensurate with the rate of increase in P dose especially from 60 to 90 Kg P_2O_5/ha. P as TCP has produced more straw when compared to MCP. Application of P as MCP has resulted in a quadratic response in lateritic alluvium, Kayal, Karapadam, coastal sandy alluvium and Kole soils and a positive linear response in Kari and Pokkali soils. The response for TCP in lateritic alluvium and Kayal soils has been quadratic; in Kari, Karapadam, coastal sandy alluvium, Pokkali and Kole, positive and linear.

A significant increase in drymatter production (Table 86) due to P application has been observed. The two sources of P differed significantly on their influence in this character. An increase in drymatter yield (14 per cent has been obtained for TCP over MCP. Individual soil has responded in a varied manner with respect to drymatter yield. Pokkali and Kole soils have respectively recorded the lowest and highest drymatter yields. Application of MCP in lateritic alluvium, Karapadam, coastal sandy alluvium and Kole soils have produced a quadratic response; while in Kari,Kayal and Pokkali, a positive linear response. Application of TCP in all the soils have recorded a positive linear response. The observations on biometric characteristics clearly indicate a prominent response of rice to the application of P. The differential response to the two sources of P in the various soil types studied may be due to differences in the P status of the soil, P fixing or P releasing capacities and such other parameters of the soils which will govern the P availability to the rice crop.

The content of P in root and straw (Tables 87 and 88) increases significantly due to different levels of P application, the increase being highest for P in straw compared to P in root, sources of P however are not significantly different from one another. The P availability in the soil becomes high as the dose of P is increased resulting a condition to allow the absorption of more P by the root. This is reflected by an increase in the content of P in both the root and straw. The P availability also depends on soil characteristics and henc differential response has been observed in various soil types.

The total P in soil (Table 89) has been significantly influenced both by the source and dose of P. Increasing doses increase its content in lateritic alluvium, Kayal and Kole soils for both MCP and TCP and produce a differential response for MCP and TCP in other soil types. As the dose of P through TCP is increased, the rate of increase in total P also has been increased.

Panicle initiation stage is the stage immediately after the phase of tillering and maturity of the tillers corresponding to maximum uptake of P. By this time a rice crop would have normally completed the uptake of nearly

90 per cent of its total P requirement. In view of this the percentage of phosphorus derived from fertilisers (PDFF) in the present experiment has been determined for seven soil types, for various levels of P, for both the carriers of P and in major plant parts such as root and straw. These are presented in Tables 90 and 91. It is significant to note that in none of the soil types, the source of fertilizer could make a significant difference in the PDFF (Appendix XV) of either the root or the straw showing thereby that both carriers viz., the soluble phosphatic and insoluble tricalcic are performing as efficiently as each other. The comparison between the zero level and the lowest level viz., 30 Kg P_2O_5/ha show that both the fertilizers are efficiently functioning in the soil. Calculation of P utilisation percentage in the plant based on P applied in the case of MCP and TCP are respectively 4.3 and 4.6 (Table 94).

With increasing doses, a significant increase in the PDFF in root has been observed. However, there is a progressive decrease in the rate of increase of PDFF in the root with incremental doses in the case of both MCP and TCP. The PDFF in straw significantly increase with dose for both MCP and TCP. However, with TCP, the rate of increase of PDFF with incremental dose increases and the incremental rate between the doses of 60 and 30 Kg

P_2O_5/ha on the one hand and 90 and 60 Kg P_2O_5/ha on the other is significantly different from one another. However, in the case of MCP, the rate of increase is fairly steady for the dose, 30 to 60 Kg P_2O_5/ha. From 60 to 90 Kg P_2O_5/ha however, it shows a significant increase in trend.

These results bring into focus three elegant points for discussion viz., the differences in the P requirement in the leaf as compared to the root, the steady increase in incremental response observed in most of the rice soil types in Kerala with TCP and the 60 Kg P_2O_5/ha acting as a barrier beyond which such an increase is found in the case of soluble monocalcium phosphate in rice soils with high P fixing capacity on which these experiments have been tried. Morphologically, the root is well known to act as a barrier for both essential as well as trace elements as in the nutrition of a crop plant as well as i protecting it against toxic elements is concerned. This ability to act as a barrier necessitates the earlier attainment of a threshhold level of nutrient in the root prior to such a level being attained in the root.

The steady increase in the percentage P derived from fertiliser brings out the potentiality of insoluble rock phosphate as phosphatic fertiliser for rice soils under acid soil conditions. It is necessary that in a judiciou national resource utilization strategy, we give priority to the use of rock phosphate in acid soils. The occurrence of a 60 Kg barrier for MCP beyond which only straw has been increased for increased level of applied phosphate may partly be due to the high P fixing capacity for soluble phosphates in almost all the soil types studied (Table 25). The soils included in the study differ considerably in their ability to maintain uniformity with respect to the PDFF values for root and straw at same levels of P application which is due to the variations in the total P status and other physico-chemical characteristics of the soils which define available P and its release from unavailable forms.

A-value, the concept introduced by Fried and Dean (1952) is the inherent nutrient supplying power or the native P supplying power of the soil. Based on A-value determinations using two different sources, the data clearly show that there is no significant difference between MCP and TCP. This means that, TCP is as efficient as MCP in the acid rice soils of Kerala. Graded doses of P applied through both the forms increase the P supplying power as measured by A-value and that this ability or power increases with increasing doses of fertilizer P applications. Table 92 shows that the A-values are lowest in Pokkali soils and highest in Karapadam soils. It further indicates certain other interesting trends. For the same dose of P as carrier MCP has created a larger spread of the A-value for the various soils than TCP. This means that the water soluble phosphatic fertilizer behaves differently in different soils while the TCP's behaviour in all the soils is very nearly similar, i.e., the spread is less. The highest dose of 90 Kg of MCP has produced maximum variatio among the soils in their A-values while the minimum variation is seen in the case of both TCP at the lowest dose of 30 Kg P_2O_5/ha.

The P utilization percentage is significantly greater to the extent of 7 per cent in plants grown in TCP applied soils compared to MCP applied ones (Table 93). Further, P utilization percentage has been decreased with increasing levels of P and thus there exists an inverse relationship between the percentage utilization and the dose of P applied. The rate of decrease in the percentage of P utilization has been significantly higher for MCP compared to TCP thus justifying the superiority of TCP in the acid rice soils of Kerala to maximise P utilization. All the seven soil types however, differ with respect to P utilization justifying their distinctiveness and consequen offering explanation to the variable response to applied P.

6.2. Harvest stage

The two P sources MCP and TCP do not produce significant differences in grain yield (Appendix XVI).

But soil types produce a significant difference in yield. This emphasises the variability in soil to be a more crucial factor in producing response than the source of P especially under Kerala rice soil situations. From the present radio-tracer experiment, the summarised result (Table 95) of a comparison of grain yield of pots with P applied as against control show a significant increase (37 per cent) in grain yield. When the level of applied P has been increased from 30 to 60 Kg P_2O_5/ha the grain yield has been increased by 20 per cent though there has been a marginal decrease in yield for the additional increase of 30 Kg P_2O_5/ha. The TCP has been more effective at 60 Kg P_2O_5/ha as far as grain yield is concerned since the grain yield is related to P utilization which is also higher for TCP. Though the findings of Motsara and Datta (1971) are of great significance with respect to use of rock phosphates, the extensive spread of the soils used and the variety of crops tried limit their applicability to different rice soil situations. The present study restricted to acid rice soils which include acid sulphate soils at one extreme to coastal sandy alluvium at the other giving in variable responce to rice under application of both MCP and TCP indicate the possibility of using cheap rock phosphates under highly acid soil situations. Though no significant correlation between grain yield and

P content in root has been observed, the P content in root has positively influenced grain yield via. soil P, PDFF (straw), available P in soil and percentage P utilization to the extent of 53 per cent as obtained through path analysis (Table 109). This indicates the multiple of factors like the P content in grain, soil P, PDFF (straw and grain), A-value and percentage P utilization contributing to grain yield as explained by their total correlation.

Significant difference in straw yield (Appendix XVI) for the two sources of P has been observed. As in grain yield, straw yield (Table 96) has also been increased by 7 per cent for the P as TCP when compared to MCP. A marked increase in straw yield (56 per cent) further substantiates the good response of rice to P application in all the soils. TCP has recorded a higher straw yield compared to MCP again proves the suitability of acid soluble form of P in the acid soils of Kerala. The straw yield has been lowest for the poor fertile coastal sandy alluvium and highest for the Kole soils as in grain yield.

The higher response to P by the root goes unnoticed always except while under research. A marked increase of 70 per cent in root weight (Table 97) compared to only 56 per cent for straw yield emphasises the importance of P application to the rice crop though consistent lack of response to P in University experimental stations and Government farms are obtained and may tempt farm managers to "skip" phosphorus which is probably only a management tool not fully based on soil fertility considerations. The effects of two sources of P on root production have differed significantly in various soils which may be due to the difference in the nature and properties of the individual soil types. The observed superiority of TCP over MCP in better root production is mostly due to the higher content of calcium. The enhanced root proliferation would have itself enhanced the utilisation of P from TCP resulting in increased growth and straw yield. The path analysis on straw yield (Table 110) and factors such as total P (root and grain), PDFF (root, straw and grain), A-value and percentage P utilization etc., further indicate the cumulative influence of these factors towards a change in straw yield. Excepting the P content in root all the other independent factors have been positively correlated with straw yield.

The drymatter yield (Table 98) at harvest has been increased by 58 per cent due to P application irrespective of the source. Since all the contributing characters for the drymatter production are higher for TCP, the total drymatter yield is also higher for TCP for an increase in dose from 30 to 60 Kg P_2O_5/ha when compared to MCP. The difference in response to the application of P by various soils is similar to the grain yield, straw yield and root weight. The response of rice to P application in the present study substantiates the need for P application in all the soils under study. However, the degree of response varies from soil to soil explaining the differential behaviour of the rice soils. Similar response have been reported from other rice soil situations by a number of workers.(Ram Singh et al. 1985 and Samiei and Singh,1985).

The P in root, straw, grain and soil (Table 99 to 102) has been increased with increase in P either as MCP or TCP. When a 257 per cent increase in P content of root over control has been observed, only 53 per cent increase is noted for P in straw indicating the influence of P application on root production. Further the result stresse the need for basal application of P for the speedy establishment of the crop. When a 11 per cent increase of P in root for an increase of P from 30 to 60 Kg P_2O_5/ha could be observed for MCP application, a 21 per cent increase in P content in root could be noted for TCP application. This indicates a better effect of TCP on root growth. A marginal increase of P in straw could also be observed for TCP for an increase in dose from 30 to 60 Kg P_2O_5/ha.

The PDFF values in root, straw and grain at harvest stages (Appendix XVII and Table 103 to 105) indicate the significant difference between MCP and TCP in their PDFF in root unlike the PDFF in straw and grain. Increasing doses of P resulted in increasing in PDFF of both root and straw. The differential response to P application in different rice soils could be due to the difference in the pattern of P released to the crop and utilized by them as observed through the PDFF values both at panicle initiation as well as at harvest stages.

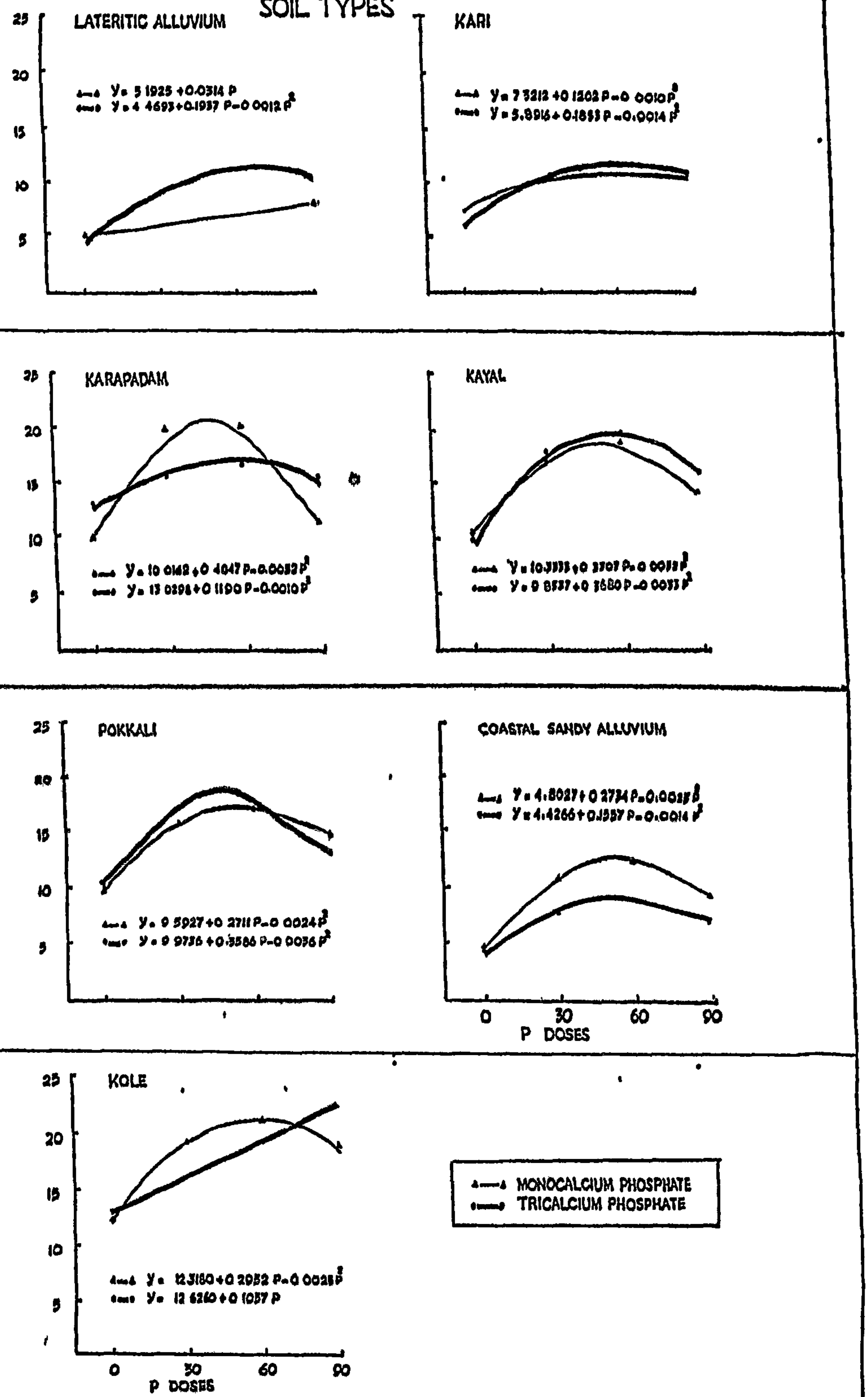
The soil available P represented by A-value (Table 106 is not observed to be significantly different for the two sources of P at harvest. However, an increase in this inherent P supplying capacity has been observed (100 per cen as the dose of P increased from 30 to 60 Kg P_2O_5/ha and 192 per cent increase for an increase in P from 30 to 90 Kg P_2O_5/ha. As the dose increases, the fixation of P also increases resulting in low P availability. The differences in P fixation, P availability etc., has resulte in the differential behaviour of the seven soil types under study.

At harvest stage also, the P utilization percentage (Table 107 and 108) has been significantly influenced by the nature of the P carrier. When the utilization percentage has been higher for TCP at Panicle initiation stage the same has been higher for MCP at harvest stage. The P utilization percentage has been increased as the dose of P decreases. This may be due to the more efficient utilization of P at lower levels since there may be more competition among the plants for the limited supply of the nutrient. A wide variation in the utilization of P by various soils has also been observed for MCP and TCP at different doses. The P utilization percentage is 14.1 at 90 Kg P_2O_5/ha as MCP and 12.8 per cent for TCP at the same dose in the present study. The Kole soils recorded the lowest percentage P utilization (10.7) and the Karapadam soils, the highest (20.1). A number of researchers supported the view that in acid soils, rock phosphate can replace superphosphate as it becomes an economical source of P. In the present study also it has been shown that TCP produces the same response as MCP in all the acid soils. However, all the earlier studies are based on replicated trials or basic studies but with out the use of ^{32}P material. The present study being based on ^{32}P gives unequivocal proof for the use of rock phosphate. The chemical composition of the fertilizer, granule size, and method of application etc., markedly influence the response of rice to phosphatic fertilizers Kanwar et al. (1982) in addition to the type of soil and the crop variety.

The response of a crop to added fertiliser depends to a great extent on the amount of applied P and the residual fertility of the soil. If the soil is severely depleted, fertilizer P will give a significant increase in yield. If the soil is well supplied, or if one is adding a large amount of fertilizer, a change in the rate of addition will not make much difference in yield. The low fertilizer use efficiency of P warrants further research for efficient management of P fertilizer.

The response of rice to the application of graded doses of MCP and TCP in the seven rice soils of Kerala has been further judged by finding out the optimum dose of P for maximum grain yield (Table 111 and Fig. 7). A linear positive relationship could be obtained for the applied dose of MCP in lateritic alluvium and TCP in Kole soils. No optimum could however be worked out for these soils for the two sources. This may be due to the varied nature of the P fixing capacity of the soils indicating differences in the nature of the first and subsequent reverted compounds in these soils. The optimum P as MCP worked out for Kari, Karapadam, Kayal, Pokkali, coastal sandy alluvium and Kole soils are 60, 46, 52, 56, 54 and 59 Kg P_2O_5/ha respectively. The highest optimum (60 Kg P_2O_5/ha) for Karapadam may be due to the differential behaviour in their P fixing capacities and P transformations. The optimum dose of P as TCP for

FIG. 7. RESPONSE FUNCTIONS FOR GRAIN YIELD AND P DOSES FOR MONOCALCIUM PHOSPHATE & TRICALCIUM PHOSPHATE FOR DIFFERENT SOIL TYPES



lateritic alluvium, Kari, Karapadam, Kayal, Pokkali and coastal sandy alluvial soils have been observed to be 81, 67, 59, 56, 50 and 55 Kg P_2O_5/ha respectively. The highest optimum observed for lateritic alluvium among the seven soils may be due to its high P fixing capacity consequent to high sesqui-oxide content. The availability of P through a less soluble P source (TCP) will be less when compared to MCP and hence a higher optimum for TCP. Though higher doses of TCP are required to reach the optimum, the unit cost of P will be less and hence low grade rock phosphates have to be preferred under the acid soil situations of Kerala.

SUMMARY

SUMMARY

Reports on lack of response to phosphorus in rice soils of Kerala are often being brought forward but from non-contiguous locations. But consistent lack of response is being observed in some of the experiments in a few research stations whose soils have been saturated with phosphorus due to continuous addition. Though the reasons for lack of response of rice to P application are many and some of them identified singly, no systematic integrated attempt to investigate the possible interactional reasons for the occurrence of this complex problem has been made so far. Thus there is a need to assess critically the factors, both soil and plant, which will favour or prevent response in the acid rice soils of Kerala. With the broad objective of assessing the factors governing response of rice plants to applications of phosphorus in the acid soils of the state, approaches in the study include devising methods for categorising the soils with a recognisable parameter with well defined limits; detailed studies on soil P fractionation; P fixation; pattern of transformation of P of selected soils due to submergence; response studies with graded doses of phosphorus on two rice varieties, a short and a medium duration and comparative evaluation on the effectiveness of two sources of

phosphorus on rice in different soils with labelled phosphorus. This integrated study reveals the following

1. The nine important physico-chemical parameters of rice soils which contribute to P fixation and P availability of 151 soil samples representing seven major rice soils of Kerala have been classified by Principal component analysis into six categories or clusters. The six categories fall within a total P content of <250, 251 - 450, 451 - 650, 651 - 900, 901 to 1250 and >1251 ppm.

2. Thus 37.09 per cent of the total soils (category 1 and 2) come under low (a total P content less than 450 ppm). 47.02 per cent (category 3 and 4) under medium (a total P ranging from 451 to 900 ppm) and 15.89 per cent (categories 5 and 6) under high (a total P content more than 900 ppm). Thus majority of the rice soils in Kerala can be categorised under medium group with respect to their total P status.

3. In comparing another method of classification of soils based on factors of P fixation and P availability, the nine parameters included for grouping with the principal component method have also been considered for classificatory analysis and index score method and it has been observed that the soils do not categorise themselves. Hence the classificatory analysis and index score method is not suitable to group our soils based on soil parameters governing phosphorus.

4. In the classificatory method, Bray-1-P has been observed to be the most variable (coefficient of variation, 95 per cent) among the nine parameters included for the study. It indicates that profound variation exists between various soils with respect to the available P content.

5. The available P as estimated by Bray 1 method does not show any pattern of increase or decrease with similar changes in total P content. Thus total P itself may not be a single factor governing P availability.

6. Significant variations in total P, inorganic and organic phosphorus fractions exist between various soil types. The total P ranged from 108 to 1763 ppm indicating the genetic differences among the soils. The coastal sandy alluvium and Kayal soils respectively contain the lowest and highest mean total P.

7. The saloid-P content has been lowest for coastal sandy alluvium and highest for Karapadam soils. Comparatively the per centage contribution by this fraction to total P has been the lowest (3.22).

8. Kari soils contain the lowest conc. of Al-P while Kole soils, the highest. The mean Al-P content of coastal sandy alluvium and Pokkali soils is very nearly on par

with the Kari soil. The mean per centage of Al-P to total P for all the soils collectively has been found to be 13.81.

9. The coastal sandy alluvium and Kayal soils have recorded the lowest and highest conc. of Fe-P respectively. Among all the inorganic P fractions Fe-P has contributed maximum to total P and the average proportion of Fe-P to total P being 15.49 per cent.

10. The mean Ca-P fraction has been lowest for coastal sandy alluvium and highest for Kayal soils. The per centage contribution of Ca-P to total P has been comparatively low (6.79) and it may be due to the acid nature of the soils.

11. The reductant P is the third abundant fraction of phosphorus. The coastal sandy alluvium and Kayal soils have respectively recorded the lowest and highest content of this fraction. The proportion of reductant P over total P has been 8.25 per cent.

12. Occluded-P has been lowest in coastal sandy alluvium and highest in Kayal soils and its per centage contribution to total P for all soil types being 2.82.

13. The sum of inorganic P is found to be lowest in coastal sandy alluvium and highest in Kayal soils. About 50 per cent of the total P is accounted by the sum of inorganic P.

14. The low organic P levels in coastal sandy alluvium and high in Kayal soils have been observed. On an average the organic P contributes 44.3 per cent on the total P.

15. The coastal sandy alluvium which has the lowest total P have recorded a low quantity of non-extractable P and Kayal soils with highest total P have shown a high conc. of this fraction. About 5.34 per cent of the total P could not be extracted by the fractionation procedure, a defect of the method.

16. The total inorganic P has been lowest in coastal sandy alluvium and highest in Kayal soils and it accounts for 55.6 per cent on the total P when all the soils are taken together.

17. A close relationship has been noted between the total P and various P fractions by way of high correlations (0.73).

18. Statistically no significant difference could be noticed among the mean PFC of Kari, Kayal, Karapadam and Kole soils. The mean PFC of a set of 5 soils (lateritic alluvium, Kari, Kayal, Karapadam and Kole) has been 49.6 per cent while that of the second set with coastal sandy alluvium and Pokkali, 36.9 per cent. The difference between the two means has also been significant.

19. Among the soils studied, coastal sandy alluvium and Kari soils have recorded the lowest and highest mean PFC respectively.

20. The PFC has been studied in detail with respect to the factors governing it by way of correlations and regressions. PFC has been negatively correlated with pH, organic carbon, total CaO, total MgO, CEC, exchangeable Ca, exchangeable Mg, sand, C/P ratio and active P. The relationships between PFC with total sesqui oxides, total Fe_2O_3, total Al_2O_3, silt, clay, C/N ratio and Fe_2O_3/Al_2O_3 have been positive.

21. The relative influence of selected independent factors viz., pH, R_2O_3, CaO, MgO, CEC, organic matter and clay on PFC of rice soils have been worked out with stepwise regression analysis. In lateritic alluvium, Karapadam, Pokkali and Kole soils, the total sesqui oxides exert maximum influence on the PFC. In Kari and coastal sandy alluvial soils, the pH and in Kayal soils, the CEC have influenced maximum on PFC. Thus the criticality of the factors in controlling the PFC of the acid soils has been worked out in the present study.

22. Upon waterlogging, all the soils have registered an increase in all the inorganic P fractions of Phosphorus. Excepting Al-P fraction by Kari soil, the coastal sandy alluvium has recorded the lowest value for all the inorganic

P fractions due to submergence. With the exception of Kolo soils for both saloid P and Al-P, Kayal soils have recorded the highest values for all the other inorganic P fractions.

23. The per centage increase in P fractions due to submergence differ with respect to soil types. The average per centage increase has been lowest for occluded-P (2.7) and highest for Fe-P (63.5).

24. The occluded-P has been observed to be contributing to 2.2 per cent (lowest) while Fe-P, 48.9 per cent (highest) in the total variation of inorganic P fractions due to submergence.

25. The difference between the mean values of available P under air dry and waterlogged conditions has been found to be significant. The air dry soils have recorded the lowest mean available P while the submerged soils, the highest.

26. Among the various methods (Bray 1, Bray 2, Olsen and Truog) tried for estimation of available P both under air dry and waterlogged soils, Olsen and Truog have recorded the lowest and highest values respectively.

27. The average per centage increase in P availability due to submergence has been lowest by Bray 1 and highest by Truog's method.

28. Intercorrelation matrix between the per centage increase in available P estimated by various methods and per centage increase in various inorganic P fractions due to submergence show that none of the correlations have been found to be significant.

29. The response of rice to graded doses of P has been evaluated in an experiment with two rice varieties over six treatments and the observations have been taken on the 30^{th}, 60^{th} day and at harvest stage of rice crop. The available phosphorus has been determined by four common extractants viz., Bray 1, Bray 2, Olsen and Truog, in the soil from various P treatments such as zero, 30, 45, 60, 90 and 120 Kg P_2O_5/ha. as superphosphate and grown to two different rice varieties, Mashoori and Jyothi at three growth stages.

30. The available P as estimated by the three methods, viz., Bray 1, Bray 2 and Olsen have been influenced by varieties, doses of P and the growth stages of the crop. The Truog's P has been affected by the varieties on the 60^{th} day and the treatments on the 30^{th} day of sampling. Significant differences in the available P estimated by different methods for various levels have been observed. The mean available P in soil at various growth stages as indicated by all the extractants (except Truog at harvest stage) has been lower in pots grown with Mashoori.

31. Excepting Truog's P at 30th day of sampling, the available P estimated by all the four methods at all stages of observation have been positively and significantly correlated with all the inorganic P fractions.

32. In the stepwise regression, it has been observed that the proportion of available P estimated by both Bray 1 and Bray 2 derived from Fe-P is greater to the extent of 90 per cent, saloid P by 78 per cent on Olsen's P and Al-P by 62 per cent on Truog's P on 30th day of sampling.

33. Al-P has contributed 98 per cent in the available P estimated by Bray 1 and Bray 2, reductant P by 87 per cent on Olsen's P and saloid-P by 12 per cent on Truog's P on the 60th day of the crop.

34. At harvest stage, Ca-P fraction has accounted 95 per cent on the Bray 1 and Bray 2-P, 97 per cent by Ca-P on Olsen's P and 36 per cent by occluded P on Truog's P.

35. Significant positive correlations have been observed between biometric or yield characteristics and available P determined by all the four methods, except Truog in general. Further Olsen's P has been responsible for about 74 and 51 per cent (highest values) respectively among the three methods on grain and straw yields.

36. Since P uptake and grain yield are highly correlated (r=0.92) the superiority and reliability of Olsen method in predicting the available P in the soil has been further

emphasised by its higher contribution (68 per cent) on the estimate of P uptake by the rice crop at its harvest stage.

37. Significant influence has been observed due to the treatments on the inorganic P fractions at all growth stages unlike the effect of varieties on P fractions. The highest dose of P has recorded highest values for all the P fractions.

38. Among the various inorganic P fractions, Fe-P has been the highest at all growth stages due to varieties, treatments and their interactions. Occluded P has been lowest due to varieties both at 30th and at harvest stages of the crop while saloid-P has been the lowest for the lowest dose both at 30th and 60th day after sowing and occluded-P at harvest stage. Occluded-P has been the lowest for the highest dose of P at all the growth stages of the crop.

39. All the inorganic P fractions have been lesser in soils grown with Mashoori variety indicating possibly a higher absorption of P from various inorganic P fractions by this variety.

40. The grain yield has been highly correlated with all the inorganic P fractions except occluded-P. The correlation coefficients between straw yield and Fe-P,

Ca-P and sum of inorganic P alone have been observed to be significant. This positive and significant relationship indicates the responsiveness of rice crop to P fertilization

41. The P uptake has also been highly correlated with major P fractions viz., Fe-P and Ca-P. Fe-P is found to be the most important form of P taken up by rice.

42. Significant influence due to varieties, treatments and their interactions has been observed on all the biometric and yield characteristics of the crop at all stages of observation. The lowest and highest values of height of plant as well as number of tillers have been recorded for the lowest and highest doses of P. Mashoori has been observed to be superior to Jyothi on tiller production. Higher doses of P beyond 60 Kg P_2O_5/ha could not produce significant influence on tiller production by both the varieties.

43. The control treatment and the highest dose have respectively recorded minimum and maximum values for both number and weight of roots. The control treatment on Jyothi and highest dose on Mashoori respectively have produced lowest and highest number of roots and inturn the root weight. The observations are similar with respect to the maximum length of roots also.

44. Mashoori out yielded Jyothi by 5.15 g/hill and the difference between them has been significant. Among the

treatments, lowest and highest doses have respectively produced lowest and highest yields. But 90 and 120 Kg P_2O_5/ha are on par with respect to grain yield and no substantial increase in yield beyond 60 Kg P_2O_5/ha has been obtained. Jyothi with zero P and Mashoori with highest dose of P have recorded the lowest and highest grain yield respectively.

45. The superiority of Mashoori on straw yield has also been observed. The influence of treatments and their interactions are very similar to the one on grain yield.

46. Varietal variation in drymatter production has also been observed. Mashoori being a medium duration crop absorbs more of P due to higher root spread, produces higher grain, straw and drymatter yields.

47. The response of rice to P application has been further supported by positive and significant correlations between biometric or yield characteristics and P uptake.

48. The effects of monocalcium phosphate (MCP), a water soluble form of P and tricalcium phosphate (TCP), an insoluble one, on seven major rice soils of Kerala have been evaluated by the use of radioactive labelled material.

49. At panicle initiation stage, P application has significantly influenced the height of plant, number of

productive tillers, weight of roots, weight of straw, total drymatter and P content in root, straw and soil.

50. Sources of P have no significant effect on height of plant, weight of roots and content of P in root and straw unlike its effect on the number of productive tillers (3 per cent increase for TCP than MCP) weight of straw (10 per cent increase for TCP over MCP) and for the drymatter (14 per cent higher for TCP than MCP). At lower doses, MCP and at a higher doses, TCP have been effective.

51. Differential responses for the two sources of P in different soil types on all the biometric characteristics have been recorded. An increase in drymatter yield (14 per cent) has been obtained for TCP over MCP. The observations on biometric characteristics clearly indicate the positive response of rice to P application. The diferential response by the two sources of P in different soils may be due to the difference in the P status of the soil, P fixing or P releasing capacities and such other parameters of the soils which will govern the P availability to rice crop.

52. Significant increase of P in root and straw has been observed due to different levels of P application over control. The response of these characters differs with soil types unlike the two sources. The soil total P has been significantly influenced by the source and doses of P.

53. The PDFF in root and straw have not been significantly affected due to the two sources of phosphatic fertilizers. Though the PDFF in root has been increased due to an increase in dose, the rate of increase has been decreased unlike the PDFF in straw where in the rate of increase has been substantial. The soils differ with respect to the PDFF values

54. No significant difference due to the two sources on the A-value has been observed, which again supports the quality of TCP for substitution of MCP in the acid rice soils. Soil types differ significantly in their A-values.

55. The per centage P utilization has been significantly influenced due to the sources of P, TCP producing 7 per cent more compared to MCP. As the dose of P increased, the per centage P utilization has been decreased. The soil types vary with respect to P utilization explaining to the differential response of rice to P in various soils.

56. No difference between MCP and TCP could be observed with respect to grain yield unlike the soil types which showed an effect. An increase of 37 per cent on grain yield between P applied and P not applied has been noted. The TCP has been more effective at 60 Kg P_2O_5/ha. There can be multiple of factors viz., the P content in grain, soil P, PDFF (straw and grain) A-value and per centage P utilization, contributing to grain yield as explained by their total correlation in the path analysis.

57. Significant difference in straw yield at harvest for the two sources of P has been observed. It has been increased by 7 per cent for TCP over MCP. An increase of 56 per cent due to P application over control further substantiates the good response of rice to P application in all soils. The superiority of TCP in acid soils has been further supported by the increase in straw yield.

58. A marked increase of 70 per cent in root weight at harvest further emphasises the importance of P application to rice. The two sources differ significantly in various soils with respect to this character. TCP has been found to be superior to MCP on root proliferation.

59. The drymatter yield at harvest has been increased by 58 per cent due to P application. The drymatter production has been higher for TCP than MCP. The soils differ significantly in drymatter yield as in grain, straw and root yield.

60. The P in root, straw, grain and soil at harvest increased with increase in P either as MCP or TCP. The differential behaviour of rice soils to these characteristics has also been observed.

61. There is significant difference between MCP and TCP for PDFF in root unlike the PDFF in grain and straw. The differential response of rice to P application in different soils has again been explained by the difference in the pattern of P released to the crop and utilized by them as observed through the PDFF values both at panicle initiation stage and at harvest.

62. As at panicle initiation stage, the per centage P utilization has been influenced by the two sources. As the dose of P increases, the P utilization decreases which may be due to the more efficient utilization of P at lower levels A wide variation with respect to different soils on this character has also been observed. The P utilization has been 14.1 and 12.8 per cent respectively for MCP and TCP.

63. In the present study it has been observed that the TCP can be a better substitute for MCP in all the rice soils.

64. The response of rice to P application either MCP or TCP has been further assessed by working out the optimum dose of P for maximum grain yield. Since linear positive relations could be obtained for MCP in lateritic alluvium and TCP in Kole soils, no optimum could be arrived at for these soils for the two sources.

65. The optimum P as MCP for Kari, Karapadam, Kayal, Pokkali, coastal sandy alluvium and Kole soils are 60, 46, 52, 56, 54 and 59 Kg P_2O_5/ha respectively. While the optimum as TCP for lateritic alluvium, Kari, Karapadam, Kayal, Pokkali and coastal sandy alluvium are respectively 81, 67, 59, 56, 50 and 55 Kg P_2O_5/ha. Though slightly higher doses of TCP are required to reach an optimum, the unit cost of P which is considerably low in rock phosphates gives an economic advantage in its use. Hence low grade rock phosphates can be preferred under acid rice soil situations of Kerala.

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*Originals not seen.

APPENDICES

APPENDIX I

Soil Sampling Sites

I. Lateritic alluvial soils

1. Perumkadavila
2. Kattakkada I
3. Kattakkada II
4. Perumpazhuthoor I
5. Perumpazhuthoor II
6. Avanakuzhi I
7. Avanakuzhi II
8. Vellayani I
9. Vellayani II
10. Karamana I
11. Karamana II
12. Vattappara
13. Vembayam
14. Vamanapuram
15. Kilimanoor
16. Nilamel
17. Kadaikal
18. Chadayamangalam
19. Ayoor
20. Marangattukonam
21. Valakom
22. Karikkom
23. Kottarakkara
24. Neduvathur
25. Melkadakkavur
26. Enathu
27. Adoor
28. Kunnamkulam
29. Kolikkara
30. Othallur
31. Panthavurpadam
32. Kalachalpadam
33. Kaladippadam
34. Kuttippuram I
35. Kuttippuram II
36. Thirunavaya
37. Codakkal
38. Edakkattuparambu
39. Chamravattom
40. Thirur
41. Ponmundam
42. Peruvanna
43. Ponmala
44. Malappuram
45. Ramapuram
46. Kunnappally
47. Kallaoppillippadam
48. Vallur
49. Pattambi RRS. I Punja
50. Pattambi RRS. II Palliyal
51. Pattambi RRS. III Wetlands
52. Pananchery
53. Mannuthy RRS.
54. Puzhakkal
55. Mananthavady

2. Kari Soils

56. Kurichikari
57. Alankari
58. Puthenkari
59. Valayar
60. Muleekkunnamkari
61. Mannarkari I
62. Mannarkari II
63. Vembanakari I
64. Vembanakari II
65. Anadhakari
66. Karuvatta I
67. Karuvatta II
68. Karuvatta III
69. Karumadi
70. Purakkad

3. Kayal Soils

71. Cherukara East
72. Cherukara West
73. E. Block East
74. E. Block West
75. H. Block East
76. H. Block West
77. Rajapuram North
78. Rajapuram South
79. Mangalamkayal East
80. Mangalamkayal South
81. Mathikayal East
82. Mathikayal West
83. Sreemoolamkayal East
84. Sreemoolamkayal West
85. Kokkakayal

4. Karapadom Soils

86. Nedumpuram
87. Valiyakiliyanveli I
88. Valiyakiliyanveli II

(Contd..........)

89.Chennamangalam
90.Kochukiliyanveli
91.Thalavady
92.Moncompu RRS. I
93.Moncompu RRS. II
94.Moncompu RRS.III
95.Pallikoottuma I
96.Pallikoottuma II
97.Cheppalakka I
98.Cheppalakka II
99.Ramankari I
100.Ramankari II
101.Kidangara I
102.Kidangara II

5. <u>Coastal sandy alluvial soils</u>

103.Kayamkulam RRS. I
104.Kayamkulam RRS. II
105.Kayamkulam RRS.III
106.Karunagappally Seed Farm I
107.Karunagappally Seed Farm II
108.Karunagappally Seed Farm III
109.Krishnapuram
110.Changankulangara
111.Pajikuzhi
112.Chalakudy RRS. I
113.Chalakudy RRS. II
114.Chalakudy RRS.III

6. <u>Pokkali Soils</u>

115.Vyttila RRS. I
116.Vyttila RRS. II
117.Vyttila RRS.III
118.Vyttila RRS. IV
119.Vyttila RRS. V
120.Vyttila RRS. VI
121.Vyttila double crop
122.Vyttila single crop
123.Panagad I
124.Panagad II
125.Panagad III
126.Thuravur I
127.Thuravur II
128.Pattanakkadu I
129.Pattanakkadu II
130.Maradu I
131.Maradu II

7. <u>Kole Soils</u>

132.Kanjanipadam
133.Eravupadam
134.Pazhamkole
135.Chaladikolepadam
136.Chettuvapuzha West
137.Jodurnkole
138.Manalurthazham
139.Anthikadukolepadam
140.Enamakkal
141.Thekkekonchira
142.Vadakkekonchira
143.Vendarupadam
144.Variampadavukole
145.Jayanthipadamkole
146.Porthurperdavukole
147.Muthyalalpadam
148.Jubilipadam
149.Therathukole
150.Kizhakkukole
151.Perunathukarathuruthikole.

APPENDIX II

Physico-chemical characteristics of rice soils

Soil Sample No.	Location	PH	O C (%)	Sand(%)	Silt(%)	Clay(%)	C / 100 soil	Exchangeable Ca me/100g soil	Exchangeable Mg me/100g soil	Exchangeable K me/100g soil	Exchangeable Na me/100g soil	Total N (%)	Fe_2O_3 %	Al_2O_3 %	R_2O_3 %	CaO %	MgO %	C/N ratio	C/P ratio	Fe_2O_3/Al_2O_3	Total P (ppm)	Bray 1 (ppm)	PFC(%)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1.	Perumkadavila	5.0	1.54	65.2	14.0	19.6	8.1	3.5	1.6	1.2	0.3	0.12	12.1	2.9	15.0	0.70	0.12	12.8	64.2	4.2	585	1.1	40.1
2.	Kattakada I	4.9	0.82	50.4	16.3	31.3	6.7	3.0	1.3	0.9	0.3	0.05	18.3	2.7	21.0	0.68	0.10	16.4	45.6	6.8	362	2.2	52.4
3.	Kattakada II	4.8	0.76	52.1	16.0	29.6	6.7	3.1	1.3	0.9	0.3	0.04	17.8	2.7	20.5	0.67	0.10	19.0	42.2	6.6	381	2.2	51.1
4.	Perumpazhuthur I	4.8	0.97	54.5	16.0	27.5	6.6	3.0	1.3	0.6	0.0	0.05	16.9	3.1	20.0	0.68	0.11	12.1	64.7	5.5	283	6.7	50.2
5.	Perumpazhuthur II	4.7	0.78	54.4	18.5	25.4	6.9	2.8	1.4	0.9	0.4	0.05	18.0	3.0	21.0	0.67	0.10	15.6	54.2	6.0	280	5.1	52.0
6.	Avanakuzhi I	5.4	1.98	80.0	4.3	12.5	9.3	4.2	1.9	1.3	0.4	0.15	8.2	6.0	14.2	0.75	0.15	13.2	90.0	1.4	465	3.4	38.3
7.	Avanakuzhi II	5.2	1.57	65.0	11.1	22.6	8.4	3.5	1.7	1.3	0.3	0.11	11.9	4.1	16.0	0.71	0.14	14.3	71.4	2.9	461	2.3	42.4
8.	Vellayani I	4.6	0.66	46.4	18.0	33.6	6.0	2.6	1.2	0.8	0.3	0.03	18.6	4.9	23.5	0.58	0.08	22.0	31.4	3.8	422	2.8	61.1
9.	Vellayani II	4.4	0.63	47.1	20.0	30.6	6.2	2.7	1.2	0.9	0.3	0.03	17.5	4.6	22.1	0.52	0.07	21.0	78.8	3.8	162	1.1	59.3
10.	Karamana R.R S I	4.9	0.96	54.4	18.5	25.6	7.0	2.8	1.4	0.9	0.2	0.08	16.9	3.6	20.5	0.69	0 11	12.0	96.0	4.7	184	6.7	53.1
11.	Karamana R.R.S. II	4.8	0.84	55.4	18.0	24.6	6.8	3.1	1.4	1.0	0.2	0.05	17.0	4.0	21.0	0.65	0.09	16.8	46.7	4.3	383	3.4	51.2
12.	Vattappara	4.8	0.99	57.4	11.0	28.6	6.9	3.1	1.4	1.0	0.3	0.08	17.2	4.8	22.0	0.62	0.08	12.4	56.0	3.6	322	0.6	54.0
13.	Vembayam	5.1	1.60	58.0	19.3	20.7	8.3	3.7	1.7	1.1	0.3	0.12	12.0	4.1	16.1	0.71	0.13	13.3	76.2	2.9	461	2.8	42.0
14.	Vamanapuram	5.3	1.98	80.1	6.3	11.6	9.6	4.3	1.9	1.3	0.6	0.14	9.0	5.3	14.3	0.74	0.15	14.1	82.5	1.7	584	3.9	38.2
15.	Kilimanoor	4.4	0.60	50.4	20.1	27.4	6.2	2.8	1.2	0.9	0.3	0.03	17.8	5.2	23.0	0.50	0.06	20.0	46.2	3.4	263	3.4	59.0
16.	Nilamel	4.8	0.78	58.0	18.0	22.4	7.0	2.9	1.4	0.9	0.2	0.05	16.0	5.5	21.5	0.60	0.09	15.6	32.5	2.9	522	1.7	54.1
17.	Kadakkal	4.6	0.69	50.8	12.5	35.0	6.5	2.9	1.3	0.9	0.1	0.04	17.5	5.0	22.5	0.56	0.07	17.3	26.5	3.5	564	3.9	58.1
18.	Chadayamangalam	5.3	2.05	80.9	6.0	9.5	9.9	4.5	2.0	1.4	0.5	0.22	9.3	5.2	14.5	0.75	0.15	9.3	68.9	1.8	602	5.1	39.0

contd....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
19.	Adoor	5.0	1.47	64.3	15.0	18.5	8.2	3.7	1.6	1.1	0.3	0.10	12.4	3.1	15.5	0.70	0.12	14.7	50.7	4.0	643	5.1	41.0
20.	Marangattukonam	5.2	1.66	60.4	8.6	25.6	8.1	3.7	1.6	1.1	0.3	0.12	12.1	3.9	16.0	0.71	0.12	13.8	79.1	3.1	482	7.9	42.1
21.	Valakom	4.9	0.87	57.4	16.1	25.0	7.2	3.0	1.3	1.0	0.3	0.06	16.5	3.8	20.3	0.68	0.10	14.5	37.8	4.3	523	9.6	51.2
22.	Karikkam	4.7	1.11	58.0	19.0	20.1	7.3	3.3	1.5	1.0	0.4	0.11	16.6	3.9	20.5	0.59	0.09	10.1	35.8	4.3	686	4.5	53.0
23.	Kottarakkara	5.1	1.62	63.0	14.1	20.2	8.4	3.4	1.7	1.2	0.3	0.15	11.6	4.2	15.8	0.71	0.13	10.8	49.1	2.8	764	9.0	42.3
24.	Neduvathur	5.3	2.05	80.3	4.1	11.3	9.2	4.1	1.8	1.3	0.3	0.20	9.1	5.1	14.2	0.75	0.16	10.3	55.4	1.8	806	2.5	39.0
25.	Melkadakkavur	4.1	0.15	33.4	20.0	44.5	4.8	2.1	1.0	0.6	0.2	0.05	18.9	6.1	25.0	0.45	0.04	15.0	7.1	3.1	464	5.6	64.1
26.	Enathu	4.8	1.20	57.5	12.1	28.4	7.4	3.3	1.5	1.0	0.3	0.05	16.2	3.8	20.0	0.61	0.07	24.0	26.7	4.3	1062	13.5	51.0
27.	Adoor	4.8	1.23	60.0	22 6	14.9	7.9	3.3	1.6	1.1	0.3	0.06	16.5	4.0	20.5	0.62	0.07	20.5	37.3	4.1	766	2.5	52.2
28.	Kunnamkulam	5.2	1.78	67.0	10.4	20.6	8.6	3.9	1.7	1.2	0.3	0.12	9.0	4.9	14.8	0.72	0.13	14.8	40.5	2.0	1007	10.1	41.0
29.	Kolikkara	5.1	1.68	70.4	12.0	15.3	8.5	3.8	1.7	1.0	0.3	0.10	12.0	3.1	15.1	0.71	0.12	16.8	36.7	3.9	822	3.9	42.0
30.	Othallur	5.0	1.71	70.9	6.7	20.3	8.5	3.6	1.6	1.1	0.3	0.11	9.1	5.2	14.3	0.70	0.12	15.6	114.0	1.8	323	4.1	40.0
31.	Panthavurpadam	4.7	1.23	50.0	14.0	23.6	7.5	3.2	1.5	1.1	0.2	0.06	16.5	4.1	20.6	0.60	0.10	20.5	38.4	4.0	721	5.6	52.4
32.	Kalachalpadam	4.3	0.40	41.5	16.2	38.3	5.4	2.4	1.1	0.8	0.3	0.02	19.2	7.3	26.5	0.51	0.07	20.0	16.7	2.6	507	5.1	65.1
33.	Kaladippadam	4.7	1.35	60.0	16.3	27.7	7.8	3.3	1.6	1.1	0.3	0.07	16.7	4.1	20.8	0.61	0.10	19.0	30.2	4.1	1032	4.6	52.0
34.	Kuttipuram I	4.8	1.23	60.5	19.0	18.4	8.0	3.7	1.6	1.1	0.3	0.05	16.0	3.7	19.7	0.60	0.10	24.6	87.9	4.3	266	6.2	50.2
35.	Kuttipuram II	5.7	2.07	85.6	4.0	5.6	10.5	4.7	2.1	1.4	0.4	0.21	8.0	4.6	12.6	0.85	0.20	9.9	90.0	1.7	445	12.3	36.0
36.	Thirunavaya	5.1	1.59	73.0	16.1	8.3	8.6	3.4	1.7	1.2	0.3	0.15	12.1	3.2	15.3	0.70	0.12	10.6	198.8	3.8	186	3.0	41.4
37.	Codakkal	5.2	1.74	75.2	12.0	10.6	8.9	3.6	1.8	1.2	0.3	0.12	8.8	5.4	14.2	0.72	0.13	14.5	124.3	1.6	309	6.2	40.0
38.	Edakkattu-parambu	5.0	1.71	72.3	8.1	16.6	8.6	3.7	1.7	1.2	0.4	0.12	9.0	5.5	14.5	0.68	0.10	14.3	171.0	1.6	221	4.1	41.3
39.	Chamaravattom	4.1	0.15	44.4	18.0	34.1	5.8	2.5	1.2	0.8	0.2	0.01	19.5	7.3	26.8	0.62	0.08	15.0	10.7	2.7	306	6.9	66.0
40.	Thirur	4.7	1.20	60.5	12.0	23.5	8.0	3.4	1.6	1.1	0.2	0.05	16.2	3.4	19.6	0.59	0.06	24.0	80.0	4.8	309	6.1	50.2

contd.......

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
41.	Ponmundam	5.0	1.81	70.5	12.3	12.2	8.7	3.9	1.7	1.3	0.4	0.13	12.2	2.8	15.0	0.67	0.09	13.9	58.4	4.4	684	5.8	41.0
42.	Peruvanna	4.7	1.26	60.5	16.2	20.3	8.0	3.7	1.6	1.0	0.3	0.06	12.0	4.5	16.5	0.58	0.06	21.0	35.0	2.7	783	3.6	48.1
43.	Ponmala	4.9	1.25	60.5	12.4	23.1	8.0	3.4	1.6	1.2	0.3	0.05	16.5	3.4	19.9	0.61	0.10	25.0	35.7	4.9	806	6.7	50.3
44.	Malappuram	5.2	1.75	71.8	10.7	13.5	8.9	4.0	1.8	1.3	0.4	0.14	12.3	3.4	15.7	0.71	0.12	12.5	36.5	3.6	1121	10.1	42.0
45.	Ramapuram	5.2	1.80	73.4	8.2	14.4	8.8	3.8	1.8	1.1	0.3	0.13	12.0	2.9	14.9	0.70	0.12	13.9	46.2	4.1	882	20.8	41.1
46.	Kunnappally	5.0	1.71	73.5	14.0	8.4	9.2	3.8	1.8	1.2	0.4	0.14	12.2	3.5	15.7	0.63	0.11	12.9	26.2	3.5	1544	16.9	42.2
47.	Kallaeppilly-ppadam	5.1	1.93	76.4	14.0	7.3	9.4	4.2	1.9	1.2	0.4	0.14	12.3	3.0	15.3	0.70	0.12	13.8	60.3	4.1	688	3.5	41.1
48.	Vallur	4.6	0.52	50.4	18.1	29.6	6.5	2.8	1.3	0.9	0.3	0.02	18.4	5.6	24.0	0.55	0.07	26.0	37.1	3.3	289	2.9	59.0
49.	Pattambi R.R.S. I	4.8	1.35	60.1	23.0	13.6	8.0	3.6	1.6	1.1	0.3	0.06	15.6	3.1	18.7	0.60	0.10	22.5	61.4	5.0	482	6.1	50.1
50.	Pattambi R.R.S. II	5.0	1.42	75.4	8.1	13.1	8.9	4.3	1.8	1.3	0.3	0.06	12.3	2.7	15.0	0.68	0.11	15.8	40.6	4.6	1101	17.7	40.0
51.	Pattambi R.R.S. III	5.1	1.48	78.4	4.0	15.5	9.2	4.2	1.8	1.2	0.4	0.10	12.0	2.9	14.9	0.68	0.10	14.8	31.5	4.1	1201	7.6	41.0
2.	Panachery	5.3	2.28	80.4	6.0	7.9	10.2	4.2	2.0	1.5	0.2	0.28	12.0	2.8	14.8	0.71	0.12	8.1	73.6	4.3	721	12.6	39.0
3.	Mannuthy R.R.S.	4.7	1.32	60.0	12.7	24.1	8.0	3.6	1.6	1.1	0.2	0.05	15.8	3.1	18.9	0.59	0.06	26.4	42.6	5.1	745	7.3	50.3
4.	Puzhakkal	4.9	1.39	60.9	12.0	23.1	8.1	3.7	1.6	1.1	0.3	0.06	12.9	4.6	17.5	0.63	0.11	23.2	49.6	2.8	604	5.8	49.0
5.	Manthavadi	4.9	1.38	61.2	8.0	27.5	8.2	3.7	1.6	1.1	0.3	0.06	17.0	3.1	20.1	0.62	0.11	23.0	153.3	5.5	186	4.6	50.0
6.	Kurichikari	3.4	3.13	70.1	12.0	15.3	12.9	5.4	2.4	0.9	2.6	0.06	4.2	12.1	16.3	0.40	0.31	5.7	101.0	0.4	706	0.4	47.6
7.	Alankari	2.1	1.36	44.0	28.0	25.1	8.9	4.0	1.7	0.5	1.7	0.30	5.3	12.8	18.1	0.31	0.20	4.5	85.0	0.4	365	1.0	62.8
8.	Puthenkari	2.5	2.26	38.4	43.0	16.5	9.4	4.2	1.8	0.5	1.9	0.39	4.7	13.1	17.8	0.32	0.15	5.8	141.3	0.4	361	0.7	59.6
9.	Vadayar	2.4	2.47	50.1	24.0	21.5	10.0	4.3	1.9	0.6	1.9	0.40	4.8	12.1	17.9	0.31	0.14	6.2	154.4	0.4	364	0.6	60.5
0.	Mulaekunnam-kari	3.3	3.16	67.1	10.0	18.6	13.3	5.6	2.3	0.8	2.6	0.58	3.8	12.2	16.0	0.35	0.16	5.5	143.6	0.3	523	12.0	46.7

contd........

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
61.	Mannarkari I	2.6	2.67	59.5	22.0	15.3	105.0	4.6	1.9	0.6	2.6	0.42	5.9	13.0	18.9	0.33	0.13	6.2	130.5	0.5	428	0.6	60.6
62.	Mannarkari II	2.8	3.00	44.4	30.0	21.3	9.4	4.2	1.8	0.6	1.9	0.46	4.5	12.4	16.9	0.35	0.17	6.5	125.0	0.4	529	0.4	55.7
63.	Vembanakari I	2.9	3.09	63.5	11.5	21.8	11.2	5.1	2.0	0.7	2.1	0.46	4.6	12.3	16.9	0.37	0.18	6.7	147.1	0.4	423	0.5	54.8
64.	Vembanakari II	2.6	2.94	55.3	18.4	24.1	10.2	5.4	1.7	0.6	2.0	0.50	6.5	12.6	19.1	0.31	0.14	5.9	113.1	0.5	545	0.5	60.0
65.	Anadhakari	2.7	3.04	46.0	30.0	21.6	11.6	5.2	2.2	0.7	2.3	0.45	4.6	12.2	16.8	0.33	0.13	6.6	104.8	0.4	643	1.7	54.5
66.	Karuvatta I	3.1	3.12	63.1	10.0	22.6	12.6	5.7	2.3	0.6	2.6	0.53	4.1	12.4	16.5	0.32	0.15	5.9	520.0	0.3	169	0.4	49.9
67.	Karuvatta II	3.8	3.18	50.0	26.2	20.6	14.2	6.3	2.7	0.9	2.8	0.55	3.0	11.7	14.7	0.45	0.20	5.6	198.8	0.3	381	2.1	44.6
68.	Karuvatta III	3.7	3.15	50.4	25.0	20.5	14.3	6.0	2.4	0.7	2.9	0.52	3.1	11.4	14.5	0.42	0.19	6.1	165.8	0.3	481	2.6	46.4
69.	Karimadi	3.7	3.22	50.4	25.0	20.1	18.0	7.9	3.2	1.1	3.6	0.52	3.2	11.3	14.5	0.43	0.21	6.0	292.7	0.3	245	1.4	45.4
70.	Purakkadu	4.1	3.24	70.9	12.1	14.1	19.2	8.3	3.5	1.2	3.8	0.61	3.0	11.0	14.0	0.50	0.23	5.3	231.4	0.3	342	8.1	42.5
71.	Cherukara East	4.0	2.79	52.1	20.3	24.3	8.8	3.1	2.6	0.7	1.2	0.40	6.5	7.4	13.9	0.65	0.20	7.0	68.1	0.9	901	2.7	50.4
72.	Cherukara West	4.1	2.79	52.7	17.0	27.2	9.5	3.3	2.9	0.8	1.3	0.39	7.2	6.9	14.1	0.68	0.12	7.2	73.4	1.0	841	1.8	50.6
73.	E. Block East	4.2	2.71	53.4	20.0	23.4	9.8	3.4	2.9	0.8	1.4	0.38	7.0	6.7	13.7	0.70	0.20	7.1	38.7	1.0	1763	2.1	49.9
74.	E. Block West	3.7	1.98	50.2	24.0	22.5	6.5	2.3	2.0	0.5	0.9	0.21	9.5	8.0	17.5	0.42	0.12	9.4	52.1	1.2	884	3.2	55.2
75.	H. Block East	3.8	1.99	49.4	43.0	5.2	6.7	2.3	2.0	0.5	0.9	0.21	10.0	7.4	17.4	0.45	0.15	9.5	52.4	1.4	845	2.1	54.1
76.	H. Block West	3.8	2.53	50.5	17.0	29.2	7.1	2.5	2.1	0.6	1.0	0.35	10.0	6.8	17.8	0.44	0.14	7.5	68.4	1.6	820	2.7	54.9
77.	Rajapuram North	4.4	3.04	58.3	27.0	13.5	13.4	4.7	4.0	1.1	1.9	0.45	4.6	4.6	9.2	0.71	0.23	6.8	58.5	1.0	1141	1.8	45.1
78.	Rajapuram South	4.1	2.74	53.6	20.5	22.4	12.3	4.3	3.7	1.0	1.7	0.39	7.3	6.7	14.0	0.71	0.24	7.0	65.2	1.1	922	0.5	51.0
79.	Mangalam East	4.2	2.67	50.4	17.1	28.0	13.3	4.6	4.0	1.1	1.9	0.31	7.4	6.4	13.6	0.73	0.20	8.6	62.1	1.2	961	1.8	50.1
80.	Mangalam West	4.2	3.00	54.6	18.0	22.8	12.2	4.3	3.7	1.1	1.7	0.43	6.5	5.0	11.5	0.71	0.21	7.0	63.8	1.3	1011	0.6	47.9

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
81.	Mathikayal East	4.3	3.06	56.8	16.2	23.1	13.9	4.9	4.2	1.1	2.0	0.44	5.9	4.2	10.1	0.72	0.32	7.0	58.9	1.4	1061	3.2	45.1
82.	Mathikayal West	4.2	3.00	55.5	18.0	24.5	13.0	4.6	3.9	1.0	1.8	0.44	7.0	4.9	11.9	0.70	0.31	6.8	93.8	1.4	703	1.1	49.0
83.	Sreemoolam East	3.9	2.56	50.5	22.0	24.3	6.0	2.8	2.4	0.6	1.1	0.30	10.8	6.7	17.5	0.60	0.20	8.5	55.7	1.7	921	1.2	55.0
84.	Sreemoolam West	3.9	2.70	51.4	22.0	23.2	5.9	2.1	1.8	0.6	0.8	0.35	10.6	6.8	17.4	0.65	0.22	7.7	71.1	1.6	842	1.1	54.2
85.	Kokkakayal	4.6	3.09	60.4	24.2	14.2	13.9	4.9	4.2	1.1	1.9	0.45	6.0	4.3	10.3	0.75	0.25	6.9	81.3	1.4	822	1.8	44.9
86.	Nedumpuram	4.8	3.05	70.4	14.0	12.2	21.1	7.4	5.3	1.9	2.5	0.36	3.0	3.9	6.9	0.50	0.12	8.5	74.4	0.8	910	3.3	34.7
87.	Valiykiliyanveli I	3.6	1.74	34.4	26.0	37.6	8.7	3.1	2.2	0.8	1.1	0.19	9.2	9.3	18.5	0.38	0.09	9.2	72.5	1.0	505	1.5	60.3
88.	Valiykiliyanveli II	3.9	1.75	34.1	28.0	35.6	9.0	3.2	2.2	0.8	1.2	0.20	8.6	8.8	17.4	0.43	0.10	8.8	31.8	1.0	1101	4.3	55.1
89.	Chennamangalam	4.0	1.86	37.3	30.0	29.6	10.0	3.6	2.5	0.9	1.3	0.22	8.8	8.8	17.6	0.45	0.11	8.5	44.3	1.0	921	2.0	55.0
90.	Kochukiliyanveli	4.4	2.13	38.5	28.7	29.6	10.6	3.8	2.7	1.1	1.3	0.25	7.9	8.6	16.5	0.48	0.12	8.5	49.5	0.9	960	5.9	50.9
91.	Thalavadi	4.4	2.28	40.5	30.6	25.3	10.5	3.7	2.6	1.1	1.4	0.26	7.5	10.0	17.5	0.47	0.12	8.8	71.3	0.8	744	4.7	54.1
92.	Moncompu R.R.S.I	4.4	2.28	50.2	19.3	27.3	11.5	4.1	2.8	0.9	1.4	0.25	8.0	8.7	16.7	0.47	0.11	9.1	78.6	0.9	582	1.4	52.1
93	.Moncompu R.R.S.II	4.3	2.49	51.2	21.0	24.6	12.0	4.3	3.0	1.1	1.6	0.28	7.5	8.6	16.1	0.48	0.12	8.9	124.5	0.9	423	8.3	49.9
94.	Moncompu R.R.S.III	4.6	1.86	59.3	22.8	13.8	17.0	6.1	4.3	1.5	2.2	0.21	3.4	3.8	7.2	0.51	0.13	8.9	93.0	0.9	409	3.4	35.1
95.	Pallikkuttuma I	4.0	1.84	36.4	32.0	27.3	9.6	3.4	2.3	0.9	1.2	0.20	8.9	8.4	17.3	0.42	0.14	9.2	68.2	1.1	564	2.7	55.4
96.	Pallikkuttuma II	4.2	2.17	53.4	20.4	23.2	14.5	5.2	3.6	1.3	1.8	0.25	7.5	8.5	16.0	0.46	0.12	8.7	74.8	0.9	606	4.1	49.6
97.	Cheppalakka I	4.0	1.86	38.3	30.2	28.3	9.1	3.3	2.3	0.8	1.1	0.21	9.1	9.1	18.2	0.41	0.11	8.9	54.7	1.0	723	4.5	54.7
98.	Cheppalakka II	4.6	3.01	65.5	12.0	18.3	17.5	5.3	4.2	1.8	2.1	0.35	3.4	3.6	7.0	0.55	0.14	8.6	97.1	0.9	668	5.3	35.4
99.	Ramankari I	4.3	2.53	54.1	20.1	22.6	15.1	5.4	3.6	1.4	2.0	0.30	6.8	8.2	15.0	0.47	0.12	8.4	72.3	0.8	683	8.6	46.1
100.	Ramankari II	4.2	2.85	54.5	21.5	20.7	17.2	6.2	4.3	1.6	2.1	0.32	6.8	8.3	15.1	0.46	0.11	8.9	83.8	0.8	605	1.8	44.9

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
101.	Kidangara I	4.3	2.88	56.4	22.0	18.4	17.0	6.0	4.3	1.5	2.0	0.33	6.9	8.1	15.0	0.45	0.11	8.7	65.5	0.9	987	2.0	46.0
102.	Kidangara II	4.3	3.01	57.5	20.1	20.1	17.5	6.3	4.4	1.6	2.1	0.35	6.5	8.5	15.0	0.46	0.12	8.6	57.9	0.8	1210	5.8	45.1
103.	Kayamkulam RRS I	4.8	0.30	85.1	4.0	7.6	2.5	1.0	0.9	0.3	0.1	0.01	2.1	4.2	6.3	0.11	0.07	30.0	21.4	0.5	366	5.9	38.4
104.	Kayamkulam RRS II	5.1	0.51	90.0	4.1	3.8	4.0	1.6	1.4	0.5	0.2	0.02	2.0	3.8	5.8	0.12	0.08	25.5	36.4	0.5	325	1.5	33.3
105.	Kayamkulam RRS III	4.8	0.39	91.2	3.6	4.6	2.6	1.0	0.9	0.3	0.1	0.01	2.0	4.0	6.0	0.10	0.06	39.0	30.0	0.5	309	12.5	38.4
106.	Karunagappally I	5.0	0.42	88.3	3.9	3.9	2.8	1.1	0.9	0.3	0.1	0.02	2.1	3.8	5.9	0.11	0.05	21.0	23.3	1.6	421	3.0	37.3
107.	Karunagappally II	5.2	0.54	89.0	4.0	3.6	4.8	1.9	1.7	0.6	0.3	0.03	2.0	3.9	5.9	0.13	0.06	18.0	23.5	0.6	460	8.8	33.4
108.	Karunagappally III	5.2	0.58	89.8	3.8	3.5	5.0	2.0	1.7	0.6	0.2	0.03	2.1	4.0	6.1	0.13	0.07	19.3	32.2	0.5	388	8.9	35.2
109.	Krishnapuram	4.9	0.45	86.3	4.7	4.8	3.0	1.2	1.0	0.4	0.2	0.02	2.2	4.3	6.5	0.11	0.05	22.5	64.3	0.5	149	11.2	38.3
110.	Changankulangara	4.9	0.46	88.2	3.7	4.8	3.5	1.4	1.2	0.4	0.2	0.03	2.1	4.2	6.3	0.12	0.05	15.3	57.5	0.5	185	3.8	37.3
111.	Payikuzhi	4.9	0.45	88.7	3.9	4.3	3.8	1.5	1.3	0.5	0.2	0.03	2.2	4.2	6.4	0.11	0.07	15.0	25.0	0.5	386	3.3	38.8
112.	Chalakudi RRS I	5.5	0.72	91.1	2.0	3.6	10.7	4.3	3.8	1.3	0.5	0.05	1.6	4.1	5.7	0.15	0.09	14.4	120.0	0.4	129	7.0	31.5
113.	Chalakudi RRS II	5.1	0.70	89.5	4.0	3.6	6.2	2.4	2.2	0.7	0.3	0.05	1.6	4.2	5.8	0.11	0.06	14.0	140.0	0.4	144	10.4	33.3
114.	Chalakudi RRS III	4.8	0.49	88.0	5.1	4.5	3.8	1.5	1.4	0.5	0.2	0.04	2.2	4.4	6.6	0.09	0.02	12.3	98.0	0.5	108	4.0	38.3
115.	Vyttila RRS I	2.6	0.21	78.0	16.0	3.6	2.5	0.9	0.5	0.6	0.3	0.01	9.0	4.5	13.5	0.06	0.18	21.0	8.4	2.0	581	34.2	44.5
116.	Vyttila RRS II	2.6	0.28	79.1	18.0	1.6	2.6	0.9	0.6	0.6	0.2	0.01	8.8	4.3	13.1	0.07	0.17	28.0	15.6	2.1	445	11.3	43.5
117.	Vyttila RRS III	2.8	1.32	80.3	13.0	3.5	4.0	1.4	0.8	1.0	0.4	0.10	8.7	4.3	13.0	0.08	0.18	13.2	60.0	2.0	543	9.9	41.4
118.	Vyttila RRS IV	2.9	1.35	80.2	9.8	6.5	4.3	1.5	1.0	1.1	0.5	0.11	8.6	4.2	12.8	0.08	0.18	12.3	71.1	2.1	448	7.9	39.5
119.	Vyttila RRS V	3.4	1.77	81.3	10.8	3.5	5.5	2.1	1.2	1.4	0.6	0.15	8.0	4.0	12.0	0.10	0.20	11.8	68.1	2.0	601	14.1	33.4
120.	Vyttila RRS VI	3.3	1.78	83.5	12.0	3.6	5.9	2.2	1.2	1.5	0.7	0.15	8.2	4.0	12.0	0.10	0.19	11.9	65.9	2.1	625	14.6	34.5

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
121.	Vyttila double crop	2.5	0.48	79.5	13.7	4.6	2.7	1.0	0.6	0.7	0.3	0.03	9.2	4.7	13.9	0.06	0.16	16.0	19.2	2.0	631	8.1	44.5
122.	Vyttila single crop	2.8	1.41	81.8	12.1	4.2	4.8	1.7	1.0	1.2	0.6	0.12	8.4	4.3	12.7	0.07	0.17	11.6	44.1	2.0	782	26.8	39.4
123.	Panangad I	2.9	1.53	81.0	12.3	3.6	4.9	1.8	1.0	1.2	0.5	0.14	8.3	4.2	12.5	0.08	0.18	10.9	102.0	2.0	345	8.2	39.5
124.	Panangad II	2.9	1.60	81.2	12.2	3.7	5.3	1.9	1.1	1.3	0.6	0.15	8.1	4.1	12.2	0.08	0.18	10.7	100.0	2.0	409	7.6	38.5
125.	Panangad III	2.6	1.05	80.2	12.9	3.8	3.1	1.1	0.6	0.8	0.3	0.10	9.4	4.6	14.0	0.05	0.15	10.5	116.7	2.0	226	3.5	44.5
126.	Thuravour I	4.0	1.89	81.6	9.7	4.6	6.1	2.2	1.3	1.7	0.7	0.16	7.9	4.0	11.9	0.13	0.23	11.8	210.0	2.0	229	2.1	32.4
127.	Thuravour II	4.9	2.56	90.1	3.9	2.9	7.5	2.7	1.6	1.9	0.8	0.30	7.4	3.7	11.1	0.15	0.25	8.5	284.4	2.0	227	2.7	29.5
128.	Pattanakadu I	5.7	3.12	91.1	4.0	1.6	11.9	4.4	2.5	3.0	0.3	0.35	6.3	3.2	9.5	0.20	0.30	6.9	346.7	2.0	241	1.9	24.5
129.	Pattanakadu II	4.6	2.14	83.5	9.0	3.0	7.6	2.7	1.6	1.9	0.8	0.25	7.5	3.8	11.3	0.15	0.24	8.6	125.9	2.0	424	6.4	30.5
130.	Maradu I	3.0	1.60	81.4	6.0	9.5	5.5	2.0	1.1	1.3	0.6	0.15	8.1	4.0	12.1	0.09	0.18	10.7	55.2	2.0	704	15.5	37.5
131.	Maradu II	2.5	1.06	80.1	12.7	3.9	3.1	1.1	0.6	0.6	0.3	0.10	9.5	4.7	14.2	0.06	0.16	10.6	34.2	2.0	783	16.9	44.5
132.	Kanjanipadam	3.5	0.78	30.4	16.0	50.1	3.2	1.1	1.0	0.6	0.2	0.06	11.2	16.9	28.1	0.18	0.10	13.0	52.0	0.7	349	3.7	55.2
133.	Erauupadam	4.0	0.79	34.6	25.4	37.0	3.5	1.2	1.1	0.7	0.2	0.07	12.8	19.2	32.0	0.28	0.15	11.3	20.8	0.7	981	11.2	57.3
134.	Pazhamkole	4.3	0.88	36.5	25.0	35.6	4.1	1.5	1.3	0.8	0.2	0.06	10.8	16.7	27.5	0.35	0.20	11.0	27.5	0.7	781	1.7	53.2
135.	Chaladikole	4.5	0.61	36.5	28.6	31.3	4.2	1.5	1.3	0.8	0.2	0.05	10.9	16.7	27.6	0.40	0.28	12.2	19.1	0.7	853	1.6	53.2
136.	Chettuvapuzha West	4.7	1.57	48.0	11.1	38.7	6.5	2.3	2.1	1.3	0.4	0.15	8.1	12.4	20.5	0.44	0.30	10.5	38.3	0.7	900	1.8	42.3
137.	Nedumkole	4.7	1.87	51.2	18.5	27.1	6.6	2.3	2.1	1.3	0.4	0.20	8.0	12.2	20.2	0.43	0.29	9.4	44.5	0.7	894	1.1	41.2
138.	Manalurthazham	4.6	1.96	53.5	8.0	34.6	6.8	2.4	2.2	1.3	0.4	0.22	8.3	12.3	20.6	0.44	0.28	8.9	98.0	0.7	489	2.8	42.3
139.	Anthikkadukole	4.5	1.05	40.1	22.2	34.1	5.0	1.8	1.6	1.0	0.3	0.10	11.8	15.3	27.1	0.41	0.30	10.5	42.0	0.6	588	3.7	58.2
140.	Enammakkal	5.0	1.48	48.4	18.0	30.5	6.7	2.3	2.1	1.3	0.4	0.12	8.1	12.2	20.3	0.55	0.45	12.3	37.0	0.7	1201	4.3	42.3

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
141.	Thekkekonchira	4.6	2.08	58.3	10.2	29.5	6.4	2.2	2.1	1.2	0.4	0.25	8.0	12.1	20.1	0.41	0.29	8.3	71.7	0.7	705	4.3	42.2
142.	Vadakkekonchira	4.4	1.15	40.1	28.0	30.0	5.6	2.0	1.9	1.1	0.3	0.11	11.0	17.0	28.0	0.40	0.30	10.5	25.6	0.7	1002	1.8	52.2
143.	Vendarupadam	4.2	1.18	31.3	25.0	41.5	5.4	1.1	1.7	1.1	0.3	0.12	11.2	17.0	28.2	0.25	0.23	9.8	69.4	0.7	426	1.7	53.1
144.	Variampadavukole	4.8	2.05	60.3	17.3	20.3	9.7	3.4	3.1	1.6	0.6	0.30	8.0	12.0	20.0	0.45	0.29	6.8	44.6	0.7	1101	8.0	42.1
145.	Jayanthpadamkole	4.6	1.21	61.2	12.0	23.6	6.5	2.2	2.0	1.3	0.3	0.15	8.1	12.4	20.5	0.42	0.29	8.1	67.2	0.7	384	0.6	42.2
146.	Porathurperdavukole	4.8	2.05	56.1	16.0	25.6	8.2	2.9	2.6	1.6	0.5	0.29	8.0	12.1	20.1	0.44	0.31	7.1	56.9	0.7	865	4.3	43.1
147.	Muthyalalpadam	4.5	1.36	41.4	26.2	30.3	6.1	2.1	1.9	1.2	0.4	0.17	11.9	15.7	27.6	0.43	0.30	8.0	64.6	0.8	506	2.9	52.3
148.	Jubileepadam	4.6	2.31	61.3	8.0	27.6	8.4	2.9	2.7	1.6	0.5	0.26	8.4	12.8	21.2	0.40	0.31	8.9	64.2	0.7	801	1.8	42.3
149.	Therathukole	4.3	1.26	37.5	22.8	36.6	6.3	2.2	2.0	1.3	0.4	0.15	11.9	15.2	27.1	0.36	0.24	8.4	45.0	0.8	604	1.1	52.2
150.	Kizhakkukole	4.4	1.51	49.5	20.9	25.4	6.5	2.2	2.1	1.3	0.4	0.14	11.6	15.4	27.0	0.41	0.28	10.8	79.5	0.8	398	0.6	53.3
151.	Perunathukara-thurithikole	4.5	1.59	45.4	20.4	30.9	6.5	2.3	2.1	1.2	0.3	0.15	12.0	15.5	27.5	0.41	0.28	10.6	83.7	0.8	386	0.6	52.2

APPENDIX III

Abstract of the analysis of variance of total P and inorganic P fractions of rice soils.

Source	df	Mean square										
		Saloid P	Al-P	Fe-P	Ca-P	Red.P	Occluded P	Sum of inorganic P	Organic P	Non extractable P	Total inorganic P	Total P
1	2	3	4	5	6	7	8	9	10	11	12	13
et-een oils	6	1789.4	16116.5	23981.3	4160.3	6674.3	534.4	162463.0	160259.7	3091.3	211988.4	740587.2
lth oils	144	189.8	3575.8	1666.7	570.3	661.8	120.7	17705.5	10401.4	306.0	22136.7	61862.8
-Value	-	9.4**	4.5**	14.4**	7.3**	10.1**	4.4**	9.2**	15.4**	10.1**	9.6**	12.0**

** Significant at 1 per cent level.

APPENDIX IV

Abstract of the analysis of variance of the Phosphorus fixing capacity of rice soils.

Source	df	Mean square
1	2	3
Total	150	-
Between soils	6	608.17**
With in soils	144	44.23

** Significant at 1 per cent level.

APPENDIX V

Abstract of the analysis of variance for the transformation of inorganic P fractions due to submergence.

Source	df	Mean square						
		Saloid P	Al-P	Fe-P	Ca-P	Reductant P	Occluded P	Sum of inorganic P
1	2	3	4	5	6	7	8	9
Conditions (C)	1	8.08	3005.64	37064.30	112.00	455.87	1.77	88537.51
Soils (S)	6	460.78*	17131.77	24874.46	4908.42	7003.71	552.40	139060.28
C x S	6	0.29	158.94	2175.00	10.15	412.28	0.03	3817.76
Error	14	122.18	17456.27	16218.96	0.004	3590.08	475.98	129828.94

* Significant at 5 per cent level.

APPENDIX VI

Abstract of analysis of variance for available P in rice soils by different extractants under air dry and waterlogged conditions.

Source	df	Mean square
1	2	3
Between soils (S)	6	1084.95**
Conditions (C)	1	1513.14*
S x C	6	211.49
Methods (M)	3	1208.10**
M x S	18	192.91
M x C	3	603.97*
M x S x C	18	138.15
Error	56	235.96

* Significant at 5 per cent level

** Significant at 1 per cent level.

APPENDIX VII

Basic data of soils used for the P response study.

<u>Mechanical seperates</u>	
Sand	47.1 per cent
Silt	20.0 per cent
Clay	30.6 per cent
<u>Chemical characteristics</u>	
pH	4.4
Ec	0.03 mmhos/cm
Total N	0.03 per cent
Total P	162 ppm
Total K	600 ppm
Bray 1-P	1.12 ppm
Organic carbon	0.6 per cent
Total CaO	0.5 per cent
Total MgO	0.07 per cent
Total sesqui-oxides	22.1 per cent
Total Fe_2O_3	17.5 per cent
Total Al_2O_3	4.6 per cent
C.E.C.	6.2 m.e./100 g
Exch. Ca	2.7 m.e/100 g
Exch. Mg	1.2 m.e/100 g
Exch. K	0.9 m.e/100 g
Exch. Na	0.2 m.e/100 g
Saloid P	9.0 ppm
Al-P	24.6 ppm
Fe-P	30.0 ppm
Ca-P	5.9 ppm
Reductant P	6.8 ppm
Occluded P	2.1 ppm
Org. P	81.6 ppm
Phosphorus fixing capacity	49 per cent

APPENDIX VIII

Abstract of analysis of variance for available P by various methods at different growth stage of the crop.

Source	df	Mean square											
		Bray I			Bray II			Olsen			Truog		
		30th day	60th day	Harvest	30th day	60th day	Harvest	30th day	60th day	Harvest	30th day	60th day	Harvest
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Variety (V)	1	36.41**	6.93**	5.45**	71.76**	11.79**	7.84**	34.61*	22.12**	3.32**	18.24	61.63**	9.88
Treatments (T)	5	39.14**	58.73**	36.28**	134.81**	99.44**	68.36**	58.98**	68.39**	50.16**	287.37**	0.98	30.50
V x T	5	4.27**	0.46	0.157*	10.10**	1.44**	0.378**	6.89	5.43	1.54**	43.96**	1.93**	11.31
Error	12	0.207	0.35	0.044	0.24	0.005	0.009	6.74	2.82	0.187	6.64	0.329	16.63

* Significant at 5 per cent level

** Significant at 1 per cent level.

APPENDIX IX

Abstract of pooled analysis of variance for available P estimated by different methods at various growth stages of rice.

Source	df	Mean square		
		30^{th} day after sowing	60^{th} day after sowing	Harvest stage
1	2	3	4	5
Methods (M)	3	234.48**	62.85**	1209.76**
Treatments (T)	5	389.14**	169.17**	149.77**
M x T	15	53.68**	21.44**	10.85**
Variety (V)	1	151.96**	86.67**	3.79
M x V	3	3.19	5.28**	7.42
T x V	5	25.23**	1.58	3.72
M x T x V	15	13.36*	2.58**	4.07
Error (pooled)	48	3.46	0.88	4.22

* Significant at 5 per cent level

** Significant at 1 per cent level.

APPENDIX X

Abstract of analysis of variance for inorganic P fractions at various growth stages of the crop.

(i) 30th day after sowing.

Source	df	Mean square						
		Saloid P	Al-P	Fe-P	Ca-P	Reductant P	Occluded P	Sum of inorganic P
1	2	3	4	5	6	7	8	9
Total	23							
Variety	1	0.00	0.05	15.68	0.43	0.00	0.05	1.82
Treatments	5	5.76**	350.85**	4602.93**	108.56**	5.43**	3.40**	10294.35**
V x T	5	0.38	0.15	17.39	0.22	0.10	0.01	6.94
Error	12	0.03	0.34	15.07	0.11	0.12	0.05	8.02

(ii) 60th day after sowing

Source	df	Mean square						
		Saloid P	Al-P	Fe-P	Ca-P	Reductant P	Occluded P	Sum of inorganic P
1	2	3	4	5	6	7	8	9
Total	23							
Variety	1	0.96	6.83	5.80	0.20	1.13	0.06	0.67
Treatments	5	5.11**	352.15**	4721.66**	117.61	7.56	2.54**	10670.71*
V x T	5	0.49	0.97	32.05*	0.48*	4.36	0.02	42.03**
Error	12	0.57	0.35	7.29	0.12	3.44	0.02	5.79

(iii) Harvest stage

Source	df	Mean square						
		Saloid P	Al-P	Fe-P	Ca-P	Reductant P	Occluded P	Sum of inorganic P
1	2	3	4	5	6	7	8	9
Total	23							
Variety	1	4.68	209.45**	23.40	2.16	21.28**	6.20**	878.46*
Treatments	5	3.02**	156.20**	4572.06**	98.45**	8.33	0.95**	9088.88**
V x T	5	0.55	2.72**	6.67	6.75	3.34	0.10**	13.08
Error	12	0.46	0.23	7.40	4.30	4.36	0.02	9.70

* Significant at 5 per cent level

** Significant at 1 per cent level.

APPENDIX XI

Abstract of analysis of variance for biometric and yield characteristics at different growth stages.

(i) 30th day after sowing.

Source	df	Mean square: Height (cm)	No. of tillers/ hill	Weight of roots/hill (g)	Total No. of roots/ hill	Maximum length of roots (cm)	Average length of roots (cm)	Total dry matter/ hill (g)
1	2	3	4	5	6	7	8	9
Total	23							
Variety	1	29.93**	0.67	8.40**	5828.17**	124.22**	7.04	39.02**
Treatments	5	494.55	75.17**	53.48**	21140.57**	266.98**	93.58**	87.18**
V x T	5	8.19**	0.57*	0.97**	1394.97**	7.30**	7.16	3.82**
Error	12	2.07*	0.17	0.059	96.83	0.882	4.25	0.0007

(ii) 60th day after sowing.

Source	df	Mean square: Height (cm)	No. of tillers/ hill	Weight of roots/hill (g)	Total No. of roots/ hill	Maximum length of roots (cm)	Average length of roots (cm)	Total dry matter/ hill (g)
1	2	3	4	5	6	7	8	9
Total	23							
Variety	1	6144.00**	44.08**	213.49**	4213.50	266.66**	112.67	172.61**
Treatments	5	640.80**	13.15**	138.75**	67319.50**	18.66**	176.08*	898.08**
V x T	5	322.80**	1.68	23.31**	8505.90	21.46**	40.67	70.40**
Error	12	3.33	-	0.0343	4005.00	1.67	48.67	0.32

(iii) Harvest stage.

Source	df	Mean square: Height of plant (cm)	No. of productive tillers/hill	Weight of roots/ hill (g)	Weight of grain/ hill (g)	Weight of straw hill (g)	Total d matter/ hill (g)
1	2	3	4	5	6	7	8
Total	23						
Variety	1	6787.21**	56.33**	165.48**	159.14**	3197.04**	6851.9*
Treatments	5	185.71**	13.20**	156.92**	170.13**	388.68**	2020.0*
V x T	5	75.63**	2.30	17.06**	13.62**	78.32**	267.4*
Error	12	1.06	-	0.019	0.10	0.118	0.2

* Significant at 0.05 level

APPENDIX XII

Abstract of analysis of variance for total P uptake at various growth stages of the crop.

Source	df	Mean square		
		30^{th} day	60^{th} day	Harvest stage
1	2	3	4	5
Total	23			
Variety	1	513.01**	800.88**	643.56**
Treatments	5	206.78**	191.37**	211.30**
V x T	5	3.01**	5.08**	4.60**
Error	12	0.15	0.37	0.06

** Significant at 1 per cent level.

APPENDIX XIII

Basic data of the soils used for the ^{32}P study.

Property	Soil Types						
	Lateritic alluvium	Kari	Karapadam	Kayal	Pokkali	Coastal sandy alluvium	Kole
	Vellayani (S_1)	Karuvatta (S_2)	Moncompu (S_3)	Mathikayal (S_4)	Panangad (S_5)	Chalakudy (S_6)	Kanjanipadam (S_7)
Sand (per cent)	47.1	54.5	53.6	56.8	80.0	89.5	48.0
Silt (per cent)	20.0	20.4	21.0	16.2	12.3	3.7	11.3
Clay (per cent)	30.6	21.3	21.9	23.1	3.9	3.9	38.5
pH	4.4	3.6	4.4	4.2	3.9	5.1	4.7
Total N (per cent)	0.03	0.53	0.28	0.44	0.11	0.04	0.20
Total P (ppm)	162.0	169.0	385.0	373.0	108.0	226.0	327.0
Bray 1-P (ppm)	1.12	0.40	0.55	2.0	0.50	1.0	0.58
Total K (ppm)	600.0	1200.0	1800.0	2000.0	200.0	1400.0	800.00
Org. C (per cent)	0.6	3.15	2.21	3.06	1.39	0.60	1.57
Total CaO (per cent)	0.5	0.45	0.47	0.72	0.18	0.10	0.25
Total MgO (per cent)	0.07	0.20	0.11	0.32	0.15	0.08	0.21
Total sesqui-oxides (per cent)	22.1	14.7	16.7	10.1	12.5	5.7	17.5
Total Fe_2O_3 (per cent)	17.5	3.0	8.0	5.9	8.3	1.6	9.0
Total Al_2O_3 (per cent)	4.6	11.7	8.7	4.2	4.2	4.1	8.5
CEC (m.e/100 g)	6.2	13.7	13.5	13.9	4.5	6.9	6.5
Exch. Ca (m.e/100 g)	2.7	6.0	4.8	4.9	1.3	2.7	2.3
Exch. Mg (m.e/100 g)	1.2	2.5	3.4	4.2	1.0	2.3	2.1
Exch. K (m.e/100 g)	0.9	2.8	1.8	2.0	1.0	0.3	1.3
Exch. Na (m.e/100 g)	0.2	0.7	1.2	1.1	0.8	0.8	0.4
P fixing capacity (per cent)	49.0	44.6	52.1	50.0	32.6	31.5	51.3

APPENDIX XIV

Abstract of analysis of variance for biometric characteristics at the panicle initiation stage of the crop (^{32}P study).

Source	df	Mean square				
		Height of plant (cm)	No. of productive tillers/hill	Weight of roots (g/hill)	Weight of straw (g/hill)	Total dry matter (g/hill)
1	2	3	4	5	6	7
Treatment	48					
Soil	6	540.83**	49.71**	3.56**	306.51**	359.07**
Source of P	1	0.02	0.08**	0.01	3.38**	3.84**
Levels of P	2	9.91**	1.82**	0.15**	0.85**	1.55
Between levels within source	2	5.80**	0.72**	0.01	1.21**	1.37
Treated Vs. control	1	107.19**	9.65**	0.97**	21.48**	30.67**
S x T	36	21.72**	4.34**	3.36**	9.25**	11.12**
Error	49	0.03	0.01	0.02	0.03	2.32

** Significant at 1 per cent level.

APPENDIX XV

Abstract of analysis of variance for total P (root, straw and soil), PDFF (root, straw), A-value and percentage utilization of P at panicle initiation (^{32}P study).

Source	df	Mean square						
		Total P (ppm)			PDFF		A-value (ppm)	Percentage utilization of P
		Root	Straw	Soil	Root	Straw		
1	2	3	4	5	6	7	8	9
Treatment	48							
Soil	6	9370.00**	1536892.51**	351495.24**	92.30**	243.18**	8.24**	51.91**
Source of P	1	0.38	57.66	31624.56**	0.11	0.48	0.002	0.14**
Levels of P	2	3857.43**	15229.91**	32725.33**	2.17**	1.09**	50.88**	3.05**
Between levels within source	2	111.85**	578.90**	3938.64**	0.03	0.37	0.012**	0.10**
Treated Vs. Control	1	17650.20**	128569.63**	266657.03**	-	-	384.39**	48.87**
S x T	36	7093.88**	36103.63**	60582.54**	9.88**	14.91**	1.81**	3.58**
Error	49	15.22	20.25	19.10	0.16	0.15	0.003	0.01

** Significant at 1 per cent level.

APPENDIX XVI

Abstract of analysis of variance for yield characteristics at harvest stage (^{32}P study).

Source	df	Mean square			
		Grain (g/pot)	Straw (g/pot)	Roots (g/pot)	Total drymatter (g/pot)
1	2	3	4	5	6
Treatment	48				
Soil	6	212.24**	1000.33**	38.59**	2323.30**
Source of P	1	0.02	8.88**	0.43**	13.50**
Level of P	2	3.42**	19.85**	2.09**	4.19**
Between levels with in source	2	0.46**	3.25**	0.04	5.44**
Treated Vs. Control	1	66.79**	388.44**	20.18**	1023.04**
S x T	36	11.79**	84.44**	9.04**	159.07**
Error	49	0.03	0.22	0.02	0.29

** Significant at 1 per cent level.

APPENDIX XVII

Abstract of analysis of variance for total P (root, straw, grain and soil), PDFF (root, straw and grain), A-value and percentage utilization of P at harvest stage (^{32}P study).

Source	df	Mean square								
		Total P (ppm)				PDFF			A-value	Percentage utilization of P
		Root	Straw	Grain	Soil	Root	Straw	Grain		
1	2	3	4	5	6	7	8	9	10	11
Treatment	48									
Soil	6	77492.52**	1229543.87**	12393597.20**	386865.95**	52.30**	152.20**	2.30**	6.78**	153.18**
Source of P	1	600.00**	2046.11**	50710.40**	8588.22**	0.01	0.33	0.28	0.06	7.71**
Level of P	2	3171.93**	28416.10**	475083.60**	15731.60**	2.22**	0.62*	0.03	48.05**	41.41**
Between levels with in source	2	80.75**	815.13**	269951.90**	2585.10**	0.03	0.09	0.02	0.02	0.71
Treated Vs. Control	1	21091.93**	135216.26**	6759511.51**	129803.39**	-	-	-	328.49**	768.83**
S x T	36	5084.58**	87050.23**	1588938.54**	25705.31**	4.94**	6.67**	0.55**	1.24	62.48**
Error	49	10.67	25.31	43.80	16.69	0.18	0.17	0.11	0.17	0.26

* Significant at 5 percent level.

** Significant at 1 per cent level.

ABSTRACT

An attempt to assess the various factors and arrive at an integrated picture on response of rice to phosphorus application in rice soils of Kerala has been made. To reach certain conclusions on some of the possible reasons for response of rice to phosphorus in the acid rice soils of Kerala, the following approaches have been resorted to. Categorising the rice soils with special reference to phosphorus and factors affecting them. Detailed studies on the various phosphorus fractions, both inorganic and organic as well as the relationships between the P fractions and important soil parameters have been worked out. Elaborate studies have been undertaken on the P fixing capacity of rice soils and the factors governing it. Phosphorus transformation studies, both inorganic P fractions and available P due to waterlogging have also been conducted. Two rice varieties, a medium and a short duration have been tested under pot culture conditions with graded levels of P and finally two ^{32}P labelled sources of phosphorus, a water soluble monocalcium phosphate and water insoluble tricalcium phosphate have been evaluated in 7 soil types representing the major rice soil types of Kerala.

As against the general local classification of rice soils such as lateritic alluvium, Kari, Kayal, Karapadam,

Kole etc., or their classification into various groups of the Taxonomy, using the statistical approach of principal component analysis, six categories or clusters, could be identified based on the nine important soil parameters. The categories could however be distinguished by their increasing ranges of total P. This study has enabled the fitting of any rice soil based on its total P status to one of six categories. The majority of the rice soils of Kerala can be categorised under the medium group.

The coastal sandy alluvium and Kayal soils respectively recorded the lowest and highest content of total P, Fe-P, Ca-P, reductant-P, Occluded-P, sum of inorganic P and organic P. Saloid P has been lowest in coastal sandy alluvium and highest in Karapadam soils while Al-P has been lowest and highest in Kari and Kole soils respectively. The Fe-P has been the major inorganic P fraction followed by Al-P and reductant-P in the acid rice soils of Kerala. Significant positive correlations have been observed between all the P fractions except saloid-P in Kari, Kayal, Karapadam, coastal sandy alluvium and Kole soils, with total P as well as with sum of inorganic P. The non-extractable P which could not also be estimated by the Chang and Jackson's procedure, is a defect which has to be rectified.

In the phosphorus fixation studies, it has been observed that the coastal sandy alluvium and Kari soils respectively recorded lowest and highest P fixing capacity. The lateritic alluvium, Kari, Kayal, Karapadam and Kole soils form one group and coastal sandy alluvium and Pokkali formed another group and there is significant difference between thse two groups. Among the factors governing the P fixing capacity of different soils, pH, Organic carbon, total CaO, total MgO, CEC, exchangeable Ca, exchangeable Mg, C/P ratio and sand content have produced negative relationship while R_2O_3, Fe_2O_3, silt, clay, C/N ratio and Fe_2O_3/Al_2O_3 ratio, positive correlations with PFC. In the stepwise regressions between PFC with pH, R_2O_3, CaO, MgO, CEC, Organic matter and clay content, it has been noted that the sesqui oxides exert a maximum per cent variation on PFC of lateritic alluvium (97) Karapadam (90), Pokkali (92) and Kole (97); pH in Kari soil (94) and coastal sandy alluvium (82) while CEC in Kayal soils (40).

The incubation studies have been conducted to evaluate the pattern of transformation of both inorganic P fractions and available P estimated by Bray 1, Bray 2, Olsen and Truog's methods due to waterlogging in selected soils representing all the rice soil types. On waterlogging, all the soils have registered an increase in the inorganic fractions of phosphorus. Those soils with a low or high content of P fractions in the air dry situation have shown correspondingly low or high values under submerged situation also. The average per centage increase due to submergence has been lowest for occluded P and highest for Fe-P and these two fractions have contributed lowest and highest in the total variation of inorganic P fractions due to submergence.

The mean available P of all the soil types by all the four methods have been lowest under air dry condition and highest under waterlogged situations. In the intercorrelation matrix between the inorganic P fractions due to submergence and available P by the four methods, none of the correlations have been found to be significant indicating that a number of other factors viz., organic P content transformation of organic P by microbial population, variation in the content of non-extractable P etc., are differently acting so as to prevent the intercorrelation matrix from becoming significant. Further studies on those aspects may enlighten on the response behaviour of rice to P. Transformation of P due to intermittent wetting and drying also requires further evaluation to more correctly predict the response pattern.

In a response study with two rice varieties, a medium and another short duration, with graded doses of P, it has been observed that Olsen's method of estimation of available P is found to be well correlated with grain as well as straw yields. The superiority of Olsen's P has been further emphasised by its high correlation with P uptake and inturn to grain yield. Among the various inorganic P fractions, Fe-P has been the highest at all growth stages of crop growth due to varieties, treatments and their interactions. All the inorganic P fractions have been lesser in soils grown with Mashoori variety. The correlations and regressions between biometric or yield characteristics with inorganic P fractions clearly indicate the positive response of rice to P application. A 60 Kg P_2O_5/ha barrier for yield has been noted for both the varieties beyond which though there is yield increase the rate of increase is not substantial. But the varieties differ significantly to P application.

The performance of two sources of P viz., a water soluble monocalcium phosphate and water insoluble tricalcium phosphate to rice have been evaluated with labelled phosphatic fertilizers in the rice soils. A clear indication of response of rice to P application has been obtained with the observations both at panicle initiation and at harvest stages. Differential response due to the sources and soils have also been observed. The observations on characters such as grain yield, straw yield, P utilisation etc., indicate that TCP can be a better substitute for MCP in the acid rice soils of Kerala. The optimum dose of P as MCP and TCP has also been worked out for getting an economic yield. Based on various aspects of the present study, future work on the following aspects may throw more light on the response of rice to phosphorus. Screening of all the varieties of rice to grade them under categories of low, medium or high and find out their critical limits. Conduct response studies on soils belonging to different clusters or categories for interpretation of response of rice based on phosphorus status and availability and delineate locations that will respond. Microbial transformation of organic P may be studied under different moisture regimes corresponding to field situations. A low fertilizer use efficiency of P warrants further research for efficient management of P fertilizers in the acid rice soils of Kerala.