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 allu (Entisol), Pokkali (Alfisol) and Kole (Entisol) possess 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 respo to phosphorus in the rice soils of Kerala in nearly all it aspects has been attempted so far. The need for this has been felt both in the University and at field level. Thu 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 vary considerably depending upon a number of factors. Judicious fertilisation 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 2.5.

The pH of the soil and of the percolates 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).

<u>Organic matter and nitrogen</u>

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 interrelated 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.

Koshy (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 conductanse 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 Karapadam 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.

Panda 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.

CEC and exchangeable bases

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, difficultly 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.

<u>Phosphorus fractions of rice soils</u>

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 Peterson 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 those soils. Similar observation was made by Mathan (1966) 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. Olsen'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, 18.8 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, +118 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 39.8 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 seen to be bound with iron as active Fe-P and occluded Fe-P and the same was found to be significantly 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 Britomutunayagam (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).

Freisen 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); Leavor and Russel (1957) and Fox et al. (1971).

Koshy and Britomutunayegam (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 basic, 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 (Raychaudhuri and Mukherjee, 1963).

Koshy and Britomutunayagam (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 70.2 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 Srivastsava (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, b)

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 Mahapatra 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 quoting 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 saloid 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 PFC 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 inconsistant. 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-622C8.

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 response. 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 Dhanka 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 (Ramamurthy 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 fertilization 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 contributiors 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 7.8 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).

Response of rice to P application

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 Chawan et al. (1957) and Digar and Mandal (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. Rehoja (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). Mahapatra and Patric 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 Bhuvaneswar (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

Steward (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 responces 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 so 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 vary 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 fertiliser application, conversely, the soils which were not responsive to P have become response when no P fertiliser 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.

Comparison of P sources for their efficiency on rice crop

With the verification of the accuracy and precision possible with levels of ^{32}P, extensive use of tagged P fertilisers 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 fertiliser, crop utilisation of the applied P and A-values as indices of soil and for fertiliser 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 utilization 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 sources 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.

Sarangenath et al. (1977) observed that citrate soluble and insoluble phosphates to be as efficiently 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 Karapadam 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 later 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 characteristic of phosphatic fertilizer that affected the response or uptake by crops was its water solubility. P fertilizers 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).

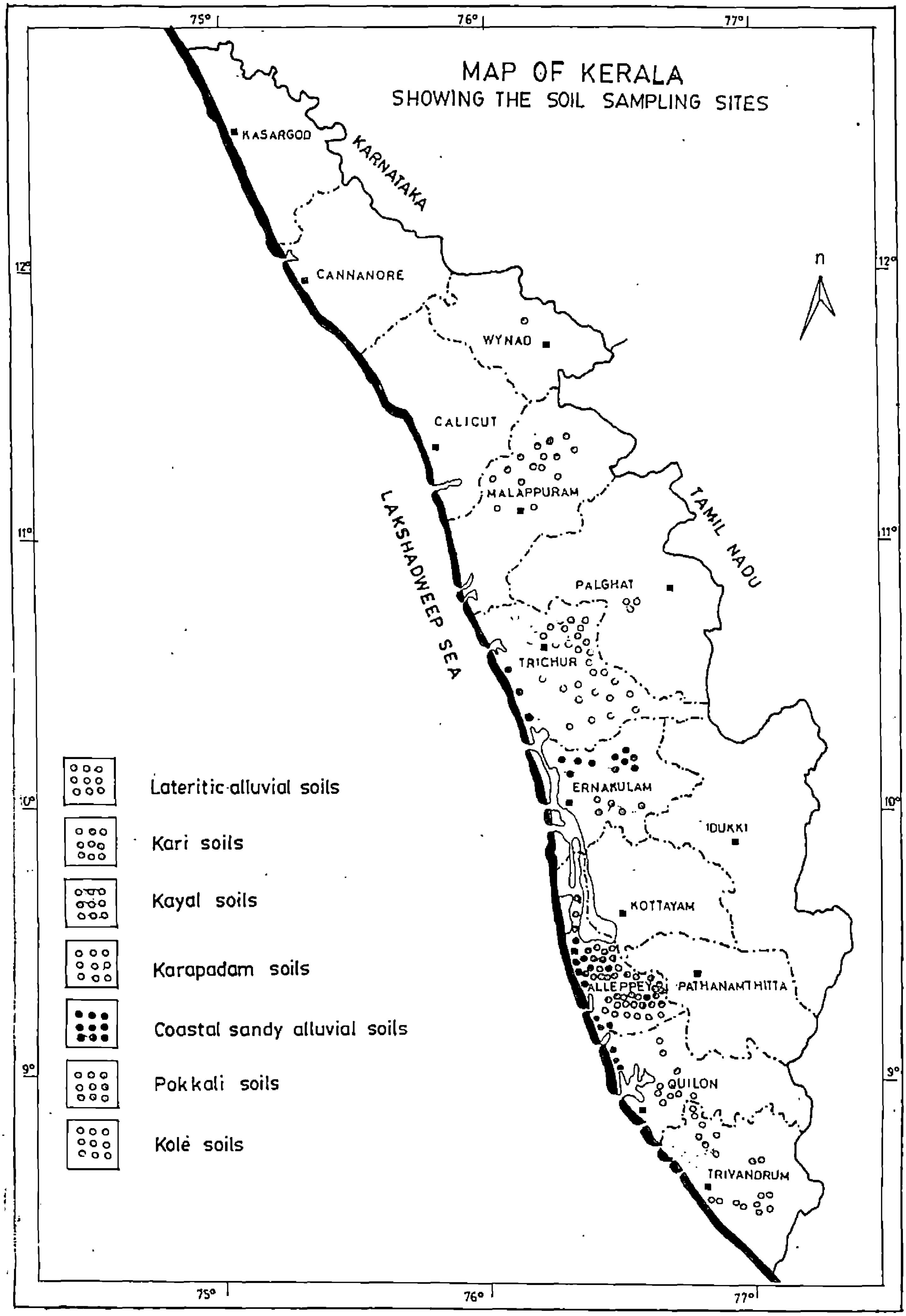
MATERIALS AND METHODS

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. General physico-chemical characteristics of rice soils

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, 1970
(ii)	Physical constants	Method of Keen and Raczkowski	Wright,1934
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, 1971
(v)	Total K	Flame photometer method	Jackson, 1967
(vi)	Organic carbon	Walkley and Black's rapid titration method	Piper, 1970
(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 M 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 molybdophosphoric 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. <u>Organic phosphorus</u>

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. Comparative evaluation of two sources of phosphorus on rice crop with ^{32}P.

A pot experiment in C.R.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 (Aquepts)
2.	Karuvatta	(S_2)	"	Kari soils (Aquents)
3.	Moncompu	(S_3)	"	Karapadom soils (Aquepts)
4.	Mathikayal	(S_4)	"	Kayal soils (Aquepts)
5.	Panangad	(S_5)	"	Pokkali soils (Aqualfs)
6.	Chalakudy	(S_6)	"	Coastal sandy alluvial soils (Psamments)
7.	Kenjanikole	(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 plythene 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 Dean (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 those 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 rica 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 n samples, each of which is defined by p characters, they can be expressed as n points scattered in a p - dimensional space. The principal component analysis aims at reducing the p axes to orthogonal m axes, where $m < p$, with a minimum loss in information. Mathematically this produces a set of new m variables from the original 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 below

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	1.1186	0.0494	-0.6024
5	Silt	0.4928	0.4422	-0.1866
6	Clay	0.3808	0.4473	0.1588
7	Total-P	0.2462	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

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

$$X_2 = 0.0986P_1+0.1051P_2+0.2464P_3-0.6024P_4-0.1866P_5+0.1588P_6-0.2402P_7+0.1769P_8-0.6375P_9$$

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	83.08	28.	149.11	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.	164.95	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	50.57
12.	91.38	68.06	37.	82.52	72.08
13.	96.69	107.55	38.	70.31	48.53
14.	96.77	137.84	39.	98.68	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	200.86
21.	108.53	116.12	46.	236.72	360.81
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	259.43

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.	69.80	37.14	80.	159.54	243.51
56.	122.55	169.33	81.	161.34	254.28
57.	105.18	84.18	82.	126.33	169.39
58.	98.76	91.02	83.	168.77	217.03
59.	99.72	85.15	84.	148.67	197.01
60.	110.82	122.10	85.	134.40	201.58
61.	104.52	110.08	86.	152.00	228.18
62.	109.35	130.13	87.	125.48	115.09
63.	92.43	88.84	88.	188.73	250.29
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	90.60	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	83.86	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.	244.09	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.	X_1 (+)	X_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	169.04
106.	69.95	96.77	131.	117.44	180.91
107.	90.00	136.00	132.	104.36	78.04
108.	63.59	89.39	133.	176.20	220.58
109.	59.67	39.96	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.	140.03	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.	108.08	90.02
119.	98.64	140.91	144.	165.97	260.10
120.	88.00	140.08	145.	88.61	85.25
121.	103.97	145.56	146.	143.06	202.12
122.	111.19	180.80	147.	123.05	149.01
123.	68.56	79.58	148.	134.28	184.49
124.	75.00	94.47	149.	131.35	134.53
125.	60.48	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	"	144
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 Karapadam, 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

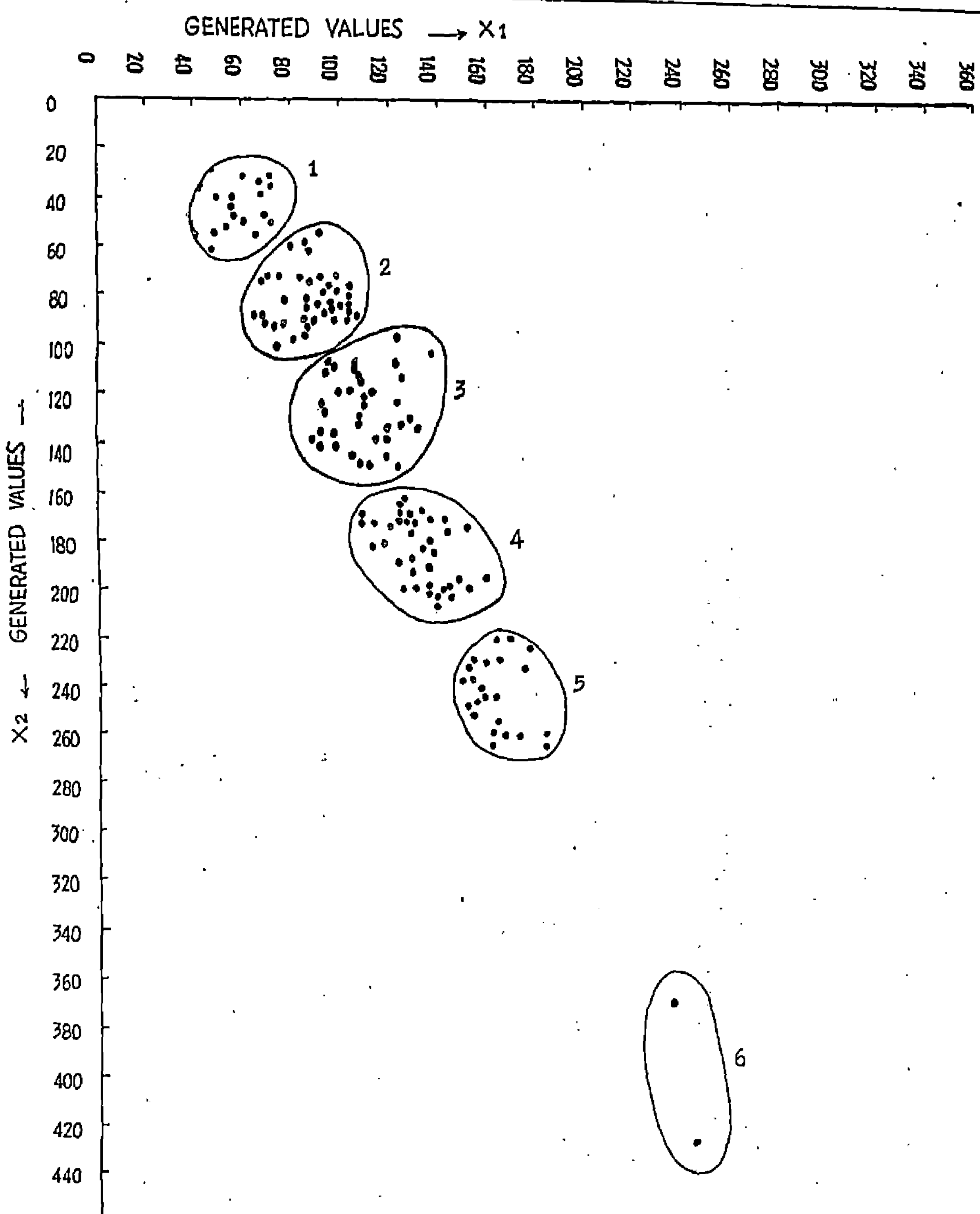


FIG. 1 SCATTER DIAGRAM SHOWING THE GROUPING OF 151 RICE SOILS

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	505
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	"	582
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	91	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

Cluster VI

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	5.88 - 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.	Karepadam	17	741.24				-	185.68	168.92	162.46
5.	Coastal sandy alluvium	12	280.83					-	185.68	179.82
6.	Pokkali	17	484.94						-	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. <u>Al-P</u> (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	25.66	-	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	35.18	-	-	-	-	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	98.47	-	-	-	-	-	-	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	15.87	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.	Kori	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.	Karapadam	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.	Kori	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, 118.8 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	83.96	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.	Karapadom	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 these 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	9.62	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	-	85.81	85.81	81.75	93.86	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.

P fraction	All soils		Lateritic alluvium		Kari		Kayal		Karapadam		Coastal sandy alluvium		Pokkali		Kole	
	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%
1. Total P	599.0	-	577.7	-	433.7	-	962.5	-	741.2	-	280.8	-	484.9	-	710.7	-
2. 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
3. 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
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
5. 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
6. 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	7.8	55.7	7.8
7. 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
8. 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
9. 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
10. 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
11. 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 Tables15 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 Extra-ctable P	Total In-organic 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.	Karl	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	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	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
.	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**
.	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
.	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
.	Karapadam	17	.18	.15	.86**	.03	.05	.008	.14	-.07	.03	.002	.04	-.07	.08	.04	-.04	.26	.74**	.27	.20	.31	.88**	.80**	.80**	.87**	-.63**	-.72**	-.13	.94**	.65**
.	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*
.	Pokkali	17	-.57*	-.48	.88**	.51*	.51*	.51*	-.53*	-.55*	-.50*	-.50*	-.49*	-.55*	.44	.23	.51*	.61*	.72**	.55*	.55*	.56*	.87**	.87**	.84**	.88**	.76**	.23	.16	.96**	.87**
.	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 then 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 <u>Correlation Coefficients between Fe-P and Soil properties</u>

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	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
1.	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
2.	Kari	15	.32	.27	** .67	-.28	-.25	-.30	.28	.49	.15	.10	.17	.38	-.06	-.28	-.37	.26	.01	.24	.10	.29	** .74	* .57	** .66	** .74	-.29	.03	-.20	.42	* .58
3.	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
4.	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
5.	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
6.	Pokkali	17	-.30	-.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
7.	Kole	20	.30	.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	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
1.	Lateritic alluvium	55	.23	.32*	.86**	-.26	-.21	-.20	.12	.13	.33*	.33*	.33*	.32*	-.25
2.	Kari	15	-.39	-.03	.84**	.51	.56*	.35	-.40	-.04	-.53*	-.58*	-.56*	-.16	-.05
3.	Kayal	15	.02	.12	.70**	.05	.24	.27	-.04	.29	-.05	-.05	-.05	-.08	.04
4.	Karapadam	17	-.01	.39	.66**	.01	-.04	.06	-.14	-.15	.28	.30	.29	.22	-.30
5.	Coastal Sandy alluvium	12	-.06	-.36	.89**	-.11	.39	-.59*	-.03	.13	-.35	-.36	-.36	.13	.04
6.	Pokkali	17	-.54*	-.48	.83**	.43	.40	.48	-.51*	-.51*	-.44	-.43	-.45	-.50*	.34
7.	Kole	20	.25	.01	.77**	-.01	-.07	.04	.14	.08	.15	.17	.15	.05	.32

Sl.No.	Soil Type	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	-.29*	-.26	.35*	.57**	.65**	.98**	.99**	.64**	.86**	.81**	.84**	-.45**	-.10	-.02	.74**	.86**
2.	Kari	.19	.37	.29	-.26	.24	.97**	.91**	.79**	.88**	.64*	.78**	-.71**	.23	.59*	.79**	.89**
3.	Kayal	.02	-.01	-.44	-.31	.52*	.96**	.96**	.74**	.55*	.76**	.76**	-.41	-.16	-.62*	.49	.73**
4.	Karapadam	-.09	-.06	-.46	.27	.41	.98**	.96**	.66**	.62**	.68**	.66**	-.37	-.16	-.29	.58*	.70**
5.	Coastal Sandy alluvium	-.15	.16	-.08	.19	.36	.98**	.95**	.85**	.90**	.78**	.85**	-.76**	.19	.62*	.58	.89**
6.	Pokkali	.36	.43	.52*	.55*	.53*	.98**	.99**	.83**	.83**	.61*	.83**	-.64**	.25	-.27	.76**	.65**
7.	Kole	-.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 <u>Correlation coefficients between Reductant P and Soil Properties</u>

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	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	.24	.36*	.87**	-.30*	-.26	-.17	.14	.15	.37**	.37**	.37**	.36*	-.27	-.33*	-.28	.36*	.59**	.67**	.98**	.98**	.85**	.88**	.82**	.85**	-.44**	-.13	-.68**	.76**	.87**
2.	Kari	15	-.48	-.12	.77**	.55*	.61*	.40	-.44	-.17	-.58*	-.62*	-.63*	-.26	.03	.19	.47	.23	-.21	.10	.97**	.86**	.70**	.82**	.64*	.70**	-.75**	.24	.63*	.76**	.84**
3.	Kayal	15	.08	.09	.77**	.06	.22	.21	-.02	-.22	-.03	-.03	-.03	-.01	.03	-.04	-.04	-.48	-.24	.59*	.96**	.88**	.79**	.65**	.82**	.82**	-.49	-.16	-.51	.53*	.79**
4.	Karapadam	17	-.04	.40	.62**	.03	-.02	.08	-.17	-.14	.30	.32	.31	.23	-.30	-.11	-.05	-.51*	.20	.41	.98**	.95**	.61*	.59*	.64**	.62**	.35	.10	.28	.52*	.66**
5.	Coastal Sandy alluvium	12	-.11	-.39	.82**	-.05	.41	-.53	-.10	.05	-.36	-.37	-.37	.05	.07	-.12	.23	-.14	.09	.32	.98**	.98**	.80**	.82**	.68*	.80**	-.71*	.11	.62*	.49	.84**
6.	Pokkali	17	-.54*	-.46	.85**	.42	.40	.47	.50*	.50*	.43	-.42	-.44	.51*	.33	.40	.41	.58*	.55*	.59*	.98**	.96**	.85**	.85**	.63**	.85**	-.65**	.22	-.19	.76**	.87**
7.	Kole	20	.32	.18	.76**	-.17	-.21	-.14	.18	.14	.29	.30	.28	.19	.11	-.36	-.18	-.58**	.20	.54*	.93**	.92**	.70**	.81**	.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

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	Ca – P	Red – 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 fractions
1.	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**
2.	Karl	15	-.40	-.10	.82**	.52*	.57*	.37	-.38	.11	-.51	-.57*	-.52*	-.26	.02	.20	.41	.40	-.31	.29	.91**	.86**	.77**	.85**	.64*	.77**	-.68**	.12	.60*	.69**	.86**
3.	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*
4.	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**
5.	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**
6.	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**
7.	kole	20	.25	.05	.75**	-.01	-.06	.03	.13	.08	.20	.22	.21	.08	.28	-.33	-.02	-.46*	.14	.54*	.58**	.92**	.69**	.82**	.61**	.69**	-.66**	-.15	-.18	.40	.75**

* Significant at 5 percent level

** Significant at 1 percent level

2.3.7. <u>Sum of inorganic P</u>

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 positive correlations were obtained between sum of inorganic P with pH and Al-P.

Table. 21 <u>Correlation Coefficients between sum of inorganic P and Soil properties</u>

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	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	.25	.38**	.99**	-.35*	-.28	-.28	.13	.09	.40**	.43**	.41**	.39**	-.28	-.37**	-.34*	.33*	.92**	.94**	.84**	.85**	.83**	.95**	.92**	1.0**	-.35*	-.08	-.02	.98**	.99**
2.	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**
3.	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	.88**	.99**
4.	Karapadam	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**
5.	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**
6.	Pokkali	17	-.55*	-.43	.99**	.46	.45	.47	-.50*	-.54*	-.43	-.42	-.43	-.50*	.32	.38	.44	.72**	.87**	.85**	.83**	.85**	.83**	.98**	.87**	1.0**	-.73**	.15	.03	.97**	.99**
7.	Kole	20	.46*	.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	.35	.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**	.65**	.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**	.63**	.65**	.82**	.99**	.82**	.99**	-.75**	.18	.05	.96**	.99**
7.	Kole	20	.46*	.19	.96**	-.29	-.37	-.22	.36	.35	.29	.31	.29	.23	.08	-.33	-.34	-.25	.42	.77**	.85**	.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	55	.26	.41**	.95**	-.36*	-.30*	-.25	.12	.10	.43**	.42**	.43**	.42**	-.26	-.42**	-.35*	.25	.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	-.89	-.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*	.89*	.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**	.98**	.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	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	55	.28	**.39	**.99	*-.36	*-.29	-.28	.13	.10	**.41	**.44	**.41	**.40	*-.29	**-.38	*-.35	*.32	**.92	**.94	**.64	**.65	**.83	**.99	**.96	**.94	*-.35	-.09	-.02	**.98	**.99
2.	Kari	15	-.01	.19	**.99	.08	.13	-.01	-.03	.24	-.19	-.25	-.19	.18	-.06	-.10	-.04	.46	.05	**.74	**.76	**.70	**.77	**.99	**.93	**.90	**-.68	.18	.19	**.67	**.97
3.	Kayal	15	.22	.06	**.99	-.19	-.29	-.02	.22	-.02	.09	.09	.09	**.78	-.08	-.13	-.20	-.11	.26	**.89	**.76	**.80	**.65	**.99	**.93	**.97	**-.70	-.14	-.43	**.86	**.99
4.	Karapadam	17	.06	.27	**.99	.08	.03	.13	-.04	-.15	.11	.12	.13	-.02	-.02	.02	.01	.02	**.87	**.82	**.66	**.62	**.70	**.99	**.93	**.96	**-.69	*-.58	-.25	**.98	**.99
5.	Coastal Sandy Alluvium	12	-.08	-.46	**.99	-.22	.32	*-.68	.04	.31	-.42	-.42	-.42	-.03	-.01	.13	.11	.15	*.66	*.65	**.85	**.80	**.74	**.99	**.93	**.90	**-.66	.44	**.61	**.91	**.99
6.	Pokkali	17	*-.55	-.43	**.99	.46	.45	.47	*-.50	*-.53	-.43	-.42	-.43	*-.50	.33	.37	.45	**.72	**.88	**.86	**.83	**.85	**.83	**.99	**.99	**.89	**-.73	.16	.03	**.97	**.99
7.	Kole	20	*.46	.13	**.98	-.27	-.36	-.20	.41	-.42	.21	.23	.22	.17	.08	-.23	-.31	-.11	**.62	**.89	**.69	**.69	**.69	**.99	**.69	**.99	**-.65	.06	*-.45	**.78	**.98

* Significant at 5 percent level

** Significant at 1 percent level

3. Phosphorus fixing capacity of rice soils

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 38.80, 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	48.47	-	-	-	-	4.99	4.54	4.37
5.	Coastal sandy alluvium	12	36.10	-	-	-	-	-	4.99	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**	0.1208	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=100.7892-1.1171X**	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	$Y=56.5235-0.1431^{**}X$	0.0069	0.8896^{**}
2.	Kari	15	-0.7626	$Y=77.5975-0.1038^{**}X$	0.0244	0.5816^{**}
3.	Kayal	15	-0.8118	$Y=73.7002-0.0857^{**}X$	0.0171	0.6590^{**}
4.	Karapadam	17	-0.6657	$Y=73.0256-0.1054^{**}X$	0.0305	0.4432^{**}
5.	Coastal sandy alluvium	12	-0.8334	$Y=61.6938-0.1706^{**}X$	0.0375	0.6946^{**}
6.	Pokkali	17	-0.9329	$Y=59.4053-0.0751^{**}X$	0.0075	0.8703^{**}
7.	Kole	20	-0.7905	$Y=49.3571-0.0923^{**}X$	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+0.2134X**	0.0050	0.9718**
2.	Kari	15	0.9363	Y=-18.5183+0.4001X**	0.0416	0.8767**
3.	Kayal	15	0.9875	Y= 33.5935+0.1205X**	0.0053	0.9752**
4.	Karapadam	17	0.9556	Y= 20.5898+0.1873X**	0.0149	0.9132**
5.	Coastal sandy alluvium	12	0.8116	Y= 10.2298+0.6961X**	0.1585	0.6587**
6.	Pokkali	17	0.9617	Y=-13.6462+0.4967X**	0.0366	0.9249**
7.	Kole	20	0.9878	Y= 1.0876+0.1426X**	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. (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	0.9194	$Y= 7.7112+0.2118^{**}X$	0.0124	0.8453^{**}
2.	Kari	15	0.8844	$Y= 22.3709+0.5857^{**}X$	0.0857	0.7822^{**}
3.	Kayal	15	0.9319	$Y= 37.3486+0.1678^{**}X$	0.0181	0.8684^{**}
4.	Karapadam	17	0.9748	$Y= 22.0535+0.3749^{**}X$	0.0222	0.9502^{**}
5.	Coastal sandy alluvium	12	0.7985	$Y= 32.6527+0.9966^{**}X$	0.2376	0.6376^{**}
6.	Pokkali	17	0.9598	$Y=-12.3663+0.7293^{**}X$	0.0551	0.9212^{**}
7.	Kole	20	0.9659	$Y= 5.2707+0.3081^{**}X$	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. (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	-0.7848	Y=59.2836-2.0656X**	0.2241	0.6159**
2.	Kari	15	-0.5312	Y=61.7361-0.7734X*	0.3421	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**	1.3037	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**	0.3460	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=61.5764-0.0108X**	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=56.8367-0.0095X**	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=80.7757-0.1242X**	0.0082	0.8122**
2.	Kari	15	-0.8758	Y=73.1796-0.0467X**	0.0072	0.7670**
3.	Kayal	15	-0.8334	Y=61.6173-0.0310X**	0.0045	0.7893**
4.	Karapadam	17	-0.8606	Y=71.8390-0.0494X**	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, Karapadom 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	-0.9260	Y=84.4074-0.2952X**	0.0165	0.8575**
2.	Kari	15	-0.8747	Y=72.9543-0.1111X**	0.0171	0.7651**
3.	Kayal	15	-0.8888	Y=61.5021-0.0361X**	0.0052	0.7900**
4.	Karapadam	17	-0.8990	Y=71.9061-0.0705X**	0.0089	0.8082**
5.	Coastal sandy alluvium	12	-0.8111	Y=56.7628-0.0263X**	0.0060	0.6579**
6.	Pokkali	17	-0.9556	Y=60.0084-0.1181X**	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. (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	-0.9134	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.	Karapadom	17	-0.9171	Y= 79.7220-0.0610X**	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 significantly 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=23.6078+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+0.0853X**	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=33.8494+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. (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	0.8503	Y=21.1792+0.0762X**	0.0065	0.7230**
2.	Kari	15	0.3440	Y=44.7594+0.0242X	0.0184	0.1183
3.	Kayal	15	0.5439	Y=44.9392+0.0210X**	0.0090	0.2958**
4.	Karapadam	17	0.9190	Y=22.4335+0.1050X**	0.0116	0.8446**
5.	Coastal sandy alluvium	12	0.5887	Y=46.7983+0.1358X*	0.0590	0.3466*
6.	Pokkali	17	0.1942	Y=45.7116+0.0648X	0.0844	0.0377
7.	Kole	20	0.5356	Y=22.3232+0.0421X*	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=59.5543-0.0016X	0.0008	0.1916
5.	Coastal sandy alluvium	12	-0.4270	Y=54.2484-0.0003X	0.0002	0.1823
6.	Pokkali	17	-0.8207	Y=53.6385-0.0005X**	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 coefficients 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+0.0080X**	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= 56.5697+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.	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	0.2892	Y= 31.1413+0.0181X*	0.0082	0.0836*
2.	Kari	15	0.8285	Y= 19.6634+0.7097X**	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	0.1283	0.3153
6.	Pokkali	17	0.3071	Y=-63.9874+0.5606X	0.4485	0.0943
7.	Kole	20	0.3965	Y= 3.6084+0.4760X	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. (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	-0.3502	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 90 per cent of the total variation on the dependant 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. $Y = 8.7207 + 2.1350^{**}X_2$ (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. $Y = 43.8299 - 5.0884^{**}X_1 + 1.6572^{**}X_2 - 0.2035X_5 + 0.0103X_7$ (1.2129) (0.1178) (0.4572) (0.0445)	0.9802
5. $Y = 40.0874 - 2.3680X_1 + 1.6331^{**}X_2 - 10.8687^{**}X_3 - 0.4399X_5 + 0.0013X_7$ (1.6755) (0.1138) (4.8076) (0.4518) (0.0430)	0.9817
6. $Y = 44.2939 - 2.8985X_1 + 1.6105^{**}X_2 - 14.3917^{*}X_3 + 13.5270X_4 - 0.4732X_5 - 0.0005X_7$ (1.7425) (0.1155) (5.7953) (12.4745) (0.4520) (0.0429)	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 parenthesis indicate the standard error.

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

	$\bar{R}^2$
1. $Y = 64.3457 - 11.3553^{**}X_1$	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
$(2.3554)\ (0.7149)\ (0.3603)$	
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. $Y = 47.0696 - 11.1712^{**}X_1 + 1.5308X_2 + 25.0056X_3 + 1.2169X_4 + 0.2564X_5 + 0.0728X_6$	0.9651
$(3.3571)\ (0.7173)\ (16.6681)\ (9.4064)\ (0.3070)\ (0.0504)$	
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
$(3.7691)\ (0.5854)\ (13.6553)\ (0.2228)\ (0.2651)\ (0.0786)\ (0.0355)$	

* 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.	$Y = 66.8399 - 1.7823^{**}X_5$	0.4006
	(0.6046)	
2.	$Y = 68.7255 - 5.6313X_3 - 1.6143X_5$	0.3568
	(27.6656) (1.0375)	
3.	$Y = 26.4711 + 13.8379X_1 - 17.4116X_3 - 2.2797X_5$	0.3313
	(20.3527) (33.1888) (1.4439)	
4.	$Y = 149.2120 - 4.9844X_1 - 2.6405X_2 - 12.0949X_3 - 3.4599X_5$	0.3897
	(23.7155) (1.8888) (32.0627) (1.6221)	
5.	$Y = 148.1450 - 3.3348X_1 - 2.6605X_2 - 16.3839X_3 - 3.5395X_5 - 0.0824X_6$	0.3325
	(25.9644) (1.9872) (38.6343) (1.7406) (0.3628)	
6.	$Y = 123.2750 + 2.5151X_1 - 2.3488X_2 - 30.5561X_3 + 57.2512X_4 - 4.0873^{*}X_5 - 0.1091X_6$	0.3753
	(25.7245) (1.9512) (39.3538) (46.7959) (1.7526) (0.3539)	
7.	$Y = 501.6910 - 58.9524X_1 + 1.0146X_2 + 31.9743X_3 - 29.4028X_4 - 1.7989X_5 - 4.8462^{*}X_6 - 4.9545X_7$	0.6534
	(29.9697) (1.9283) (37.6354) (47.7290) (1.5682) (1.7860) (1.8472)	

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

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

	$\bar{R}^2$
1. $Y = 20.6072 + 1.8722^{**}X_2$	0.9073
(0.1545)	
2. $Y = 18.7575 + 1.1774^{**}X_2 + 0.4916^{**}X_7$	0.9642
(0.1696) (0.0989)	
3. $Y = 32.5965 + 1.0952^{**}X_2 - 0.5103^{*}X_5 + 0.2587^{*}X_7$	0.9742
(0.1481) (0.2033) (0.1253)	
4. $Y = 40.0757 - 2.7109X_1 + 1.0273^{**}X_2 - 0.5594^{*}X_5 + 0.1666X_7$	0.9757
(2.0669) (0.1532) (0.2014) (0.1407)	
5. $Y = 59.6752 - 2.8338X_1 + 0.8726^{**}X_2 - 7.9914X_3 - 0.7437^{**}X_5 + 0.0669X_7$	0.9775
(1.9972) (0.1861) (5.8313) (0.2364) (0.1541)	
6. $Y = 57.1599 - 2.6405X_1 + 0.8573^{**}X_2 - 8.3040X_3 - 0.6880X_5 + 0.0266X_6 + 0.0943X_7$	0.9756
(2.2278) (0.2040) (6.2250) (0.3335) (0.1068) (0.1951)	
7. $Y = 64.7227 - 2.4720X_1 + 0.8097^{**}X_2 - 9.5645X_3 - 27.2065X_4 - 0.8172^{*}X_5 + 0.0250X_6 + 0.0131X_7$	0.9744
(2.3090) (0.2224) (6.6956) (41.6510) (0.3963) (0.1100) (0.2363)	

* 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.	$Y = 92.3676 - 11.2161^{**}X_1$	0.8227
	(1.6463)	
2.	$Y = 59.7074 - 8.2320^{**}X_1 + 2.8960X_2$	0.8636
	(2.1008) (1.4737)	
3.	$Y = 48.8237 - 6.2159X_1 + 3.1556X_2 - 0.1861X_5$	0.8552
	(3.4080) (1.5854) (0.3039)	
4.	$Y = 60.2915 - 8.8890X_1 + 2.8885X_2 + 28.8888X_3 - 0.1342X_5$	0.8440
	(6.3222) (1.7260) (51.7361) (0.3312)	
5.	$Y = 69.1790 - 10.5502X_1 + 2.8107X_2 + 40.6623X_3 - 0.0974X_5 - 0.1378X_7$	0.8237
	(9.3854) (1.8788) (72.0874) (0.3836) (0.5375)	
6.	$Y = 63.1879 - 9.9046X_1 + 3.2796X_2 + 28.8844X_3 + 15.0039X_4 - 0.1133X_5 - 0.1933X_7$	0.8001
	(10.2739) (2.3707) (86.9090) (39.2481) (0.4163) (0.5982)	
7.	$Y = -38.5082 - 12.4454^{*}X_1 + 8.0707^{**}X_2 - 167.5950^{**}X_3 - 3.6143X_4 - 1.2122^{**}X_5 - 3.3013^{**}X_6 + 0.1597X_7$	0.9845
	(4.1464) (0.9232) (35.4900) (11.4326) (0.1869) (0.4344) (0.4344)	

* 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.	$Y = 10.5612 + 2.7165^{*}X_2 - 70.3467^{*}X_3$	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.	$Y = -1.8820 - 2.6874X_1 + 2.9987^{*}X_2 - 98.2271 + 96.0613X_4 + 0.1998X_5 + 0.0678X_6$	0.9443
	(3.1157) (1.4069) (88.0348) (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) (1.4031) (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

		$\bar{R}^2$
1.	$Y = 13.2504 + 1.4267^{**}X_2$	0.9767
	(0.0520)	
2.	$Y = 13.2645 + 1.4253^{**}X_2 + 0.0011X_6$	0.9754
	(0.0865) (0.0525)	
3.	$Y = 14.7615 + 1.3971^{**}X_2 - 0.1073X_5 + 0.0060X_6$	0.9744
	(0.1144) (0.2040) (0.0545)	
4.	$Y = 18.1260 + 1.2874^{**}X_2 - 5.6807X_3 - 0.0258X_5 + 0.0505X_6$	0.9747
	(0.1462) (5.2314) (0.2163) (0.0679)	
5.	$Y = 20.6348 - 0.6435X_1 + 1.2588^{**}X_2 - 4.1557X_3 - 0.0014X_5 + 0.0663X_6$	0.9734
	(1.5886) (0.1662) (6.5692) (0.2306) (0.0800)	
6.	$Y = 20.5825 - 0.8218X_1 + 1.2656^{**}X_2 - 9.7499X_3 + 8.6551X_4 + 0.0481X_5 + 0.0763X_6$	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 alluvium 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 significantly 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	103.53
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 Kole soils (187.70 and 232.40 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 (27.20 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 (C_1)	Waterlogged (C_2)	
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 (C_1)	Waterlogged (C_2)	
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. Ca-P

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 (Kurichikari), 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
Kole	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 (Enamakkal). 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	2.56	15.14	2.38	51.33	158.22
2.	"	Kunnappally	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	20.29	2.16	38.09	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	10.40	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	39.55	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	158.22
2.	"	Kunnappaliy	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	Moncompu	4.36	20.45	48.84	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	158.90

4.2.5. Reductant P

The contribution from reductant P consequent to submergence ranged from 9... 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.

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	Water-logged	Mean (M)
Bray 1	11.86	0.54	2.10	5.93	7.15	12.28	5.30	5.17	7.74	6.45
Bray 2	15.25	1.00	2.68	7.36	15.24	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	18.66
Mean (S x C)	14.58	1.19	2.41	7.86	12.35	24.78	5.28	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 = 10.86

" Methods (M) = 8.21

(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_4) 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	Karuvatta	60.00	82.86	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.	Karapadam	Moncompu	58.75	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	53.98	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 (Enammakkal), the highest (84.90) and the average being 61.14.

4.3.3. Olsen

The percentage increase of available P due to submergence 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 matrix between percentage 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	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	0.004	-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	-0.083	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 30th 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	9.03	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	11.85	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	

	V_1	V_2		
M_1	9.72	7.25	C.D. for comparison of Methods (M) (0.05)	= 1.0793
M_2	13.61	10.16	" Treatments (T)	= 1.3219
M_3	11.99	9.58	" (M x T)	= 2.6437
M_4	16.83	15.09	" (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	2.58	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	9.89	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	-
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	
M_1	5.22	4.27						
M_2	7.23	6.09						
M_3	6.70	5.92						
M_4	19.36	20.65						

C.D. for comparison between Methods (0.05) (M) = 1.1920

" Treatments (T) = 1.4598

" (M x T) = 2.9197

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. Inorganic P fractions at various growth stages

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

	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
V_2	2.15	3.45	4.25	4.70	5.16	5.50	4.20
Mean	2.15	3.55	4.23	4.75	5.20	5.33	-

(ii) Al-P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	25.00	29.95	33.15	38.80	41.60	51.05	36.59
V_2	24.95	29.35	32.75	38.75	42.10	51.10	36.50
Mean	24.98	29.65	32.95	38.78	41.85	51.08	-

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

(iii) Fe-P

	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
V_2	30.85	75.10	89.00	93.10	111.35	124.70	87.35
Mean	30.95	74.65	87.45	93.23	115.40	127.28	-

(iv) Ca-P

	T_1	T_2	T_3	T_4	T_5	T_6	Mean
V_1	6.15	10.55	12.75	15.15	17.30	20.90	13.80
V_2	6.75	9.95	13.45	15.45	17.45	21.35	14.07
Mean	6.45	10.25	13.10	15.30	17.38	21.12	-

C.D. for comparison between (0.05)	Fe-P	Ca-P
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	-

C.D. for comparison between (0.05)		(v)	(vi)
	Varieties (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 comparison 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.

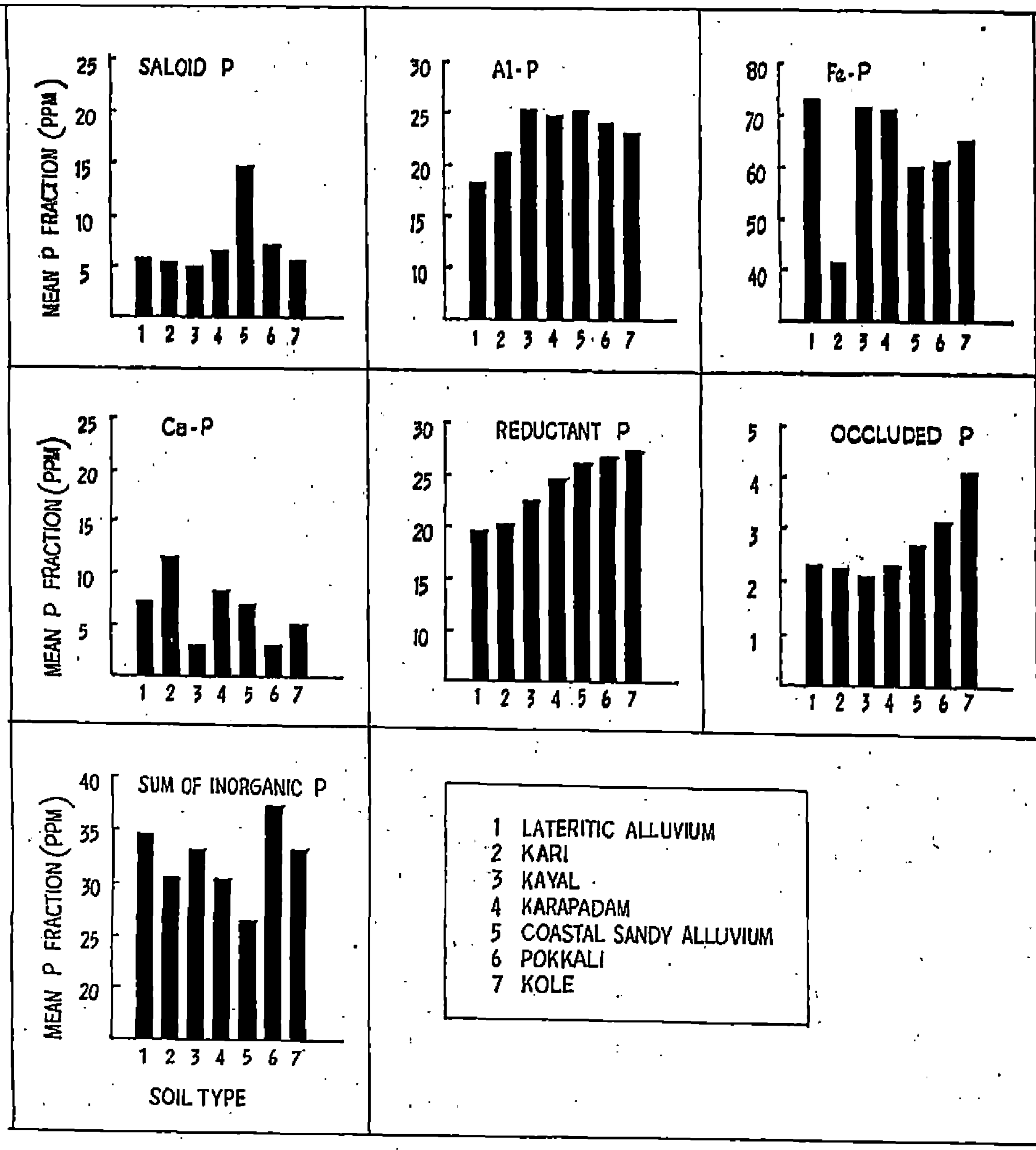
At 30th day after sowing the mean saloid P, Al-P, Fe-P, Ca-P, reductant P, occluded P and sum of inorganic P in soils grown with Jyothi and Mashoori varieties of paddy were 4.20 and 4.20, 36.59 and 36.50, 88.97 and 87.35, 13.80 and 14.07, 9.64 and 9.65, 4.01 and 4.10, and 156.36 and 155.83 ppm respectively. 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 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 Thripathi (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



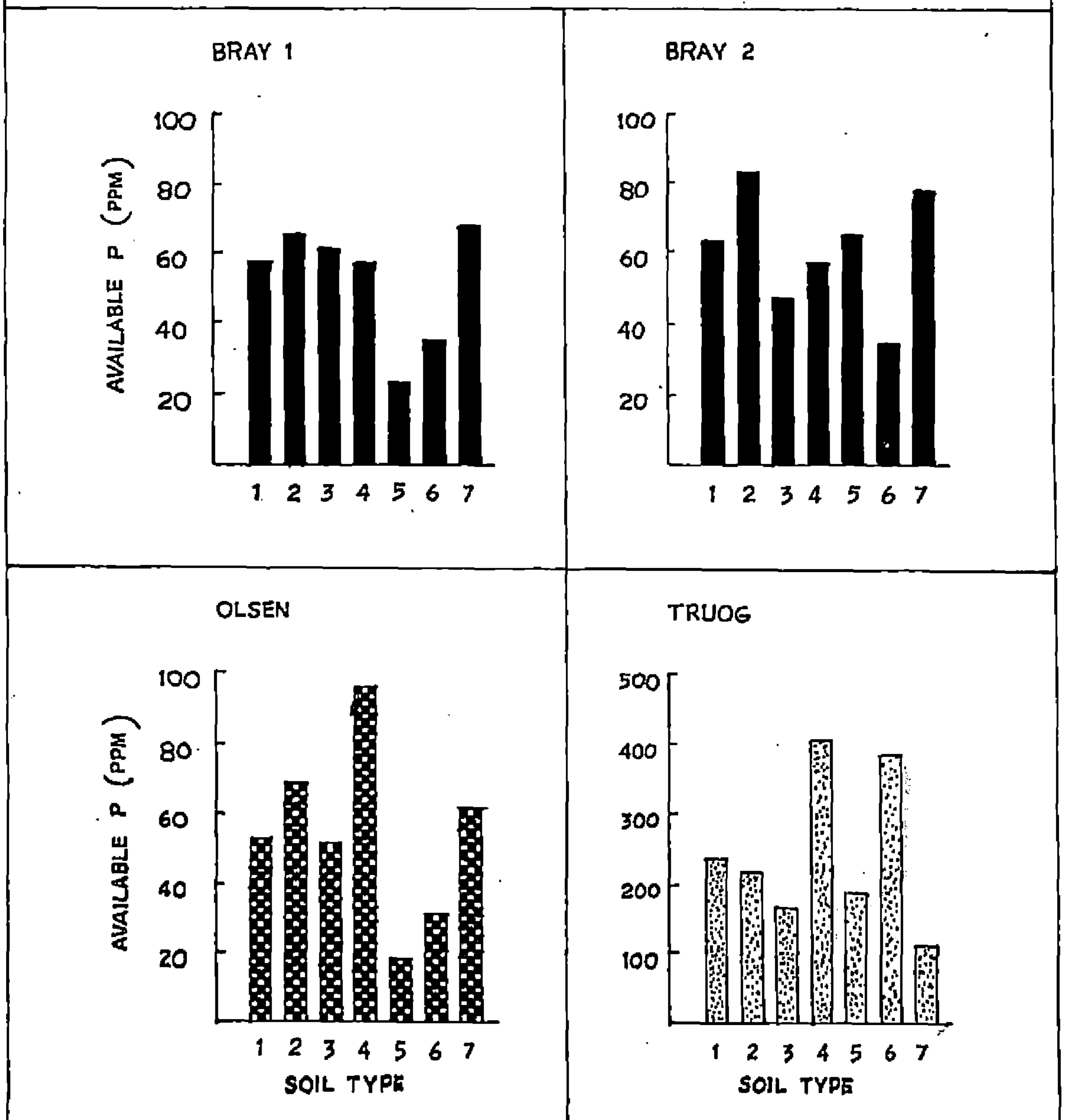
by 35 per cent, Fe-P increased by 64 per cent and Ca-P did not undergo much change due to waterlogging. The observations by Mandal and Khan (1975) indicated that continuous waterlogging for 110 days caused an increase in Fe-P in all soils and the work by Verma and Tripathi (1982) found a maximum increase 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 Tripathi (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 under 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 submergence, 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

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

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 solubilising them differentially under submergence. In fact these are aspects which have not been studied in detail and which 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 cent 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 extractants 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 of 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 has been further judged with the help of correlations and regressions (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 the growth stage as observed by Ramamoorthy and Bisen (1971) and also the moisture regime and other soil conditions.

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

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 X) has been observed to be significant unlike the varietal and the interactional effects. The addition of phosphatic fertilisers 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 30^{th} day and at harvest. Low values of saloid-P have been recorded for soils under the lowest dose of phosphatic fertiliser on 30^{th} and 60^{th} 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.

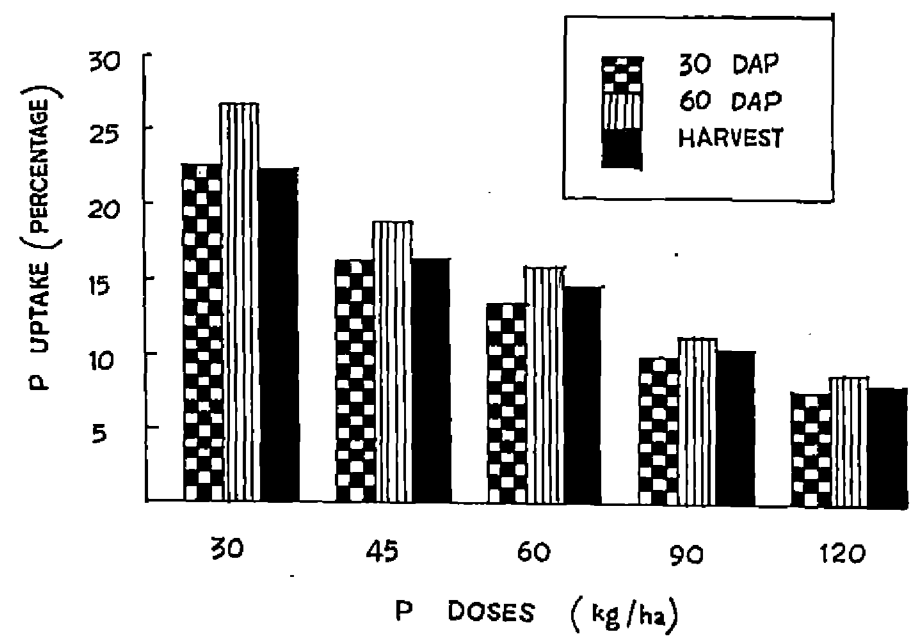
The grain yield has been significantly correlated with all the inorganic P fractions except occluded-P but the correlation coefficients between straw yield with Fe-P, Ca-P and sum of inorganic-P have alone been significant (Table 78). The significant relationships indicate the responsiveness of the rice 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 60 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 30^{th} day. At 60^{th} 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 4^{th} 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 superiority 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 component

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 observed 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 hence 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 fertilizers (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 there by 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 fertilisers are efficiently functioning in the soil. Calculation of P utilization 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 in 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 fertilizer brings out the potentiality of insoluble rock phosphate as phosphatic fertilizer for rice soils under acid soil conditions. It is necessary that in a judicious 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 Kacapadam 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 variation 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 decreasedwith 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 consequently 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 response 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 utilization 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 Samiel and Singh, 1985).

The P in root, straw, grain and soil (Tables 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 stresses 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.

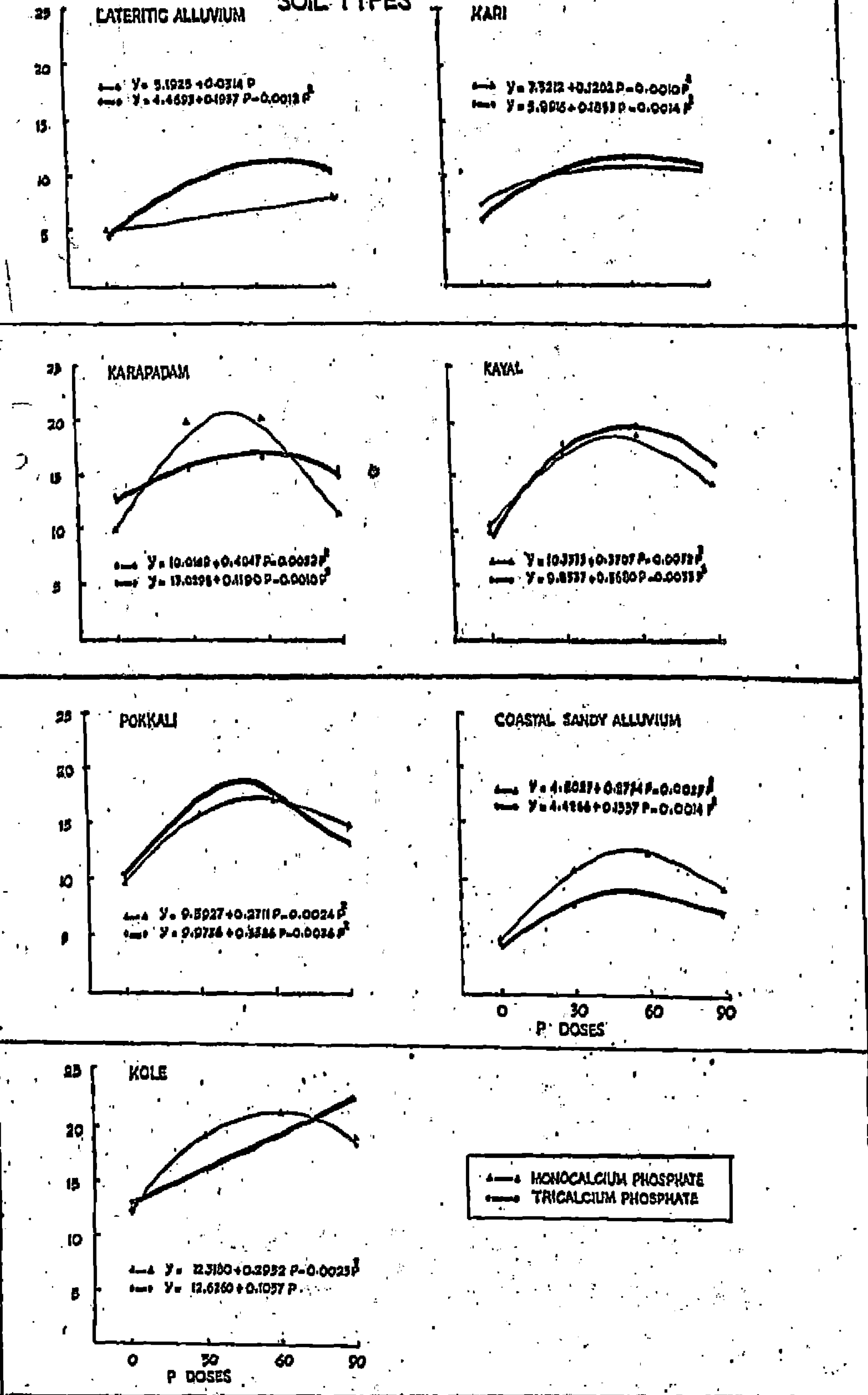
The soil available P represented by A-value (Table 106) is not observed to be significantly different for the two sources of P at harvest. However, an increase in this inherent P supplying capacity has been observed (100 per cent as the dose of P increased from 30 to 60 Kg P_2O_5/ha and 192 per cent 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 resulted 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 Kole 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 30^{th} 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 30^{th} 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 60^{th} 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 fertilisation

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 wall 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 similer 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 differential 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 fertilisers. 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 utilisation 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 utilisation has been decreased. The soil types vary with respect to P utilisation 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 substentiates 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 utilised 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 12.0 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 those 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. Edakkuttuparambu
39. Chamravattom
40. Thirur
41. Ponmundam
42. Peruvanna
43. Ponmala
44. Malappuram
45. Ramapuram
46. Kunnappally
47. Kallaeppillippadam
48. Vallur
49. Pattambi RRS. I Punja
50. Pattambi RRS. II Palliyal
51. Pattambi RRS. III Wet lands
52. Panancherry
53. Mannuthy RRS.
54. Puzhakkal
55. Mananthavady

2. Kari Soils

56. Kurichikari
57. Alankari
58. Puthenkari
59. Vadayar
60. Mulaekkunnamkari
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. Kokkokayal

4. Karapadam 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. Coastal sandy alluvial soils

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. Pokkali Soils

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. Kole Soils

132. Kanjanipadam
133. Eravupadam
134. Pazhamkole
135. Chaledikolepadam
136. Chettuvapuzha West
137. Nedumkole
138. Manalurthazham
139. Anthikadukolepadam
140. Enamakkal
141. Thekkekonchira
142. Vadakkekonchira
143. Vendarupadam
144. Variampadavukole
145. Jayanthpadamkole
146. Porthurpardavukole
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.E.C. me/100g 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

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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
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 [illegible]	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	60.0	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	1.33	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	9.0	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	8.8	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.	Edakkattuparambu	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

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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
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.	Fattambi 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
52.	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
53.	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
54.	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
55.	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
56.	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
57.	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
58.	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
59.	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
60.	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	15.0	0.35	0.16	5.5	145.6	0.3	523	12.0	46.7

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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
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	16.9	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	54.6
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	5.8	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	0.6	1.3	0.39	7.2	6.9	14.1	0.68	0.12	7.2	73.4	1.0	641	1.6	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	17.6	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	1.6	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	63.6	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.	Valiykillyanveli 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	8.6	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	0.6	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	74.6	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	0.6	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	83.6	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	11.8	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	8.9	346.7	2.0	241	1.9	24.5
129.	Pattanakadu II	4.6	2.14	63.5	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.	Pazhemkole	4.3	0.88	36.5	25.0	35.6	4.1	1.5	1.3	0.8	0.2	0.08	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	29.3	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	4.6	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	6.6	44.6	0.7	1101	8.0	42.1
145.	Jayanthpadamkole	4.6	1.21	61.2	12.0	23.6	6.3	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	0.6	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	0.6	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	0.6	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	Occlu-ded P	Sum of inorga-nic P	Orga-nic P	Non extract-able P	Total inorga-nic 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
ith n 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	600.17**
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	37044.30	112.00	455.87	1.77	88537.51
Soils (S)	6	460.78*	17131.77	24874.46	4988.42	7003.71	552.60	139060.28
C x S	6	0.29	158.94	2175.00	10.15	412.28	0.03	3017.76
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.

Mechanical seperates	
Sand	47.1 per cent
Silt	20.0 per cent
Clay	30.6 per cent
Chemical characteristics	
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**	9.68
Treatments (T)	5	39.14**	58.73**	36.28**	134.81**	99.44**	68.36**	58.90**	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		
		30th day after sowing	60th day after sowing	Harvest stage
1	2	3	4	5
Methods (M)	3	234.48**	62.85**	1209.76**
Treatments (T)	5	389.14**	163.17**	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) 30[th] 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	1.02
Treatments	5	5.76**	350.85**	4602.93**	108.56**	3.43**	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) 60[th] 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	21.38**	6.20**	878.46**
Treatments	5	3.02**	156.20**	4572.06**	98.65**	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	0.48	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

tract 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	172.81**
Treatments	5	640.80**	13.15**	138.75**	67319.50**	18.66**	176.00*	888.00**
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**	185.40**	159.14**	3197.04**	6851.9*
Treatments	5	185.71**	13.20**	156.02**	170.13**	388.68**	2020.0*
V x T	5	75.63**	2.30	17.06**	13.62**	78.32**	287.4*
Error	12	1.06	-	0.019	0.10	0.118	0.2

* Significant at 0.05 level

** Significant at 0.01 level.

APPENDIX XII

Abstract of analysis of variance for total P uptake at various growth stages of the crop.

Source	df	Mean square		
		30th day	60th 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**	306.31**	359.07**
Source of P	1	0.02	0.08**	0.61	3.30**	3.84**
Levels of P	2	9.91**	1.82**	0.15**	0.83**	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**	21.46**	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**	1.89**	58.88**	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	17659.20**	128569.63**	266657.03**	-	-	384.39**	48.87**
S x T	36	7093.80**	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**	28.59**	2323.30**
Source of P	1	0.02	6.88**	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**	12293597.20**	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.

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

BY

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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.

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 these 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, Al_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 these 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 utilization 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.

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	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	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	55	.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	-.45	-.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**	.98**	.85**	.99**	-.66**	.11	-.45*	.81**	.96**

* Significant at 5 percent level

** Significant at 1 percent level