THE DISTRIBUTION FIXATION AND AVAILABILITY OF PHOSPHORUS IN THE KOLE SOILS OF KERALA

By

SHEELA S.

THESIS
submitted in partial fulfilment of the
requirements for the degree
MASTER OF SCIENCE IN AGRICULTURE
Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
College of Agriculture
Vellayani, Trivandrum

1988

DECLARATION

I hereby declare that this thesis entitled "THE DISTRIBUTION FIXATION AND AVAILABILITY OF PHOSPHORUS IN THE *KOLE* 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 any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Sheela. S
(SHEELA, S.)

Vellayani,
19.11.1988

CERTIFICATE

Certified that this thesis entitled "THE DISTRIBUTION FIXATION AND AVAILABILITY OF PHOSPHORUS IN THE KOLE SOILS OF KERALA" is a record of research work done independently by Miss SHEELA, S. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Dr M.M. KOSHY
Chairman
Advisory Committee
Director of Centre of Excellence
for Tropical Soils
College of Agriculture, Vellayani

Vellayani,
19.11.1986

APPROVED BY

Chairman

Dr M.M. KOSHY

Members

1. Shri P.A. Korah

2. Dr Alice Abraham Alice Abraham

3. Shri U. Mohamed Kunju

External Examiner

ACKNOWLEDGEMENT

I wish to place on record my heartful thanks to Dr M.M. Koshy, Director, Centre of Excellence for Tropical Soils, College of Agriculture for suggesting the problem and for his valuable guidance during the course of this thesis.

I am greatly indebted to the members of my advisory Committee, Sri P.A. Korah, Associate Professor, Centre of Excellence for Tropical Soils, Dr Alice Abraham, Professor, Department of Soil Science and Agricultural Chemistry and Dr G. Raghavan Pillai, Professor of Agronomy for their help and constructive criticisms during the preparation of the thesis.

My sincere thanks are due to Dr N. Saifudeen and Sri P. Rajendran, Assistant Professor of Soil Science and Agricultural Chemistry for their valuable suggestions and help in the chemical analysis.

My sincere thanks are due to Dr P. Saraswathy, Associate Professor, Department of Agricultural Statistics for her valuable suggestions and help in the statistical analysis.

My heartful thanks are also due all the members of the staff and students of the Department of Soil Science and Agricultural Chemistry for their co-operation during the course of the research work.

I am everlastingly grateful to all of my friends for their love, understanding help and encouragement showered on me during the last two years.

I am extremely grateful to the Indian Council of Agricultural Research for the fellowship awarded to me during the course of my post graduate studies.

My grateful acknowledgement is due to the Kerala Agricultural University for the laboratory and library facilities provided during the course of the investigation.

I also like to record my boundless gratitude and indebtedness to my family members for their constant inspiration and help.

SHEELA, S.

Vellayani,

CONTENTS

LIST OF TABLES

<u>Table No.</u>

LIST OF ILLUSTRATIONS

INTRODUCTION

INTRODUCTION

The Kole soils of Kerala extend over an area of approximately 11,000 hectares in the Trichur and Malappuram districts. They lie between 0.5 and 2.0 metres below the mean sea level and are water-logged and submerged for the major part of the year. These soils are highly acidic in reaction and are considered as problem soils. Soil acidity is one of the causes of the imbalance in nutrition in these soils. The availability of certain elements like Al, Mn and Fe increase in acid soils leading to toxicity whereas the availability of a major element like phosphorus is minimized due to reaction with active Fe and Al.

Phosphorus is one of the major nutrient elements essential for plant growth. The importance of phosphorus in plant nutrition is well recognised. It is ranked next only to nitrogen in limiting crop production and it has been designated as the "Master Key to Agriculture". Now it is considered as a major constraint for successful crop production in Indian soils because, on the one hand the finite reserve of this non renewable resource is getting exhausted fast and on the other its deficiency is becoming widespread.

Extensive soil surveys carried out in Kerala reveal that about 90 percent of the cultivated soils of the state are deficient in both total and available phosphorus. It is well known that phosphorus exists in soils in different forms such saloid-P, Al-P, Fe-P, Red-P, Ca-P and organic phosphorus. These various forms differ in their availability to plants as well as in their stability in soil. A knowledge of the nature and distribution of soil phosphorus in these different forms is a prerequisite for assessing the availability of P to the crops.

Phosphorus deficiency is not only quite widespread but also acute in certain rice growing soils of Kerala. Soil test values of available phosphorus is a broad indication of the need for applying phosphorus but this information alone is not adequate. For the purpose of formulating recommendations, a knowledge of the soil characteristics, especially P fixing capacity is very important. On high P fixing soils, a lower dose might not give a response and soil hunger may persist.

Extensive work has been carried on phosphorus problems in different types of soils in Kerala. But very little work has so far been done in this regard on the Kole soils occuring in this State. So the present investigation was undertaken with the following objectives:

1. To study the chemical nature and distribution of native phosphorus in Kole soils.

2. To study the fixation and availability of P in these soils.

3. To study the availability of added phosphate fertilizers.

4. To study the amount of native phosphorus present in silt and clay.

5. To study P retention in silt and clay in these soils.

It is hoped that the present study on the distribution, fixation and availability of phosphorus in the Kole soils will provide valuable information for the effective management of P in these problem soils.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

A precise knowledge of the distribution, fixation and availability of phosphorus in soils is considered to be a pre-requisite to understand and interpret the behaviour of added phosphorus in the soils. An attempt is made here to review some of the earlier work carried out on these aspects, which is of relevance to present study.

Chemical nature and distribution of phosphorus in soils

Phosphorus exists in the soil in various forms, both organic and inorganic, which vary widely in the chemical composition and availability to crops.

Total phosphorus

Total phosphorus in soils can vary over a wide range, depending upon parent material, degree of weathering and organic matter.

Vertical distribution of total phosphorus has been reported in numerous studies (Allaway and Rhoades, 1951; Godfrey and Rieckon, 1954; Pearson et al. 1940). They reported that total phosphorus decreased with depth.

Gupta (1965) studied the distribution of phosphorus in sugarcane growing soils of Bihar. Total phosphorus in most of the soil profiles decreased with depth except in heavy clay soils of Bihar and some immature soils where the total phosphorus increased with depth indicating the effect of parent material.

Venugopal (1969) found that P_2O_5 content in 14 Kerala Soils ranged between 0.01 and 0.25 percent. He has also recorded that phosphorus content decreased with depth in most of the profiles studied.

Abdul Hameed (1975) studied the fertility status of <u>Kole</u> soils and revealed that in surface layer the value of total phosphorus ranged from 0.09 percent to 0.24 percent and in middle layer the range of the nutrient was between 0.03 percent to 0.22 percent. In all the profiles the total P_2O_5 decreased with depth.

Kothandaraman and Krishnamoorthy (1979) reported that total phosphorus get accumulated in surface layers in organic, clayey and calcareous soils and there was a sharp fall in total phosphorus in subsequent layers. The abnormal values in certain horizons was explained as lithological break.

Available phosphorus

Brito-Mutunayagam and Koshy (1951) observed that acetic acid soluble phosphorus which was considered to be the available form of the smallest phosphorus fraction in Kerala Soils. This fraction tended to decrease with depth.

Raychaudhuri and Landey (1960) observed that soils of high clay and silt contents retained more phosphorus and showed low availability to plants.

Patel and Mehta (1962) studied the vertical distribution of phosphorus in Gujarat soils and found that the top layers were rich in total, as well as available phosphorus, as compared to soils in the lower horizons. No significant relation between factors like pH, organic matter, and the finer fractions of the soil and the total and available phosphorus was found to exist. The integrated action of all these factors affected the phosphate status of these soil profiles.

In their investigation of the vertical distribution of phosphorus in the profiles of non calcareous, calcareous, alluvial and heavy clay soils, Gupta and Sen (1964) found that the top layers were richer in total and available phosphorus, than the lower layers. Availability of phosphorus decreased with depth in all the soils studied.

Pareek and Mathur (1969) found higher concentrations of available phosphorus in the surface layers. This was attributed to the distribution pattern of organic matter, pH, sesquioxides and clay content in the soils and also the requirement of crop and the rooting depth.

Mehta et al. (1979) correlated available phosphorus to different soil properties and found that available phosphorus was positively correlated with organic matter, organic phosphorus and negatively correlated with clay content and sesquioxides.

Inorganic forms

Dyer (1894) was probably the first to effect a fractionation of soil phosphorus by extracting available phosphorus with one percent citric acid.

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

(1) Inorganic phosphorus in neutral and alkaline soils probably a calcium phosphate: hydroxy apatite.

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

(iii) Organic phosphorus compounds

According to Hibbard (1931) the phosphorus forms in alkaline soils consist of hydroxyfluor apatite and chlorapatites, wavellite and organic compounds. Mc George and Breazeale (1931) concluded that calcium phosphate existed in calcareous soils mainly in the carbonate apatite form.

Dean (1937) found that in acid soils phosphorus existed mostly in alkali soluble forms whereas in alkali soils the acid soluble form predominated.

Ghani and Aleem (1943) studied the different fractions of soil phosphorus in some Indian soils and found that the acetic acid soluble fraction was considerably low in acid soils over a pH range of 4.2 to 5.8. This fraction occurred in the highest proportion in neutral and alkaline soils. Iron and aluminium phosphates were high in acid soils and tended to decrease with increase in pH.

Chang and Jackson (1957) studied the fractionation of soil phosphorus and reported that iron phosphates, particularly reductant soluble form dominated in highly weathered soils.

Chang and Jackson (1958) found that in laterite soils the iron phosphate and part of aluminium phosphate finally become occluded in an iron oxide coating which was formed during the course of chemical weathering of these soils.

Chai Moo Cho and Cladwell (1959) observed that iron and aluminium phosphates predominated in acid soils while calcium phosphate dominated in the calcareous soils.

Goel and Agrawal (1959) found that the surface soils of Kanpur contained more iron and aluminium phosphates than calcium phosphate.

Chu and Chang (1960) determined the forms of phosphorus in soils of Taiwan and distinguished three different distribution patterns for calcium, iron and aluminium phosphates. The predominant phosphorus fraction in latosols was that of iron phosphates and in calcareous alluvial soil it was calcium phosphate while alluvial soils developed from acid sand stone and shale were dominated by both iron and calcium phosphates.

Ramamoorthy and Velayutham (1976) have discussed the chemistry of P cycle in soil-plant system. Their analysis of Indian data has showed the importance of Fe and Al-p in the profiles of mature and sub mature soils, the amounts of these fractions in these soils increased, while those of total P decreased. In immature soil profiles Ca-p was the most important fraction of inorganic phosphorus.

Kothandaraman and Krishnamoorthy (1977) examined red, black, laterite and alluvial soils of Tamil Nadu and found that there was marked variation in the vertical distribution of P fractions in these soils. No definite pattern of distribution of Al-P and Fe-P was observed but the surface layers were rich in Al-P and Fe-P. Ca-P increased with depth in calcareous soil. Of the different inorganic fractions Al-P and Ca-P predominated in black and alluvial soils whereas Fe-P, reductant-P and occluded P were high in laterite soils.

Aiyer and Nair (1979) studied the phosphorus fractions of major rice soils of Kerala. The Fe-P fraction was the most dominant in all the soils accounting for 21.8 to 39.3 percent of total-P in the soils.

Tandon (1980) discussed the distribution of different forms of phosphorus in Indian soils and concluded that Ca-P constituted 40-50 percent of total phosphorus in most neutral to alkaline soils, and even more than 50 percent P in highly calcareous soils. In acid soils, the increase in Al-P and Fe-P was less than the decrease in Ca-P mainly because of the predominance of reductant soluble and occluded forms.

Organic-P

Ghani and Aleem (1943) found that the organic phosphorus compounds occurred in the highest amount under acid conditions and decrease with increase in pH upto neutral reaction and then increased with increase in pH.

Brito-Mutunayagam and Koshy (1951) found that organic phosphorus constituted the largest fraction in acid soils, and it decreased generally with depth.

Fuller and Mc George (1951) found that organic phosphorus concentrated on the uppermost layers and subsequently decreased with increasing depth.

Williams and Saunders (1956) found that the total soil P decreased down the profiles reflecting mainly a marked fall in the organic-p. Clay and silt together contained 85 percent and more of the total soil organic-p. In the top soils the proportions of total P in organic form were 27-67 percent for the whole soils and 50-65 percent for the clays and silts.

Bapat et al. (1965) studied the forms of phosphorus in Vidarbha Soils and found that inorganic phosphorus comprised the major portion of soil phosphorus. Organic phosphorus was generally low and decreased with depth.

Sharma (1967) studied the phosphorus status of the soils of the Kulu district of Himachal Pradesh and reported that the total phosphorus of these soils increased with increase in clay content. The organic matter and organic phosphorus were highly correlated. On an average organic phosphorus constituted 36 to 66 percent of the total phosphorus and decreased with depth.

Sharma et al. (1979) reported that organic P ranged between 90 and 690 ppm and comprised about 11 to 34 percent of the total P, with an average of 23 percent. There was a negative correlation between organic P and soil pH and sand fraction but a positive one between organic phosphorus and organic carbon, silt and clay fraction.

Koshy (1971) studied the inter relationships between organic carbon, nitrogen and organic phosphorus in the surface layers of some Kerala soil types and reported a wide variation in their contents. The result showed that the organic phosphorus content ranged from 0.0022 to 0.0378 percent and that the organic C/organic P and N/organic P ratios did not tend to be constants similar to C/N ratios of soils.

Forms of soil phosphorus and their relation to availability

The knowledge of the various forms of P present in soil and the conditions under which these become available to plants is a prerequisite for assessing the availability of soil phosphorus to crops. One of the approaches to judge the availability of different forms of soil phosphorus to the growing crop is to correlate various phosphate fractions with soil test values for available phosphorus.

Laveerty and Mc Lean (1983) reported that Al-P was considerably more available to plants. Fe-P and phosphorus availability were highly correlated to iron and aluminium contents as well as ammonium chloride extractable forms.

Al Abbas and Barber (1964) studied the relationship between plant uptake of phosphorus and the various phosphorus fractions in the soil. According to them, ferrous phosphate was highly correlated with plant uptake.

According to Chang (1965) iron phosphate was the main source of phosphate absorbed by rice under submergence in acidic and calcareous soils. He directly measured the quantity of phosphorus absorbed from each chemical form of inorganic phosphate.

Chu and Chang (1966) clearly proved that calcium phosphate was not an important source of available P either in acidic soils or in calcareous soils.

Nair and Aiyer (1966) found that the form of phosphorus taken up by rice plants from water logged acid soils was iron phosphate.

Cholitkal and Tyner (1971) investigated the distribution of inorganic phosphorus fractions in relation to availability in the low land rice soils of Thailand. From isotopic exchange studies they showed that Fe-P is the prime source of labile P in soils.

From a study of phosphate fertility in water logged soils, Mahapatra and Patrick (1971) observed that water logging increased the proportion of native Al-P and Fe-P and decreased reductant soluble P but did not affect Ca-P.

Raghupathy and Raj (1973) conducted pot culture experiments with the soils of Tamil Nadu to study the fluctuations of soil phosphorus fractions during paddy growth under flooded conditions. The study showed that available P and Al-P content were higher on the 15th day after transplantation than at post harvest stage in the soils.

Thakur et al. (1975) found that Fe-P fraction formed the major portion of native inorganic phosphorus fractions. Al-P, Fe-P and Ca-P fractions increased at both flowering and harvesting stages of rice.

From their study on the evaluation of iron phosphate as source of P in rice soils, Kar and Hussain (1977) concluded that the insoluble iron phosphates were not readily available to plants in well drained soils. However they undergo reduction to more soluble ferrous forms in water logged soils, so Ca-P as a good source of P to lowland rice. The performance of iron phosphate was comparable to super phosphate under submergence.

Using the multiple correlation and regression, Singhania and Goswami (1979) studied the relationship between inorganic phosphate fractions and available phosphorus in four major soils viz., alluvial, black, red and laterite. Al-P was found to be the main source of Olsen and Bray extractable P.

Bhajan Singh et al. (1979) revealed that the P uptake by rice was significantly correlated with saloid-P, Al-P and Ca-P had a negative correlation with P uptake by rice.

Sharma and Tripathi (1984) reported that Al-P and Bray P were significantly correlated to each other.

Sudhir et al. (1987) found that Al-P was the more important fraction contributing towards the availability of phosphorus in soils followed by Red-P and saloid-P.

Phosphorus fixing capacity of soils

Yuvan et al. (1960) investigated the rate of fixation of applied phosphorus and found that more than 80 percent of the applied phosphorus was fixed as iron and aluminium phosphates. They showed that only 10 percent of the applied phosphorus remained in an available form in the soil.

Koshy and Brito-Mutunayagam (1965) studied the mechanism of phosphorus fixation in soils and the nature of the retained phosphates. 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 soils but did not exclude the possibility of adsorption by clay minerals as well.

Kar and Chakravarthy (1969), from their study on P fixation in five West Bengal acid soils with pH values varying from 4.37 to 6.18 observed that about 30 to 50 percent of the added soluble phosphates get fixed during crop growth.

Mandal and Khan (1972) in their investigation on the release of phosphorus from insoluble phosphatic materials in acidic low land soils noted that within 15 days of application more than 86 percent of the phosphorus added as superphosphate was converted to unavailable form.

Nad et al. (1975) determined the phosphorus fixing capacity of the soils belonging to different major soil groups. Simple and multiple correlation and regression studies showed that the amount of clay and free oxides in the soils were two dominant factors determining the P fixing capacity. Calcium carbonate, pH and silt content did not show any significant correlation with P fixation while sand showed a negative and organic carbon a positive correlation. Clay and free oxides together accounted for 69 percent of P fixed. Of the various soil groups, black, red, laterite, mixed red and black, red and yellow and coastal alluvial soils exhibited higher P fixation than alluvial, gray brown, desert and other soils.

Madhusoodhanan and Padmaja (1983) studied the phosphorus fixing capacity of the major rice soils of Kerala. They found that phosphorus fixing capacity of Kole, Kayal, Laterite, Karapadom and coastal sandy soils were 84.0, 72.3, 80.6, 77.8 and 36.8 percent respectively.

Dolui and Gangopadhyay (1984) observed that the clay content of soil was the dominant factor determining P fixing capacity.

Frageria and Barbosa (1987) studied phosphorus fixation in the oxisols of central Brazil and revealed that it may take values between 77 and 90 percent depending on levels of P applied.

Factors affecting phosphorus fixing capacity of soils

Soil reaction

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

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

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

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

The specific adsorption of phosphate, sulphate and molybdate by soil colloids was generally considered to decrease as 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) also.

Exchangeable ions

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

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

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

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 soil was established by a number of workers (Raychaudhuri and Mukerjee, 1941; Coleman et al. 1960; Hsu, 1965 and Vijayachandran, 1966). Significant correlation between the total sesquioxide, 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 P fixation was well brought out by Coleman (1942, 1944 a,b), Kanwar (1956), Leaver and Russel (1957) and Fox et al. (1971).

Datta and Srivastava (1963) found that organic matter has a high phosphate bonding energy. They attributed the differences in the bonding energies of soils, having identical contents of free sesquioxides to the differences in the organic matter content of the soils. According to these authors the high phosphate fixing capacity of laterite soils is due to high content of sesquioxide alone, but due to lower organic matter content as well.

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

Simple 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 percent of the P fixed.

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

Soil texture

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

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

Koshy and Brito-Mutunayagam (1965) investigated the mechanism of P fixation in acid 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. The results favoured the chemical precipitation theory of P fixation in soil but did not exclude the possibility of adsorption by clay mineral 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 percent of the P fixed. Danilo Lopez-Hernandez and Burnham (1982) observed that clay content affected P sorption but only at a 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 percent of P fixation in these soils was attributed to $CaCO_3$. 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 the fixation of P in alkaline calcareous soils of Rajasthan was significantly correlated with the $CaCO_3$ content of the soil. Similar results were obtained by Kumaraswami and Dhanapalan Mosi (1969) and Jose (1973) in the soils of South India.

Organic matter

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

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

Transformation of applied phosphorus in soil

Even soils containing large amounts of total phosphorus may frequently exhibit a deficiency of this element. This anomalous behaviour of unavailability of available P even after its application in the soil is due to phosphorus fixation. Factors responsible for such unavailability of P are numerous such as the presence of hydroxides of iron and aluminium, high acidity of the soil, adsorption on clay surface and depletion of 'Ca'.

Gardner (1930) and Metzger (1940) have reported the conversion of soluble forms of phosphorus into sprangly soluble compounds by reaction with the cations of soil solution such as iron, aluminium and calcium.

Hibbard (1935) stated that the soils had no definite "fixing power" but that fixation was a function of the concentration in solution at equilibrium.

Murphy (1939) explained the retention and low availability of phosphate in kaolinite and kaolinitic soil as due to the exchange of added phosphate with OH ion of the hydroxy layer in the kaolinitic crystal lattice.

Stout (1939) and Coleman (1942) concluded that the failure of crops to respond to the added phosphate could be attributed to the rapid fixation of phosphate by the soil.

Ghani and Aleem (1943) and Kurtz et al. (1946) have found that in acid soil phosphorus become unavailable due to the formation of iron and aluminium phosphate and accumulation of organic compounds.

Bray and Kurtz (1945) found that incubation produced an increase in extractable inorganic P that was greater in the presence of added inorganic P than its absence.

Chang and Jackson (1958) found that phosphorus fertilizer added to the soil was transformed into all three forms Al-P, Fe-P and Ca-P according to the principle of solubility product.

Wright and Peach (1960) reported that under low pH range phosphate was converted into iron-P. Analysis of soil from long term manurial plots also have confirmed this view.

Laveerty and Mc Lean (1963) have shown by adding tagged soluble P to soils of high P fixing capacity that the major portion of the added P was converted into Fe-P form whereas in soils of low phosphorus fixing capacity the major conversion was to the Al-P form.

In their study of the mechanism of phosphorus fixation in soils and the nature of retained phosphates, Koshy and Brito-Mutunayagam (1965) observed that alkali soluble inorganic fraction comprised of iron and aluminium phosphates.

Yuvan et al. (1960) and Bapat&Badekar (1965) investigated the rate of fixation of applied P by soils and found that more than 80 percent of the applied phosphorus was fixed as Fe-P and Al-P. Only 10 percent of the applied P remained in the available form in the soil.

Chang and Jackson (1958) investigated the occurrence of the various forms of soil P in relation to fertilizer practices and found that the phosphorus added to the soil was converted to calcium, aluminium and iron phosphates. These transformation were observed in acid, as well as, neutral soils.

Fassbender (1968) reported that a high percentage of the added P is retained and bound to iron and aluminium and that due to this, significant amounts of highly soluble phosphate fertilizers become unavailable in soils.

Kar and Chakravarthi (1969) in their study of five West Bengal acid soils with the pH varying from 4.8-6.3 observed that about 30-50 percent of the added soluble phosphate got fixed during the crop growth. Analysis showed an appreciable increase in Al-P and Fe-P and a small increase in occluded Al-P. Calcium phosphate was unaffected except in a soil having pH 6.18.

Appett and Schalscha (1970) investigated the changes in native and applied phosphate in volcanic ash derived soils of Southern Chile. Initially, most of the added P was recovered in the NH_4F extractable fraction.

Singh and Ram (1977) found that the slow rate of conversion of added P into Ca-P in lateritic soil might be due to its slightly acidic reaction and higher rate of conversion in the soil might be due to their alkaline reaction and free $CaCO_3$ especially in recent alluvium.

Singh and Ram (1977) reported that the amount of added P converted to Al-P decreases as Fe-P increases, in all soils except in recent alluvium.

Khana and Mahajan (1971) studied the behaviour of added phosphate in soils of varying physical properties. They observed that more than half of the added phosphate was changed to Al-P, 47-92 percent at pH 4.7 and 35.56 percent at pH 6.6 followed by Fe-P, 18-44 percent at pH 4.7 and 17.34 percent at pH 6.6. In alkaline calcareous soil saloid bound P and Ca-P were much more than in acid soils.

Mandal and Mandal (1973) reported that the total amount of P recovered as saloid-P, Al-P, Fe-P and Ca-P in different soils accounts for 55 to 98 percent of the added amount. Approximately 45 percent of added P might be transferred into reductant soluble Fe-P and or occluded Al-P.

Singhania and Goswami (1978) found that in soils with acid to neutral pH, the highest amount of applied P was recoverable in Fe and Al-P fractions after 20 days, but Ca-P was the major fraction after a period of 80 days, particularly in soils having higher calcium content.

Hooker et al. (1980) reported that reversion of water soluble P is very rapid in calcareous soils. They also found that over a period of time there was a decrease in the more soluble plant available fractions resulting in a shift of P from extractable to non extractable form.

In a study of the transformation of P added to three acid soils of Himachal Pradesh, Sharma et al. (1980) found that most of the added P was transformed into Al-P which increased upto 7 days and later decreased slowly with time upto 90 days at all levels of application. The conversion of added P into Fe-P fraction increased slowly with time upto 90 days and very little was changed to Ca-P.

Singh and Dixit (1983) reported that on addition of moisture saloid bound, Al & Fe-P contents increased as compared to their original values on incubation.

Yadavanshi et al. (1986) found that the major portion of added P not utilized by wheat crop got converted into Al-P (41.5 percent) followed by Fe-P (23.1 percent). The transformation into Ca-P was of a low magnitude and it was most negligible in the case of saloid-P.

Sudhir et al. (1987) revealed that graded doses of NPK fertilizers increased the saloid-P, Al-P, Fe-P, Red-P and available P status of soil. However, Ca-P remained at the original level. Among Al-P, Fe-P and Ca-P fractions Fe-P showed the highest increase over control (29.5 ppm) indicating a shift from Al-P and Ca-P to Fe-P. Al-P was found to be the most important fraction contributing towards available phosphorus.

Availability of different phosphatic fertilizers

Recently a large number of phosphatic fertilizers containing varying amounts of water soluble phosphorus are available in market. However, the availability of phosphorus is a problem depending upon the P fixing capacity of soils. Relative efficiency of water soluble and insoluble phosphatic fertilizers was studied by many workers. A wide range of results varying from equal response, increased response and decreased response have been reported.

Mandal and Khan (1972) and Singh and Datta (1973) have reported that rockphosphate can be effectively used as phosphatic fertilizers in acid soils. Rastogi et al. (1976) indicated the superiority of superphosphate to rockphosphate in maintaining the available P status of acid soils. This apparent contradictions may be due to the variability in factors like soil characters, temperature and moisture regimes.

Chang and Chiang (1953) indicated that rockphosphate and superphosphate were of comparable value in acid soils but the difference in neutral and alkaline soils was quite apparent. Koshy and Brito-Mutunayagam (1961), studied the fixation and availability of phosphorus in soils of Kerala and found that rockphosphate gave the maximum amount of N/2 acetic acid soluble phosphorus as compared to other forms.

Atanasiu (1971) has reported that fertilizer containing water soluble phosphate showed a good response to yield of plants. Moreover, Rhenania phosphate soluble in ammonium citrate has a better fertilizer effect than superphosphate in acid soils as well as in calcareous and alkaline soils. He also reported that in Kenya and Liberia on laterite soils the citrate soluble phosphate had a better effect than the water soluble form.

Mandal and Khan (1972) have reported that rockphosphate and basic slag were more effective than superphosphate for growing rice in acid soils. They also showed that within 15 days of application more than 86 percent of the phosphorus added as superphosphate was converted to unavailable forms. The rockphosphate maintained a high amount of available phosphorus in the soil than superphosphate.

From laboratory incubation studies, Dashrath Singh et al. (1976 a) have reported that the phosphorus availability of different sources of phosphate like Udaipur phosphate, Mussoorie phosphate, Laccadive phosphate and Superphosphate mixed with phosphobactrin species was initially reduced upto 75 days of incubation due to incorporation of phosphorus solubilizer and afterwards increased.

Dashrath Singh et al. (1976 b) have found that the availability coefficient ratio (ACR) was 0.60 for Udaipur, 0.75 for Mussoorie and 0.21 for Laccadive at 60 kg P_2O_5/ha level. They have also compared Udaipur, Mussoorie and Laccadive rockphosphates with superphosphate and found the percentage efficiency to be 78, 62 and 54 respectively.

Hundal and Sekhon (1976) have reported that effectiveness of nitric phosphate increased with the proportion of its water soluble fraction. Dicalcium phosphate and superphosphate were almost equal in their effectiveness. Rockphosphate was the best effective source of fertilizer phosphorus.

Motsara and Datta (1976) have reported from the results of a field trial, that rockphosphate proved to be as effective as superphosphate. As for the residual effect, rockphosphate was a better source of phosphorus than superphosphate in acid soils.

From the results of a three year trial with maize and wheat on the comparative efficiency of different phosphatic fertilizers, Meelu et al. (1977) have reported that on wheat wholly water soluble phosphorus sources proved equally effective and gave significantly higher yield to the extent of 13.8 to 22.5 percent and 8.9 to 17.2 percent over suphala (30 percent water soluble phosphate) and nitro phosphate (50 percent water soluble phosphate) respectively.

Atanasiu et al. (1978) have reported that in cases of low phosphorus application (45 kg P_2O_5/ha), water soluble phosphate resulted in better maize development and higher phosphorus uptake at the beginning of the growing period, but water soluble and mixed phosphate gave better results during the later stages of growth.

Singh and Mehrotra (1978) found that pyrites applied with superphosphate or rockphosphate gave better effect on wheat than when they were applied alone.

Mishra and Gupta (1978) reported that Mussoorie rockphosphate was a better source of phosphorus for maize in acid soils as compared to superphosphate.

Hundal et al. (1979) have reported that the efficiency of various sources of fertilizer phosphorus was enhanced with increase in the proportion of water soluble phosphorus. Dicalcium phosphate and nitrophosphate - superphosphate of

70 percent water solubility were almost equal in their effectiveness.

Mishra et al. (1980) have shown that the response of maize to Mussoorie rockphosphate was very poor, but spectacular improvement in its efficiency occurred when it was mixed with pyrites in a 1:2.5 ratio. A mixture of Mussoorie rockphosphate and superphosphate in equal proportions on total phosphorus basis was found to be 83.1 percent as effective as superphosphate for increasing the grain yield of maize. But Mussoorie rockphosphate used alone was significantly inferior to the other three sources of phosphorus tested.

Kabeerathumma and Mohankumar (1986) found that Mussoorie rockphosphate was as effective as superphosphate in direct effect but superior to its in residual value in acid soils.

Phosphorus retention character of clay and silt

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

Patel and Viswanath (1946) reported that phosphate fixing capacity of Indian soils increased with the increase in their clay content.

Pathak et al. (1950) studied phosphate fixing capacity of sand, silt and clay fractions of micaceous alluvial soils and found that clay fraction in general fixed the maximum amount of P_2O_5 followed by silt and sand fractions.

Kanwar (1956) found that the phosphate fixing capacity of different soil separates increased with decreasing particle size but even coarse and fine sand fractions showed high phosphate fixing capacity which was attributed to the presence of reactive sesquioxides.

Williams and Saunders (1956) studied the distribution of phosphorus in soil profiles and particle size fractions and reported that the P content of the fractions vary widely depending on the soil. But total P is normally highest in the clay and lowest in the coarse sand.

Bates and Baker (1960) found that the clay fraction of the top soil contains large amounts of P soluble in NaOH.

Halstead (1967) noted that coarser fractions contributed a relatively larger proportion of P in some soils, when the total P in a given particle size fraction in the soil was considered. He also reported that a major part of the added P was recovered in Al and Fe-P forms. Al-P was the primary form of recovery except in fine silt and clay fractions of Podsol soils where Fe-P was more predominant.

Hanley and Murphy (1970) reported that in general all forms of P were highest in clay fractions and lowest in sand. They also reported that a significant negative correlation was obtained between the percent clay in soil and total P content of its clay fraction.

John and Gardner (1971) reported that P levels depended very little on soil texture for the majority of the soils although there was some over evidence in favour of fine particle sizes over sand fractions as a source of P in one of the profile.

Singh et al. (1986) found that phosphate of silt + clay generally accounted for 40-90 percent of total P.

MATERIALS AND METHODS

MATERIALS AND METHODS

In order to study the distribution, fixation and availability of phosphorus in the Kole soils of Kerala the following 15 representative localities were identified in the Kole lands of Trichur district. Both surface and subsurface samples were collected from the under mentioned localities from depths of 0-20 cm and 20-40 cm.

1. Chettupuzha
2. Manakkody-Varyam
3. Manakkody-Anjumuri
4. Eravu
5. Kanjani
6. Manaloor
7. Thekke Konjira
8. Kannothu
9. Mullaseri
10. Anthikad
11. Chezhur
12. Alappadu
13. Pullu
14. Pazhuvil
15. Cherpu

Laboratory Studies

A. Physico-chemical Characters

All the samples were air dried in shade and ground with a wooden mallet. Each sample was then screened through a 2 mm sieve and the screenings were collected and stored in labelled stoppered glass bottles.

The sampled soils were examined for the following physico-chemical characteristics using standard analytical procedures.

1. Mechanical composition

The mechanical composition of the soils was determined by the International pipette method after oxidation of the organic matter with hydrogen peroxide. Cementing agents were removed by treating with 2N HCl and 1N sodium hydroxide which brought about proper dispersion of the clay (Piper, 1966).

2. Soil reaction

The soil pH was measured in a 1:2.5 soil water suspension using a photovolt pH meter with a combined glass/reference electrode.

3. Electrical conductivity

Specific conductivity was determined in a 1:2.5

soil water extract using an Elico Soil Bridge.

4. Cation exchange capacity (CEC)

The cation exchange capacity was estimated using neutral normal ammonium acetate as described by Jackson (1973).

5. Organic Carbon

Organic carbon was determined by the Walkley and Black's rapid titration method as given by Jackson (1973).

6. Total Nitrogen

The total nitrogen content was estimated using the microkjeldhal method (Jackson, 1973).

7. Total Phosphorus

Total P_2O_5 was determined in hydrochloric acid extract by the Vanadomolybdo phosphoric yellow color method as given by Jackson (1973).

8. Available Phosphorus

Bray No. 1 available P was extracted using dilute acid fluoride solution (0.03N NH_4F in 0.025 N HCl), (Bray and Kurtz, 1945). The phosphorus in the extract was determined colorimetrically by chlorostannous reduced molybdophosphoric blue colour method in hydrochloric acid system (Jackson, 1973).

Total Calcium

Calcium was estimated using an Atomic Absorption Spectrophotometer (PE-3030). One ml of the hydrochloric acid extract of the soil was made upto 50 ml and fed to the Atomic Absorption Spectrophotometer. The amount of calcium present was determined and expressed as CaO.

10. Sesquioxide content

The sesquioxides in the hydrochloric acid extract was precipitated with excess of ammonium hydroxide in the presence of ammonium chloride and filtered. The precipitate was washed free of chloride, dried in an oven, and ignited in a muffle furnace to constant weight. The R_2O_3 content was reported as percentage on oven dry basis (Piper, 1966).

11. Total Aluminium

Total aluminium was estimated using an Atomic Absorption Spectrophotometer (PE-3030). One ml of the hydrochloric acid extract of the soil was made upto 50 ml and fed to the Atomic Absorption Spectrophotometer and the aluminium was determined and expressed in mg/g of soil.

12. Total Iron

Total iron in the hydrochloric acid extract was determined colorimetrically using the method proposed by Jackson, 1973.

B. Phosphate Studies

I. Fractionation of native soil phosphorus

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

(i) Saloid bound phosphate (saloid-P) 1M NH_4Cl extractable P.

One gram of soil that had passed through a 0.15 mm sieve was placed in a 100 ml centrifuge tube and 50 ml of 1M NH_4Cl solution was added. The suspension was shaken for 30 minutes and centrifuged. The saloid-P in the supernatent solution was determined by chlorostannous reduced molybdophosphoric blue colour method in H_2SO_4 system as described by Jackson (1973).

(ii) Aluminium phosphate (Al-P) - 0.5M NH_4F extractable P.

To the soil in the centrifuge tube, 50 ml of the 0.5 M NH_4F solution buffered to pH 8.2 with NH_4OH was added, shaken for an hour and centrifuged. The supernatent solution was filtered through activated carbon and the Al-P in a 10 ml aliquot of the filtrate was estimated by the chlorostannous reduced molybdophosphoric blue colour method in HCl system (Jackson, 1973) after adding 15 ml of 0.8 M boric acid to eliminate the interference of fluoride.

(iii) Iron phosphate (Fe-P) 0.1 M NaOH extractable P.

The soil residue left after the above 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 hour 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-P in the filtrate was determined by the chlorostannous reduced molybdophosphoric blue colour method in H_2SO_4 system.

(iv) Reductant soluble phosphate (Red-P)

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. To this was added 1 g of sodium dithionate solution and it was shaken for 15 minutes. The contents were then 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 50 ml volumetric flask and the soil residue was washed twice with saturated NaCl solution. The washings were also collected in the flask and made upto mark. The reductant soluble P in the solution was estimated as described by Chang et al. (1966).

(v) Occluded phosphate (occluded-P)

To the soil left in the tube after the dithionate-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 molybdophosphoric blue colour method in HCl system.

(vi) Calcium phosphate (Ca-P) 0.25 M H_2SO_4 extractable P

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

Organic phosphorus (Organic-P)

This was estimated as the difference between total phosphorus and the sum of the various inorganic fractions.

II. Fixation and availability of phosphorus

(a) Phosphorus fixing capacity of the soils

The phosphorus fixing capacity of the soils was estimated by the method of Patel and Viswanath (1946).

Ten grams of air dried soil, passing through a 70 mesh sieve was placed in a 150 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 tube and contents were shaken for 24 hours in a mechanical shaker. The suspension was centrifuged and the P content in the clear solution was estimated by the Vanado-molybdophosphoric yellow colour method as described by Jackson (1973). The decrease in concentration was taken as the amount of P fixed. This fraction expressed as percent of the phosphorus added was designated as the phosphorus fixing capacity of the soil.

(b) Availability of added phosphatic fertilizers

The phosphatic fertilizers used in these investigations, were superphosphate (16% P_2O_5) and Mussoorie rockphosphate (22.4% P_2O_5). The availability of these different fertilizers was studied in typical Kole soils by incubating

50 g portions of soil mixed with these two fertilizers at the rate of 40 mg P_2O_5/100 g of soil. The soils were incubated at room temperature for 1 hour, 1 day and 1, 2, 4, 6, 8 and 10 weeks at constant moisture regime. At the end of each incubation period 2-3 g of the wet soil was transferred to a shaking bottle and extracted with Bray 1 solution. Available P_2O_5 in each sample was determined colorimetrically and expressed in mg P_2O_5/100 g dry soil.

(c) Relative amounts of native phosphate in clay and silt

50 g of soil was weighed into a shaking bottle. 500 ml of distilled water were added and the flask shaken on a rapid reciprocating shaker for 16 hours to bring about the dispersion of the clay and silt fractions. The soil water suspension was then transferred to a tall cylinder, made upto 1000 ml and shaken well. The cylinder and suspension was placed under a Robinson's pipette and aliquots of the silt + clay and clay fractions were drawn and pipetted out into two weighed 100 ml Erlenmeyer flasks after specified intervals. The two fractions were evaporated to dryness and their weights determined. The amounts of clay and silt were thus obtained. The residues were then digested with 10 ml of 1:1 perchloric-sulphuric acid mixture and made upto 100 ml and the phosphate in each determined

colorimetrically. From this, phosphate present in by clay and silt fractions was calculated.

(d) Added phosphate retained by clay and silt

50 g of the soil was treated with 50 mg P_2O_5 as KH_2PO_4 in 50 ml solution and the soil was air dried. The treated sample was dispersed by the method described above. The soil was then transferred to a tall cylinder, the suspension made upto 1000 ml, shaken well and pipetted for the clay and silt fractions into two weighed Erlenmayer flasks. The two fractions were evaporated to dryness and their weights determined. The residues were then digested with 10 ml of 1:1 perchloric-sulphuric acid mixture and made upto 100 ml and phosphate in each determined colorimetrically. The amounts of added P_2O_5 retained in these two fractions were calculated by difference.

(e) Relative amounts of added P reverted to different forms of soil phosphorus

To 5 g portions of the soil 50 ml lot of KH_2PO_4 solution containing 2 mg P_2O_5 were added. This corresponded to 40 mg of P_2O_5 per 100 g soil (174.7 ppm of P). The mixture of soil and solution was gently boiled to dryness, then moistened with distilled water and finally air dried. 2.0 g of the treated sample was chemically fractionated into different forms of phosphorus by the method proposed by Peterson and Corey (1966). From the fractionation values of the treated and untreated samples, added phosphate retained by each fraction was obtained.

RESULTS

RESULTS

The results obtained in the present study are given below:

A. PHYSICO-CHEMICAL PROPERTIES OF THE SOILS

The data on the physical and chemical properties of soils are furnished in Tables 1 and 2 respectively.

(1) Mechanical composition

The texture of the soils varied from sand to clay, but most of them were sandy loams. The coarse sand fractions in these soils varied from 3.8 percent in subsurface layer of Manakkody-Varyam to 70.4 percent in the subsurface layer of Manakkody-Anjumuri. Fine sand varied from 2 percent to 27.2 percent in the subsurface layer samples of Manakkody-Varyam and Kanjani respectively. The silt fraction varied from a minimum value of 5.6 percent in the surface layer of Kanjani to a maximum value of 47.0 percent in the subsurface layer of Chettupuzha area. Clay content ranged between 2.4 percent in the surface layer of Alappadu and 70.0 percent in the surface layer of Pullu (Table 1).

(2) Chemical characteristics

The data on the chemical characteristics of the soil

Table 1 Mechanical composition of soils

No.	Location	Depth cm	Coarse sand %	Fine sand %	Silt %	Clay %	Textural class
1	2	3	4	5	6	7	8
I a.	Chettupuzha	0-20	14.0	2.8	38.3	42.9	Clay
b.	"	20-40	15.9	4.9	47.0	29.2	Clay
II a.	Manakkody-Varyam	0-20	6.2	2.4	39.2	47.8	Clay
b.	"	20-40	3.8	2.0	32.5	58.9	Clay
III a.	Manakkody (Anjumuri)	0-20	69.2	3.1	22.2	3.5	Sandy loam
b.	"	20-40	70.4	8.0	15.0	5.0	Sandy loam
IV a.	Eravu	0-20	50.4	15.3	26.0	5.5	Sandy loam
b.	"	20-40	35.8	21.4	14.2	27.0	Sandy clay loam
V a.	Kanjani	0-20	68.6	21.4	5.6	2.5	Sandy
b.	"	20-40	56.6	27.2	6.5	7.0	Sandy
VI a.	Manaloor	0-20	33.9	22.3	32.6	8.0	Sandy loam
b.	"	20-40	34.5	24.8	21.8	16.7	Sandy loam
VII a.	Thekke Konjira	0-20	31.7	19.8	20.0	23.2	Sandy clay loam
b.	"	20-40	42.3	22.7	6.0	26.4	Sandy clay loam

Table 1 contd.

1	2	3	4	5	6	7	8
VIII a.	Kannothu	0-20	40.6	16.6	33.4	9.0	Sandy loam
b.	"	20-40	36.3	16.9	40.9	5.7	Sandy loam
IX a.	Mullaseri	0-20	51.1	13.2	30.8	2.7	Sandy loam
b.	"	20-40	67.1	6.7	18.0	6.3	Sandy loam
X a.	Anthikad	0-20	48.7	15.1	26.3	7.7	Sandy loam
b.	"	20-40	66.9	10.3	16.3	5.5	Sandy loam
XI a.	Chezhur	0-20	33.5	11.6	27.5	25.7	Sandy clay loam
b.	"	20-40	21.9	22.5	42.0	12.6	Loam
XII a.	Alappadu	0-20	59.3	23.3	14.0	2.4	Sandy
b.	"	20-40	48.8	22.2	24.7	3.7	Sandy
XIII a.	Pullu	0-20	7.1	4.9	15.0	70.0	Clay
b.	"	20-40	4.3	5.4	31.7	56.0	Clay
XIV a.	Pazhuvil	0-20	21.2	19.6	22.4	33.6	Clay loam
b.	"	20-40	22.8	14.1	26.8	34.0	Clay loam
XV a.	Cherpu	0-20	14.9	17.7	22.9	42.3	Clay loam
b.	"	20-40	15.0	21.0	27.6	35.6	Clay loam

Table 2 Chemical characteristics of soils

No.		Location	Depth cm	pH	CEC me/ 100 g of soil	Organic carbon %	Organic matter %	Total N %	Total P_2O_5 %	Ses-qui-oxides	Total Alumi-nium mg/g	Total Iron mg/g	Avai-lable P_2O_5 ppm	Total CaO %
1		2	3	4	5	6	7	8	9	10	11	12	13	14
I	a.	Chettupuzha	0-20	5.0	11.4	2.16	3.72	0.12	0.34	21.50	94.1	62.50	33	0.153
	b.	"	20-40	4.2	17.3	1.07	1.84	0.17	0.24	15.90	50.8	50.00	22	0.139
II	a.	Manakkody-Varyam	0-20	5.0	9.3	2.19	3.78	0.26	0.36	25.75	85.8	69.63	26	0.192
	b.	"	20-40	4.6	18.4	1.62	2.79	0.10	0.20	29.00	155.6	74.10	19	0.270
III	a.	Manakkody (Anjumuri)	0-20	5.2	6.4	0.98	1.69	0.12	0.19	11.45	52.8	41.78	20	0.190
	b.	"	20-40	4.4	8.2	0.23	0.40	0.08	0.16	10.00	30.6	53.93	20	0.090
IV	a.	Eravu	0-20	5.2	6.4	1.62	2.79	0.11	0.24	16.00	67.6	46.93	29	0.107
	b.	"	20-40	5.2	9.3	0.93	1.60	0.06	0.16	15.90	62.1	58.03	20	0.067
V	a.	Kanjani	0-20	5.1	6.3	1.10	1.90	0.05	0.14	2.40	9.7	4.48	20	0.142
	b.	"	20-40	4.4	7.2	2.57	4.43	0.06	0.23	4.00	10.9	8.03	50	0.178
VI	a.	Manaloor	0-20	4.0	6.4	1.65	2.84	0.12	0.24	14.20	38.1	43.73	34	0.107
	b.	"	20-40	4.4	7.2	0.58	0.99	0.10	0.14	10.10	30.7	26.78	33	0.087
VII	a.	Thekke Konjira	0-20	4.4	7.2	2.07	3.57	0.06	0.21	11.00	24.6	30.90	50	0.146
	b.	"	20-40	4.0	15.4	1.50	2.59	0.07	0.10	6.75	18.6	17.85	37	0.048

Table 2 contd.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
III a.	Kannothu	0-20	4.2	8.5	1.29	2.22	0.08	0.22	13.00	42.00	33.93	40	0.054
b.	"	20-40	4.0	15.4	0.91	1.57	0.06	0.14	12.40	56.80	33.93	36	0.048
IX a.	Mullaseri	0-20	3.9	5.4	1.28	2.20	0.06	0.17	5.60	13.50	17.85	33	0.139
b.	"	20-40	3.9	6.1	0.96	1.66	0.04	0.13	7.25	47.00	15.15	27	0.129
X a.	Anthikad	0-20	4.1	5.6	2.28	3.93	0.10	0.17	6.50	39.70	21.75	37	0.143
b.	"	20-40	3.9	5.0	0.98	1.69	0.04	0.13	8.85	22.70	21.25	25	0.139
XI a.	Chezhur	0-20	4.0	11.4	1.99	3.43	0.10	0.20	12.50	40.10	30.35	22	0.061
b.	"	20-40	3.4	6.5	0.85	1.47	0.04	0.09	15.50	16.50	66.98	7	0.057
XII a.	Alappādu	0-20	5.4	5.4	0.58	0.99	0.08	0.23	24.60	21.03	18.98	25	0.179
b.	"	20-40	5.1	6.1	0.14	0.24	0.06	0.13	22.10	18.50	23.30	20	0.124
III a.	Pullu	0-20	4.6	21.5	2.16	3.72	0.20	0.30	22.00	44.90	49.65	29	0.158
b.	"	20-40	4.4	18.3	1.51	2.60	0.12	0.19	22.65	56.50	46.78	16	0.095
XIV a.	Pazhuvil	0-20	4.7	11.4	1.86	3.21	0.11	0.27	14.50	22.40	28.23	25	0.126
b.	"	20-40	4.5	12.6	1.43	2.47	0.10	0.18	15.40	50.40	36.78	9	0.076
XV a.	Cherpu	0-20	4.6	18.5	2.58	4.45	0.10	0.17	19.10	69.40	42.85	12	0.098
b.	"	20-40	4.3	21.6	1.46	2.52	0.04	0.12	21.30	19.60	58.95	11	0.071

samples are presented in Table 2. All the soils were acidic in reaction. The pH of the soils ranged between 3.4 and 5.4. The CEC of the soils varied from 5.0 me/100 g of soil in the surface layer of Anthikad to 21.6 me/100 g of soil in the subsurface layer of Cherpu. The organic carbon content of these soils varied between 0.14 percent in the subsurface layer of Alappadu and 2.58 percent in the surface layer of Cherpu. Organic matter content varied between 0.24 percent in the subsurface layer of Alappadu and 4.45 percent in the surface layer of Cherpu. Total nitrogen ranged from 0.04 percent in the subsurface layer of Mullaseri, Anthikad, Chezhur and Cherpu areas to 0.26 percent in the surface layers of Manakkody-Varyam area. Total phosphorus in the soils varied from 0.09 percent in the subsurface layer of Chezhur area to 0.36 percent in the surface layer of Manakkody-Varyam area. The average phosphorus for the surface layer was found to be 0.23 percent and for the subsurface layer it was 0.16 percent. In all locations except Kanjani the total phosphorus decreased with depth. Available phosphorus varied from 7 ppm in the subsurface layer of Chezhur area to 50 ppm in the sublayer of Thekke Konjira and Kanjani area. Available phosphorus also decreased with depth at all locations except in Kanjani. The total calcium oxide content in the soils ranged from 0.048 percent in the subsurface layer of Thekke Konjira and Kannothu areas to 0.270 percent in the subsurface layer of Manakkody-Varyam area. Total sesquioxide content of the soils varied from 2.4 percent in the surface layer of Kanjani to 29.0 percent in the subsurface layer of Manakkody-Varyam area. Total aluminium content of the soils was within a minimum value of 9.7 mg/g in the surface layer of Kanjani location and a maximum of 94.1 mg/g in the surface horizon of Chettupuzha area. Total iron content ranged between 4.48 mg/g in the surface layer of Kanjani area and 74.1 mg/g in the subsurface layer of Manakkody-Varyam.

B. PHOSPHATE STUDIES

(1) Distribution of phosphorus in the Kole soils

(a) Fractionation of native soil phosphorus

The results of fractionation of native soil phosphorus are presented in Table 3 and the proportion of each fraction expressed as percent of total P of the soils studied is given in Table 4.

The data reveal that there is considerable variation in the nature of distribution of various fractions, and that none of these fractions constitutes a fixed proportion of the total P. It is, however note-worthy that of the different forms of inorganic soil phosphorus, iron phosphate constitutes the most predominant fraction in almost all the soils studied. The next largest fraction is that of Red-P followed in order by Ca-P, Al-P, occluded-P and saloid-P. In the surface layers organic-P constituted one of the largest fractions but in the subsurface layers Fe-P constituted the largest portion.

Saloid-P

The saloid-P varied from 3.0 ppm in the subsurface layer of Chezhur to 17.9 ppm in the surface layer of Thekke Konjira with an average of 7.7 ppm.

In the surface samples it varied from 4.2 ppm at Cherpu to 17.9 ppm in the Thekke Konjira soil with an average of 9.2 ppm. In the subsurface soil the variation was from 3.0 ppm in Chezhur soil to 11.5 at Kanjani with an average of 6.1 ppm. The mean percentage contribution of saloid-P to total-P was 0.96 and 0.94 percent respectively in the surface and subsurface layers. Between the surface and subsurface layers there was significant difference in saloid-P content (Appendix 1). Saloid-P was found to be the smallest fraction in these soils.

Al-P

This fraction varied from 6.8 ppm in the subsurface layer of Chettupuzha soil to 71.2 ppm in the surface layer of Chettupuzha region with an average of 28.4 ppm.

In the surface samples it varied from 13.6 ppm in Kanjani to 71.2 ppm in Chettupuzha soil with an average of 35.2 ppm. In the subsurface soils the variation was from 6.8 ppm in Chettupuzha soil to 44.1 ppm in Thekke Konjira soil with an average of 21.5 ppm. The mean percentage contribution of Al-P to total-P was 3.64 and 3.50 respectively in the surface and subsurface layers. Generally this fraction decreased with depth. Statistical analysis showed that between the two depths there was significant difference in the proportion of this fraction (Appendix I).

Fe-P

Fe-P values for all the samples ranged from 137.8 ppm in the subsurface layer at Kanjani to 549.2 ppm in the surface layer of Manakkody-Varyam soil with a mean value of 276.6 ppm. In the surface layers its value varied from 167.6 ppm at Mullaseri location to 549.2 ppm at Manakkody-Varyam with an average of 298.9 ppm. In the subsurface layers Fe-P content ranged between 137.8 ppm in Kanjani area and 447.2 ppm in Manakkody-Varyam with an average of 254.3 ppm. Between the two layers there was significant difference in the Fe-P content (Appendix I). In all the soils Fe-P decreased with depth.

In these soils, the mean contributions of Fe-P to total-P were 29.64 percent and 38.76 percent respectively for the surface and subsurface samples.

Red-P

Red-P varied from a minimum value of 18.3 ppm in subsurface layer of Thekke Konjira location to a maximum value of 443.4 ppm in the surface layer of Manakkody-Varyam with an average of 195.3 ppm.

The surface layer of Kanjani area had the lowest Red-P content of 32.5 ppm while that of Manakkody-Varyam contained the highest amount of 443.4 ppm. The average Red-P content for the surface layer was 240.2 ppm. In the subsurface layers it varied from 18.3 ppm in Thekke Konjira to 253.6 ppm in Kanjani area, the average being 150.4 ppm. The distribution of Red-P decreased with depth at all locations except in Kanjani soil. There was no significant difference for this fraction between the two layers (Appendix I). The extent of contribution of Red-P to total-P was 24.05 and 21.03 percent for the surface and subsurface layers respectively (Table 4).

Occluded-P

The occluded-P ranged between 5.6 ppm in the subsurface

Table 3 Fractionation of native soil phosphorus (ppm)

No.	Location	Depth cm	Total-P	Saloid-P	Al-P	Fe-P	Red-P	Occluded-P	Ca-P	Organic P
1	2	3	4	5	6	7	8	9	10	11
I a.	Chettupuzha	0-20	1493.8	11.4	71.2	487.6	225.5	20.4	122.5	555.2
b.	"	20-40	1045.6	9.4	6.8	391.4	63.9	5.6	195.0	373.5
II a.	Manakkody-Varyam	0-20	1572.0	8.0	44.1	549.2	443.4	23.1	120.8	383.4
b.	"	20-40	870.5	4.4	33.7	447.2	50.4	11.6	190.8	132.4
III a.	Manakkody-Anjumuri	0-20	828.5	6.5	30.5	309.6	56.5	19.0	53.3	353.1
b.	"	20-40	698.8	5.5	25.9	280.2	109.3	8.0	83.3	186.6
IV a.	Eravu	0-20	1048.5	9.3	42.2	349.3	288.9	16.4	23.8	318.6
b.	"	20-40	690.3	7.1	32.7	251.5	225.2	7.8	38.5	127.5
V a.	Kanjani	0-20	627.7	6.1	13.6	168.9	32.5	17.9	15.0	373.7
b.	"	20-40	998.2	11.5	9.6	137.8	253.6	15.0	27.5	543.2
VI a.	Manaloor	0-20	1033.3	11.8	23.9	358.5	303.6	18.4	38.8	278.5
b.	"	20-40	616.3	4.7	20.9	303.5	135.7	13.3	27.3	110.9
VII a.	Thekke Konjira	0-20	920.5	17.9	68.7	267.3	287.5	13.9	52.3	212.9
b.	"	20-40	446.3	9.3	44.1	236.2	18.3	11.1	17.0	110.3

Table 3 contd.

1	2	3	4	5	6	7	8	9	10	11
VIII a.	Kannothu	0-20	970.5	10.4	25.5	295.2	361.3	16.2	17.8	244.1
b.	"	20-40	601.1	4.9	21.8	158.5	278.8	7.6	7.5	122.0
IX a.	Mullaseri	0-20	724.1	11.1	48.3	167.6	184.3	14.2	14.0	284.6
b.	"	20-40	549.5	3.9	8.4	187.8	167.8	7.6	7.0	167.0
X a.	Anthikad	0-20	759.9	12.1	32.5	170.3	228.0	6.4	39.8	270.8
b.	"	20-40	549.9	6.6	20.7	150.8	166.2	7.3	42.1	156.2
XI a.	Chezhur	0-20	853.9	7.1	24.7	272.9	194.5	15.8	8.3	330.6
b.	"	20-40	423.3	3.0	21.5	208.2	52.6	11.1	6.2	120.7
XII a.	Alappadu	0-20	986.9	7.6	16.0	259.8	432.2	33.3	19.3	218.7
b.	"	20-40	559.9	6.2	9.4	235.5	142.5	19.8	32.3	114.2
XIII a.	Pullu	0-20	1313.8	9.6	23.2	320.5	258.4	21.6	49.3	631.2
b.	"	20-40	808.7	8.5	21.4	220.1	255.0	7.6	33.8	262.3
XIV a.	Pazhuvil	0-20	1183.9	5.5	20.2	209.4	276.3	14.4	29.0	629.1
b.	"	20-40	792.9	3.1	16.0	268.6	250.2	8.9	22.5	223.6
XV a.	Cherpu	0-20	752.9	4.2	43.7	296.5	130.3	22.4	21.5	234.3
b.	"	20-40	530.3	3.1	29.6	268.6	86.6	10.8	10.8	120.8
Surface mean				9.2	35.2	298.9	240.2	18.2	41.7	354.6
Subsurface mean				6.1	21.5	254.3	150.4	10.2	48.1	184.8

Table 4 Fractionation of native soil phosphorus (percent of total P)

No.	Location	Depth cm	Saloid-P	Al-P	Fe-P	Red-P	Occluded-P	Ca-P	Organic-P
1	2	3	4	5	6	7	8	9	10
I a.	Chettupuzha	0-20	0.76	4.76	32.63	15.09	1.37	8.2	37.15
b.	"	20-40	0.89	0.65	37.43	6.12	0.53	18.65	35.72
II a.	Manakkody-Varyam	0-20	0.51	2.80	34.94	28.20	1.47	7.69	24.39
b.	"	20-40	0.50	3.88	51.37	5.78	1.33	21.92	15.21
III a.	Manakkody (Anjumuri)	0-20	0.78	3.68	37.37	6.82	2.29	6.44	42.62
b.	"	20-40	0.78	3.71	40.09	15.64	1.14	11.93	26.82
IV a.	Eravu	0-20	0.89	4.03	33.32	27.55	1.57	2.26	30.38
b.	"	20-40	1.03	4.74	36.44	32.63	1.12	5.58	18.47
V a.	Kanjani	0-20	0.97	2.17	26.92	5.19	2.85	2.39	59.52
b.	"	20-40	1.44	1.19	17.27	6.71	1.88	3.45	68.06
VI a.	Manaloor	0-20	1.14	2.31	34.69	29.28	1.78	3.75	26.95
b.	"	20-40	0.77	3.40	49.25	22.02	2.15	4.42	17.98
VII a.	Thekke Konjira	0-20	1.95	7.46	29.04	31.24	1.51	5.68	23.13
b.	"	20-40	2.08	9.88	52.92	4.15	2.49	3.81	24.71

Table 4 contd.

1	2	3	4	5	6	7	8	9	10
VIII a.	Kannothu	0-20	1.07	2.62	30.62	37.23	1.67	1.83	25.17
b.	"	20-40	0.82	3.63	26.37	46.38	1.26	1.25	20.29
IX a.	Mullaseri	0-20	1.53	6.67	23.14	23.17	1.96	1.93	39.31
b.	"	20-40	0.70	1.52	34.18	30.54	1.38	1.27	30.40
X a.	Anthikad	0-20	1.59	4.28	22.41	30.00	0.85	5.23	35.63
b.	"	20-40	1.19	3.77	27.42	30.22	1.33	7.65	28.62
XI a.	Chezhur	0-20	0.83	2.89	31.96	22.78	1.85	0.97	38.72
b.	"	20-40	0.72	5.07	49.19	12.42	2.62	1.46	28.51
XII a.	Alappadu	0-20	0.77	1.62	26.33	43.79	3.38	1.95	22.15
b.	"	20-40	1.11	1.67	42.06	25.45	3.53	5.76	20.44
XIII a.	Pullu	0-20	0.73	1.77	24.51	19.67	1.64	3.73	48.05
b.	"	20-40	1.18	2.64	27.22	31.53	0.93	4.17	32.45
XIV a.	Pazhuvil	0-20	0.46	1.71	17.69	23.34	1.23	2.46	53.13
b.	"	20-40	0.39	2.02	33.87	31.55	1.12	2.84	15.59
XV a.	Cherpu	0-20	0.56	5.81	39.38	17.31	2.98	2.86	31.11
b.	"	20-40	0.52	4.94	56.39	14.47	1.71	1.79	20.19
Surface mean			0.96	3.64	29.64	24.05	1.89	4.84	35.83
Subsurface mean			0.94	3.50	38.76	21.03	2.00	5.19	26.88

layer of Chettupuzha and 33.3 ppm in the surface layer of Alappadu area with an average of 14.2 ppm.

In the surface layers the occluded-P content varied from 6.4 in Anthikad to 33.3 ppm at Alappadu with an average of 18.2 ppm. Its content in the subsurface layers ranged from 5.6 at Chettupuzha to 19.8 ppm at Alappadu, the average being 10.2 ppm. Between the two depths there was significant difference in occluded-P. In general in most soils occluded-P decreased with depth; and the mean percentage contribution of this fraction to total-P in these soils was 1.89 and 2.00 respectively for the surface and subsurface layers.

Ca-P

The Ca-P content ranged between 6.2 ppm in the subsurface layer at Chezhur area and 195.0 ppm in the subsurface layer of Chettupuzha location with an average of 44.9 ppm.

In the surface layers its value varied from 8.3 ppm in Chezhur to 122.5 ppm in Chettupuzha location with an average of 41.7 ppm. In the subsurface soils it ranged between 6.2 ppm in Chezhur and 195.0 ppm in Chettupuzha area with an average of 48.1 ppm. At most locations this fraction decreased with depth but in some places it increased with depth. Between the two depths there was no significant difference in the value of this fraction (Appendix I). The average contribution of Ca-P to total-P was 4.80 and 5.20 percent for the surface and subsurface soils respectively.

Organic-P

Organic-P in the soils varied between a minimum of 110.3 ppm in subsurface layer of Thekke Konjira and a maximum of 555.2 ppm in surface layer of Chettupuzha with an average of 269.7 ppm.

In the surface layer the variation was between a minimum of 212.9 ppm at Thekke Konjira and a maximum of 555.2 ppm at Chettupuzha. The average value for the surface was 354.6 ppm. In the subsurface layers it ranged between 110.3 ppm in the Thekke Konjira area and 543.2 ppm in the Kanjani area with an average of 184.8 ppm. The 't' test indicated a significant difference between the surface and subsurface layers for this fraction (Appendix I). At all locations except Kanjani area, organic-P decreased with depth. The average contribution of organic-P to total-P was 35.83 and 26.88 percent for the surface and subsurface soils respectively.

II. Fixation and availability of phosphorus

(a) Phosphorus fixing capacity

In Table 5 the details relating to the phosphorus

Table 5 Phosphorus fixing capacity (percent)

Locations	Depth	
	0-20 cm	20-40 cm
Chettupuzha	73	66
Manakkody-Varyam	73	80
Manakkody-Anjumuri	45	51
Eravu	63	68
Kanjani	55	28
Manaloor	78	68
Thekke Konjira	69	77
Kannothu	78	75
Mullaseri	48	50
Anthikad	34	42
Chezhur	68	80
Alappadu	15	23
Pullu	72	78
Pazhuvil	65	77
Cherpu	80	88
Mean	61.07	63.40

fixing capacity of soils are presented. The minimum and maximum values for phosphorus fixing capacity in the soils examined were 15 and 88 percent. The lowest value was observed in the surface sample of the soil at Alappadu and the highest value was registered in the subsurface layer of the soil at Cherpu. In the top surface layer the value ranged between 15 percent at Alappadu and 80 percent at Chezhur with an average of 61.07 percent. In the subsurface layer this value ranged from 23 percent at Alappadu to 88 percent at Cherpu with a mean value of 63.40 percent.

The phosphorus fixing capacity of 30 samples of soil belonging to the Kole soils of Kerala was determined and to bring out the difference in phosphorus fixing capacity with depth, a paired 't' test was conducted (Appendix I). Simple correlation and regression studies were made to find out the nature and degree of association of various soil characteristics with phosphorus fixing capacity. The 't' test showed no significant variation in phosphorus fixing capacity between the two depths.

(b) Relative amounts of added P reverted to different chemical forms of soil P

The results of fractionation after application of KH_2PO_4 at the rate of 40 mg P_2O_5/100 g soil (174.7 ppm of P) are given in Tables 6 and 7. The data reveal that in surface soil the maximum recovery as saloid-P (71.61 percent) took place in the Kanjani area and the minimum recovery of 23.41 percent took place at Alappadu with an average of 37.39 percent. In the subsurface samples the maximum recovery as saloid-P (48.48 percent) took place at Kanjani and the minimum recovery of 14.65 percent took place in the soil from Chezhur with an average of 27.64 percent.

Next to saloid-P, the percentage recovery of added P was in the form of Al-P. In the case of the surface soil samples the maximum recovery (40.07 percent) took place in the soil from Chettupuzha and minimum recovery (12.14 percent) in the soils from Kanjani with an average of 30.63. In the case of the subsurface soil samples a maximum reversion of 32.51 percent and a minimum reversion of 15.57 percent was noted at Thekke Konjira and Kanjani respectively with an average of 27.13 percent.

Reversion of added P to Fe-P varied from 8.41 percent to 33.03 percent in the soil from Chezhur and Cherpu respectively within a mean value of 17.53 percent in the case of surface soil samples. For the same fraction percentage conversion in the subsurface samples ranged between 17.34 percent at Thekke Konjira and 33.03 percent at Cherpu with an average of 23.19 percent.

Table 6 Fractionation of soil phosphorus after treatment (ppm)

No.	Location	Depth cm	Total-P	Saloid-P	Al-P	Fe-P	Red-P	Occluded-P	Ca-P	Organic-P
1	2	3	4	5	6	7	8	9	10	11
I a.	Chettupuzha	0-20	1668.5	77.6	141.2	510.6	232.6	28.8	122.6	555.1
b.	"	20-40	1220.3	75.7	49.6	423.5	88.7	14.2	195.2	373.4
II a.	Manakkody-Varyam	0-20	1746.7	61.0	102.4	580.1	466.5	32.4	120.9	383.4
b.	"	20-40	1045.2	48.6	86.2	490.3	76.0	20.9	190.8	132.4
III a.	Manakkody-Anjumuri	0-20	1003.2	68.5	87.2	343.3	72.0	25.2	54.2	352.8
b.	"	20-40	873.5	56.1	74.7	319.1	131.6	22.1	83.4	186.5
IV a.	Eravu	0-20	1223.2	76.6	100.4	382.5	300.2	21.1	23.9	318.5
b.	"	20-40	865.0	69.8	89.3	293.5	237.2	9.5	38.5	127.2
V a.	Kanjani	0-20	802.4	131.2	34.8	184.5	37.9	25.1	15.3	373.6
b.	"	20-40	1172.9	96.2	36.8	168.9	283.7	16.6	27.5	543.2
VI a.	Manaloor	0-20	1208.2	85.8	71.7	385.7	322.5	25.6	39.0	277.9
b.	"	20-40	791.0	64.1	67.4	336.5	160.9	24.3	27.3	110.5
VII a.	Thekke Konjira	0-20	1095.2	98.5	128.7	288.6	296.5	17.6	52.4	212.9
b.	"	20-40	621.0	71.7	100.9	266.5	36.9	17.7	17.0	110.3

Table 6 contd.

1	2	3	4	5	6	7	8	9	10	11
VIII a.	Kannothu	0-20	1145.2	84.1	66.5	324.1	385.3	22.7	18.4	244.1
b.	"	20-40	775.8	43.8	59.8	199.1	324.7	18.5	7.9	122.0
IX a.	Mullaseri	0-20	898.8	80.2	103.4	184.6	211.7	19.9	14.4	284.6
b.	"	20-40	724.2	35.8	54.9	231.1	208.3	20.1	7.4	166.6
X a.	Anthikad	0-20	934.6	87.4	82.0	187.9	258.0	9.0	39.9	270.4
b.	"	20-40	724.6	57.9	62.9	181.6	205.2	18.7	42.1	156.2
XI a.	Chezhur	0-20	1028.6	55.9	82.4	287.6	241.9	21.9	8.4	330.5
b.	"	20-40	598.0	28.6	74.4	240.9	98.6	28.4	6.5	120.6
XII a.	Alappadu	0-20	1161.6	48.5	75.6	303.9	449.1	46.7	19.5	218.3
b.	"	20-40	734.6	42.1	47.8	284.9	170.6	42.7	32.3	114.2
XIII a.	Pullu	0-20	1488.5	65.4	80.4	369.2	263.1	30.0	49.4	631.0
b.	"	20-40	983.4	52.6	76.2	271.5	267.5	19.5	33.8	262.3
XIV a.	Pazhuvil	0-20	1358.6	49.6	76.0	257.2	297.4	20.2	29.2	629.0
b.	"	20-40	967.6	36.3	71.5	319.8	271.8	22.8	22.6	223.6
XV a.	Cherpu	0-20	927.6	48.2	98.3	352.1	141.7	31.4	21.7	234.2
b.	"	20-40	705.0	36.3	80.7	326.3	107.6	22.5	10.9	120.7

Table 7 Increase in phosphorus in different fractions due to treatment (percent)

No.	Location	Depth cm	Saloid-P	Al-P	Fe-P	Red-P	Occluded-P	Ca-P	Organic-P
1	2	3	4	5	6	7	8	9	10
I a.	Chettupuzha	0-20	37.89	40.07	13.17	4.06	4.81	0.05	-0.05
b.	"	20-40	37.95	24.50	18.37	14.20	4.92	0.11	-0.05
II a.	Manakkody-Varyam	0-20	30.34	33.37	17.70	13.22	5.32	0.05	0
b.	"	20-40	25.30	30.05	24.68	14.65	5.32	0	0
III a.	Manakkody-Anjumuri	0-20	35.48	32.46	19.29	8.87	3.55	0.52	-0.17
b.	"	20-40	28.96	27.93	22.27	12.76	8.07	0.06	-0.06
IV a.	Eravu	0-20	38.52	33.31	19.00	6.47	2.69	0.06	-0.06
b.	"	20-40	35.89	32.40	24.04	6.87	0.97	0	-0.17
V a.	Kanjani	0-20	71.61	12.14	8.93	3.09	4.12	0.17	-0.06
b.	"	20-40	48.48	15.57	17.80	17.23	0.92	0	0
VI a.	Manaloor	0-20	42.36	27.36	15.57	10.82	4.12	0.11	-0.34
b.	"	20-40	34.00	26.62	18.89	14.42	6.30	0	-0.23
VII a.	Thekke Konjira	0-20	46.14	34.34	12.19	5.15	2.12	0.06	0
b.	"	20-40	35.72	32.51	17.34	10.65	3.78	0	0

Table 7 contd.

1		2	3	4	5	6	7	8	9	10
VIII	a.	Kannothu	0-20	42.20	23.47	16.54	13.74	3.72	0.33	0
	b.	"	20-40	22.27	21.75	23.24	26.27	6.24	0.23	0
IX	a.	Mullaseri	0-20	39.56	31.54	9.73	15.68	3.26	0.23	0
	b.	"	20-40	18.26	26.62	24.79	23.18	7.16	0.23	¯0.23
X	a.	Anthikad	0-20	43.10	28.33	10.07	17.17	1.49	0.06	¯0.23
	b.	"	20-40	29.36	24.16	17.63	22.32	6.53	0	0
XI	a.	Chezhur	0-20	27.93	33.03	8.41	27.14	3.49	0.06	¯0.06
	b.	"	20-40	14.65	30.28	18.73	26.33	9.90	0.17	¯0.06
XII	a.	Alappadu	0-20	23.41	34.12	25.24	9.67	7.68	0.11	¯0.23
	b.	"	20-40	20.55	21.98	28.28	16.08	13.11	0	0
XIII	a.	Pullu	0-20	31.94	32.74	27.88	2.69	4.80	0.06	¯0.11
	b.	"	20-40	25.24	31.37	29.42	7.16	6.81	0	0
XIV	a.	Pazhuvil	0-20	25.24	31.94	27.36	12.08	3.32	0.11	¯0.06
	b.	"	20-40	19.00	31.77	29.30	11.91	7.96	0.06	0
XV	a.	Cherpu	0-20	25.19	31.25	31.83	6.53	5.15	0.11	¯0.06
	b.	"	20-40	19.00	29.25	33.03	12.02	6.70	0.06	¯0.06
		Surface mean		37.39	30.63	17.53	10.43	3.98	0.14	¯0.13
		Subsurface mean		27.64	27.13	23.19	15.74	6.31	0.12	¯0.12

Fixation of added phosphate in the form of Red-P was also quite considerable and it ranged from 2.69 percent in the soil from Pullu to 27.14 percent at Chezhur with a mean value of 10.43 percent in the case of surface soil samples. In the case of the subsurface samples the percentage reversion to this form varied from 6.87 percent in the soil from Eravu to 26.33 percent at Chezhur with an average value of 15.74 percent.

Only a small portion of added P was converted to occluded-P and it varied from 1.49 percent in the soil from Anthikad to 7.68 percent at Alappadu with an average of 3.98 percent in the case of surface soil samples. In the subsurface soil samples the percentage reversion varied from 0.92 percent in the soil from Kanjani to 13.11 percent at Alappadu with an average of 6.31 percent.

Only a very small proportion of added P was converted to Ca-P forms of soil while organic-P form show a slight decrease. It appeared that a small part of organic-P got mineralized to inorganic forms consequent on treatment.

c) <u>Availability of added phosphatic fertilizers</u>

The results of the experiment on the availability of superphosphate and Mussoorie rockphosphate in the <u>Kole</u> soils are presented in Tables 8(a) to 8(c).

Change in the available P_2O_5 at different intervals due to superphosphate treatment is shown in the Table 8(a). The data reveal that the maximum accumulation of available P_2O_5 was on the 7th day of incubation. For this period of incubation, the value varied from 17.3 mg P_2O_5/100 g of soil at Manakkody-Varyam to 43.6 mg P_2O_5/100 g of soil at Kanjani with an average of 23.1 mg P_2O_5/100 g of soil. The mean values of the available phosphorus for the eight periods at different localities ranged from 12.8 mg P_2O_5/100 g of soil at Pullu to 29.6 mg P_2O_5/100 g soil at Kanjani with an average of 17.7 mg P_2O_5/100 g of soil.

The data further show that there was significant increase in available P_2O_5 due to superphosphate treatment. The mean values of available P_2O_5 for the 15 locations for different periods were 19.0, 21.2, 23.1, 18.9, 16.9, 14.6, 14.0 and 13.9 mg P_2O_5/100 g of soil with an average of 17.7 mg of P_2O_5/100 g of soil.

Change in available P_2O_5 due to Mussoorie rockphosphate treatment in these soils at different intervals are given in Table 8(b), the data reveal that the maximum accumulation of the available P_2O_5 was on the 28th day of incubation. For this period of incubation the value varied from 16.1 mg P_2O_5/100 g of soil at Pullu and Manakkody-Varyam to 33.1 mg P_2O_5/100 g of soil at Kanjani with an average of 21.0 mg

Table 8(a) Change in available phosphate with time due to superphosphate treatment

P_2O_5/100 g of soil (mg)

Location	Periods								Mean
	1 hour	1 day	7 days	14 days	28 days	42 days	56 days	70 days	
Chettupuzha	17.6	19.1	22.6	19.6	18.3	14.1	13.4	13.3	17.2
Manakkody-Varyam	12.1	15.3	17.3	16.1	13.9	11.2	11.1	11.0	13.5
Manakkody-Anjumuri	17.0	20.5	22.4	19.5	17.8	16.3	14.4	14.1	17.8
Eravu	16.4	19.4	21.5	19.2	17.6	15.4	14.1	14.1	17.2
Kanjani	38.7	41.3	43.6	25.0	23.5	21.6	21.4	21.3	29.6
Manaloor	14.3	19.4	20.7	18.9	17.7	14.8	14.2	14.2	16.8
Thekke Konjira	18.7	20.5	21.4	19.1	17.6	15.2	14.9	14.3	17.8
Kannothu	17.0	17.6	18.8	16.6	15.6	13.3	13.3	13.2	15.6
Mullaseri	28.7	30.8	31.8	25.9	20.9	17.5	16.6	16.5	23.6
Anthikad	25.6	26.0	28.6	23.1	20.7	16.2	17.0	17.0	22.0
Chezhur	18.5	20.8	20.9	17.3	14.0	12.0	12.0	12.1	15.9
Alappadu	16.9	19.31	20.7	17.0	15.2	14.2	14.1	14.1	16.5
Pullu	12.1	14.1	17.5	14.4	12.4	11.2	10.4	10.3	12.8
Pazhuvil	14.9	16.2	19.5	16.8	14.4	11.8	11.6	11.6	14.6
Cherpu	16.9	17.9	19.6	16.4	14.4	12.4	11.3	11.3	15.0
Mean	19.0	21.2	23.1	18.9	16.9	14.6	13.9	13.9	17.7

Table 8(b) Change in available phosphate with time due to Mussoorie phosphate treatment P_2O_5/100 g soil (mg)

Locations	Periods								Mean
	1 hour	1 day	7 days	14 days	28 days	42 days	56 days	70 days	
Chettupuzha	10.1	12.6	15.7	19.7	19.9	16.8	15.1	15.1	15.6
Manakkody-Varyam	9.6	11.5	14.8	15.1	16.1	13.1	12.1	12.0	13.0
Manakkody-Anjumuri	12.5	14.8	17.1	19.9	20.0	16.1	14.1	14.1	16.1
Eravu	10.9	13.9	16.1	17.6	19.9	14.2	13.5	13.5	14.9
Kanjani	26.6	29.7	32.8	33.8	33.1	30.3	28.2	28.0	30.3
Manaloor	9.2	13.2	17.9	20.9	20.0	17.8	14.6	14.6	16.0
Thekke Konjira	10.1	12.6	16.6	21.4	21.5	16.7	16.5	16.4	16.5
Kannothu	9.5	12.5	16.5	18.2	19.1	15.1	14.5	14.2	14.9
Mullaseri	24.5	26.2	27.8	29.6	27.9	21.3	17.1	17.0	23.9
Anthikad	17.2	19.4	23.5	24.5	25.5	23.2	18.1	18.0	21.2
Chezhur	9.7	12.7	16.0	19.6	21.1	19.3	14.3	14.2	15.9
Alappadu	7.9	10.1	13.0	15.1	18.8	15.8	12.3	12.3	13.2
Pullu	8.0	10.7	18.1	15.2	16.1	14.6	12.3	12.2	13.4
Pazhuvil	8.7	11.5	13.9	17.9	17.9	14.4	12.8	12.5	13.7
Cherpu	9.6	12.6	15.7	17.9	18.0	15.0	13.4	13.4	14.5
Mean	12.3	14.9	18.4	20.4	21.0	17.6	15.3	15.2	16.9

Table 8(c) Change in available phosphate with time without any treatment

P_2O_5/100 g of soil (mg)

Location	Periods								Mean
	1 hour	1 day	7 days	14 days	28 days	42 days	56 days	70 days	
Chettupuzha	3.3	3.5	5.7	5.9	5.0	3.6	3.5	3.5	4.3
Manakkody-Varyam	2.6	3.1	3.7	4.0	3.5	2.2	2.0	2.0	2.9
Manakkody-Anjumuri	2.0	2.3	3.1	3.5	2.8	2.0	2.0	2.0	2.5
Eravu	2.9	3.6	4.3	3.9	3.6	3.2	3.2	3.1	3.5
Kanjani	2.0	2.3	3.2	3.1	3.0	2.9	2.4	2.3	2.7
Manaloor	3.4	4.1	4.9	3.4	3.1	3.0	3.2	3.2	3.6
Thekke Konjira	5.0	6.6	6.9	6.5	5.2	5.2	5.2	5.1	5.1
Kannothu	4.2	4.9	5.0	5.0	4.9	4.5	4.3	4.3	4.7
Mullaseri	3.4	4.8	3.0	4.3	4.2	3.9	2.5	3.5	4.1
Anthikad	3.9	4.8	5.3	5.6	4.1	4.0	4.0	4.0	4.5
Chezhur	2.5	3.4	3.8	4.0	3.2	2.1	2.0	2.0	2.9
Alappadu	2.8	3.3	4.4	4.5	4.1	3.1	3.0	3.0	3.5
Pullu	3.1	4.0	4.2	4.9	3.1	3.1	3.1	3.1	3.6
Pazhuvil	2.9	3.3	4.9	4.4	3.1	2.9	2.7	2.7	3.4
Cherpu	1.5	1.9	2.1	2.3	1.9	1.6	1.5	1.5	1.5
Mean	3.0	3.7	4.5	4.4	3.7	3.2	3.1	3.0	3.6

P_2O_5/100 g of soil. The mean value of the available P_2O_5 for the eight periods at the different locations ranged from 13.0 mg P_2O_5/100 g of soil at Manakkody-Varyam to 30.3 mg P_2O_5/100 g of soil at Kanjani with an average of 16.9 mg P_2O_5/100 g of soil.

The data also showed that there was significant increase in available P due to the Mussoorie rockphosphate treatment. The mean values of available phosphorus for the 15 locations at different periods were 12.3, 14.9, 18.4, 20.4, 21.0, 17.6, 15.3 and 15.2 mg P_2O_5/100 g of soil with an average of 16.9 mg P_2O_5/100 g of soil.

There was no significant variation in the native available P_2O_5 due to incubation. There was significant difference in available P_2O_5 due to the two treatments over control. However there was no significant difference between the two treatments (Appendix II).

d) Relative amounts of native phosphorus in clay and silt

The data on the analysis of total native phosphorus associated with clay and silt fractions are given in Table 9.

The amount of native P_2O_5 associated with the clay and silt in the *Kole* soils varied from 645 ppm in silt fraction of the subsurface layer of the soil at Cherpu to 22701 ppm in the clay fraction of the surface soil at Eravu. The amount of P_2O_5 in the clay fraction alone ranged from 2036 ppm in the subsurface layer at Cherpu to 22701 ppm in the surface layer at Eravu. In the surface layers the amount of P_2O_5 in the clay fraction ranged from 2204 ppm at Cherpu to 22701 ppm in the soil from Eravu with an average of 9509 ppm. In the subsurface layers this value ranged from 2036 ppm at Cherpu to 9904 ppm in the soil from Kannothu with an average of 4563 ppm.

A perusal of the data in Table 9 reveal that the amount of P_2O_5 in the clay decreases markedly with depth. The 't' test showed that there was significant difference in the amounts of native phosphorus associated with clay in the two layers (Appendix III a).

The amount of native P_2O_5 associated with the silt varied from 645 ppm in the subsurface layer of Cherpu to 3373 ppm in the subsurface layer of Kanjani. In the surface layer samples this value ranged between 1097 ppm at Alappadu and 2540 ppm at Manaloor with a mean value of 1738 ppm. In the subsurface layer the variation was from 645 ppm in the soil from Cherpu to 3373 ppm in the soil from Kanjani with an average of 1364 ppm.

The data in Table 9 show that the amount of P_2O_5 in

Table 9 Amount of total native phosphorus in clay and silt

No.	Location	Depth cm	Clay %	Amount of P_2O_5 in clay ppm	F value (clay)	Silt %	Amount of P_2O_5 in silt ppm	F value (silt)
1	2	3	4	5	6	7	8	9
I a.	Chettupuzha	0-20	42.9	4834	2073	38.3	1518	581
b.	"	20-40	29.2	4009	1170	47.0	815	383
II a.	Manakkody-Varyam	0-20	47.8	4586	2192	39.2	1836	719
b.	"	20-40	58.9	1759	1036	32.5	1165	376
III a.	Manakkody-Anjumuri	0-20	3.5	9757	341	22.2	2051	455
b.	"	20-40	5.0	5760	288	15.0	1386	208
IV a.	Eravu	0-20	5.5	22701	1248	26.0	2216	576
b.	"	20-40	27.0	3630	980	14.2	1669	237
V a.	Kanjani	0-20	2.5	17248	431	5.6	2053	114
b.	"	20-40	7.0	9137	639	6.5	3373	219
VI a.	Manaloor	0-20	8.0	15675	1254	32.6	2540	828
b.	"	20-40	16.7	3549	592	21.8	2279	496
VII a.	Thekke Konjira	0-20	23.7	6551	1552	20.0	1475	295
b.	"	20-40	26.4	2632	695	6.0	1533	92

Table 9 contd.

1	2	3	4	5	6	7	8	9
VIII a.	Kannothu	0-20	9.0	10592	953	33.4	1929	644
b.	"	20-40	5.7	9904	564	40.9	1279	523
IX a.	Mullaseri	0-20	2.7	12835	346	30.8	1561	408
b.	"	20-40	6.3	3430	216	18.0	1052	189
X a.	Anthikad	0-20	7.7	9011	694	26.3	1588	417
b.	"	20-40	5.5	7491	412	16.3	1622	264
XI a.	Chezhur	0-20	25.7	4412	1134	27.5	1564	430
b.	"	20-40	12.6	3230	407	42.0	646	271
XII a.	Alappadu	0-20	2.4	14124	338	14.0	1097	153
b.	"	20-40	3.7	6930	256	24.7	1245	307
XIII a.	Pullu	0-20	70.0	3094	2166	15.0	1404	210
b.	"	20-40	56.0	2281	1277	31.7	876	277
XIV a.	Pazhuvil	0-20	33.6	5002	1680	22.4	2178	487
b.	"	20-40	34.0	2670	907	26.8	880	232
XV a.	Cherpu	0-20	42.3	2204	932	22.9	1054	241
b.	"	20-40	35.6	2036	735	27.6	645	178
	Surface mean			9509	1156		1738	437
	Subsurface mean			4563	678		1364	283

the silt decreases with depth. But 't' test showed that there was no significant difference in the amount of phosphate associated with the silt fractions between the two layers (Appendix III a).

(e) Added phosphate retained by clay and silt

Data relating to the amounts of added phosphate retained by clay and silt in the *Kole* soils of Kerala ranged from 1247 ppm in silt fraction of the subsurface layer of the soil at Cherpu to 37622 ppm in clay fraction of the surface layer of the soil at Eravu (Table 10).

The amount of added phosphate retained by clay alone ranged from 3099 ppm in the subsurface layer of the soil at Manakkody-Varyam to 37622 ppm in the surface layer of the soil at Eravu. In the surface layer soil it varied from 4075 ppm at Cherpu to 37622 ppm at Eravu with an average of 17299 ppm. In the subsurface layers the value ranged from 3099 ppm in the soil from Manakkody-Varyam to 17055 ppm in the soil from Kannothu with an average of 9115 ppm statistical analysis showed that ($t = 2.76$) there is significant difference for P retention between the clays of the surface and subsurface layers (Appendix III a).

Total P_2O_5 retained by the silt fraction ranged from

Table 10 Added phosphate retained by clay and silt

No.	Location	Depth cm	Clay %	Silt %	Amount of P_2O_5 in clay ppm	Amount of P_2O_5 in silt ppm
1	2	3	4	5	6	7
I a.	Chettupuzha	0-20	42.9	38.3	7308	2424
b.	"	20-40	29.2	47.0	6637	1427
II a.	Manakkody-Varyam	0-20	47.8	39.2	6928	2898
b.	"	20-40	58.9	32.5	3099	3247
III a.	Manakkody-Anjumuri	0-20	3.5	22.2	21853	3819
b.	"	20-40	5.0	15.0	12897	3467
IV a.	Eravu	0-20	5.5	26.0	37622	3662
b.	"	20-40	2.7	14.2	6933	3271
V a.	Kanjani	0-20	2.5	5.6	37047	3917
b.	"	20-40	7.0	6.5	16157	6090
VI a.	Manaloor	0-20	8.0	32.6	26508	4460
b.	"	20-40	16.7	21.8	7233	2765
VII a.	Thekke Konjira	0-20	23.7	20.0	11211	2175
b.	"	20-40	26.4	6.0	6173	3707

Table 10 contd.

1	2	3	4	5	6	7
VIII a.	Kannothu	0-20	9.0	33.4	18330	3453
b.	"	20-40	5.7	40.9	17055	1627
IX a.	Mullaseri	0-20	2.7	30.8	24612	3020
b.	"	20-40	6.3	18.0	8601	2333
X a.	Anthikad	0-20	7.7	26.3	18042	3021
b.	"	20-40	5.5	16.3	16101	3187
XI a.	Chezhur	0-20	25.7	27.5	7912	2908
b.	"	20-40	12.6	42.0	7835	1317
XII a.	Alappadu	0-20	2.4	14.0	25196	3436
b.	"	20-40	3.7	24.7	15049	2586
XIII a.	Pullu	0-20	70.0	15.0	4824	2300
b.	"	20-40	56.0	31.7	4111	1659
XIV a.	Pazhuvil	0-20	33.6	22.4	8012	3502
b.	"	20-40	34.0	26.8	4927	1670
XV a.	Cherpu	0-20	42.3	22.9	4075	2046
b.	"	20-40	35.6	27.6	3921	1247
	Surface mean				17299	3136
	Subsurface mean				9115	2573

1247 ppm in the subsurface soil at Cherpu to 6090 ppm in the subsurface soil at Kanjani. In the surface layer it varied from 2046 ppm in the soil from Cherpu to 4460 ppm in the soil from Manaloor with an average of 3136 ppm. In the subsurface soils it varied from 1247 ppm in the soil at Cherpu to 6090 ppm in the soil at Kanjani with an average of 2573 ppm. There was no significant difference between the phosphorus retention characters of the silt fraction of the surface and subsurface samples ($t = 1.18$, Appendix III a).

The relative phosphorus fixing capacities of the silt and clay were tested by the 't' test and it was found that there was significant difference between clay and silt for this character. The clay retained more phosphorus than silt (Appendix III b).

DISCUSSION

DISCUSSION

The present study was carried out in the soils of the Kole area of Kerala with a view to studying the distribution, fixation and availability of phosphorus. A knowledge of the amount and chemical nature of the phosphorus compounds present in a soil is a prerequisite for understanding and interpreting the behaviour of added phosphorus in the soil. The present investigation was therefore, undertaken to study the distribution of different forms of phosphorus in the soil, fixation and availability of phosphorus and availability of added phosphate fertilizers in the Kole soils of Kerala in relation to their physico-chemical properties.

Fifteen representative localities were identified in the Kole lands of Trichur district. Both surface and subsurface samples were collected from depths of 0-20 cm and 20-40 cm. The texture of soils varied from sand to clay, but most of them were sandy loams. Silt fraction in these soils varied from 5.6 to 47.0 percent in the two layers of these soils. The clay content ranged between 2.4 and 70.0 percent. All soils were acidic in reaction, the pH of the soils ranging between 3.4 and 5.4. The organic carbon content of these soils varied between 0.14 and 2.58 percent. Total nitrogen varied from 0.04 to 0.26 percent. Total calcium oxide content in the soils ranged from 0.048 to 0.270 percent, and the total sesquioxide content varied from 2.4 to 29.0 percent. Total aluminium was within a minimum value of 9.7 mg/g and a maximum of 94.1 mg/g and total iron ranged between 4.48 and 74.10 mg/g. The results of the studies are discussed in relation to these soil parameters.

PHOSPHATE STUDIES

1. Distribution of phosphorus in the Kole soils

(a) Fractionation of native soil phosphorus

Soil test values for available phosphorus give a broad indication of the need for applying phosphorus but this information alone is not adequate for this purpose. A knowledge of the amount and chemical nature of the various fractions of P in the soil and the conditions under which they become available to plants is a prerequisite for assessing the availability of P to crops. Since different forms of soil P have different solubilities, the availability and uptake of P largely depend on the amounts of the different forms present in the soil. Organic matter, calcium oxide and the sesquioxide appear to be the guiding factors in determining the distribution of different forms of P in soils (Misra and Ojha, 1969).

The Kole lands and the soils of the northern portion of Tallapalli taluk are known to be rich in total P_2O_5 (Anon, 1938) though the availability is low. Ninety two percent of the area contain less than 0.008 percent of available P_2O_5. Only a small area of the Kole land region contained sufficient amounts of available P_2O_5. Koshy and Brito-Mutunayagam (1965) found the phosphate content to be between 0.024 to 0.256 percent in 10 typical soil profiles of Kerala State. Hassan (1980) studied the chemical characteristics of Kerala soils and reported that in Trichur and Malappuram areas, total-P ranged from 0.028 to 0.230 percent. The P_2O_5 content in the soils presently studied varied from 0.09 to 0.36 percent which is in agreement with the results obtained by aforesaid authors.

Vertical distribution of phosphorus in profile, also has been studied by many authors. Kaila (1956) and Venugopal (1969) found a decrease in total P_2O_5 with depth. In conformity with the above findings, the total P_2O_5 in all Kole profiles studied except at Kanjani decreased with depth.

From the correlation studies (Appendix IV) it is observed that total-P significantly and negatively correlated with coarse sand and fine sand ie. $^-0.4637$ and $^-0.4631$, positively correlated with silt, clay and organic carbon ie. 0.3217, 0.4278 and 0.4994 respectively. Total-P was found to be correlated with inorganic fractions viz., saloid-P (0.3853), Al-P (0.3509), Fe-P (0.7081), Red-P (0.6043), occluded-P (0.4856), Ca-P (0.4863) and organic-P (0.7075). These results agree closely with the results of Kothandaraman and Krishnamoorthy (1979) and Mehta et al. (1979).

Available phosphorus (Bray 1) in all soil samples was determined and it varied between 7 and 50 ppm. The maximum accumulation of available phosphorus was found in the surface layers of the soils and it decreased with depth except at Kanjani. Higher concentration of available phosphorus was noticed in the surface layers by Pareek and Mathur (1969). Runge and Rieckon (1966) concluded that this may be due to distribution pattern of organic matter and also the requirement of the crop and its rooting depth.

From the Appendix IV it is observed that available P content of soil was negatively correlated with silt ($r = {}^{-}0.1906$); clay ($r = {}^{-}0.2994$); sesquioxides ($r = {}^{-}0.4216$); total aluminium ($r = {}^{-}0.0788$); total Fe ($r = {}^{-}0.4322$) and phosphorus fixing capacity ($r = {}^{-}0.2303$). It was positively correlated with coarse sand ($r = 0.2397$); fine sand ($r = 0.2047$); organic matter ($r = 0.3095$) and total phosphorus ($r = 0.1821$). It was also observed that available phosphorus had a significant positive correlation with saloid-P ($r = 0.7734$) and Red-P

(0.3538) with Al-P and organic-P, the available phosphorus had a positive correlation but it was not significant. These observations are in agreement with the findings of Mehta et al. (1979) and Sharma et al. (1979). A positive correlation between Al-P and Bray-1 available P was also noticed by Tuner and Rice (1952).

Available P estimated by Bray-1 method has not shown any definite pattern of increase or decrease with an increase or decrease in total-P content. Thus total-P itself may not be a single factor governing P availability. There may be factors like P fixing capacity, R_2O_3, pH, clay, organic matter etc. which are important to characterise the soils and define the phosphorus availability.

Saloid-P was the lowest fraction in these soils, ranging from 3.0 to 17.9 ppm. According to Kothandaraman et al. (1979) low values for this fraction may be attributed to high P fixing capacity. The results of the present investigation are in conformity with the findings of the above workers, because P fixing capacity and saloid-P were found to be negatively correlated ($r = ^{-}0.1531$). As in the case of available P_2O_5, saloid-P was positively correlated with coarse sand (r = 0.0329); fine sand (r = 0.0230); pH (r = 0.0144); organic carbon (r = 0.4296); total P_2O_5 (r = 0.3853) and CaO (r = 0.2039). This fraction was negatively correlated with silt ($r = {}^{-}0.0364$); clay ($r = {}^{-}0.1095$); total sesquioxides ($r = {}^{-}0.1969$); total aluminium ($r = {}^{-}0.0558$); total Fe ($r = {}^{-}0.1856$) and PFC ($r = {}^{-}0.1531$). Comparatively low concentration of saloid-P in certain locations must be due to the high content of clay; and the sesquioxides. Since organic carbon and saloid-P are positively correlated surface soils contain higher amounts of this fraction. Appendix I shows that there is significant difference in saloid-P between surface and subsurface soils.

In all the locations saloid-P decreased with depth except at Kanjani which must be due to accumulation of organic matter in the subsurface layer.

The Al-P fraction is the third most abundant fraction present in these soil next to Fe-P and Red-P. The mean Al-P present in surface layer soil was 35.2 ppm and in subsurface layer it was 21.5 ppm. According to Hsu and Jackson (1969); low value of Al-P is due to its greater solubility and fixation of P as Fe-P and Red-P. Statistical analysis (Appendix I) shows that there is significant difference in Al-P content between the surface and subsurface layers. In the surface layer samples Al-P contributed to 3.64 and in the subsurface layer samples it contributed to 3.50 percent of total-P. The high R_2O_3 content in the soil and also pH may explain the dominance of this fraction in these soils. It was actually observed that Al-P was negatively correlated with coarse sand (r = -0.2566) and fine sand (r = -0.1800) and positively correlated with silt (r = 0.1317); clay (r = 0.2361); and the sesquioxides (r = 0.1271); total Al content (r = 0.3654) and Fe content (r = 0.3165). Al-P was positively correlated with other inorganic P fractions viz., saloid-P (r = 0.4885); Fe-P (r = 0.4087); Red-P (r = 0.1120); occluded-P (r = 0.1787) and Ca-P (r = 0.1680). The results of the present investigation are in agreement with the findings of earlier workers such as Vijayachandran (1966) and Kothandaraman and Krishnamoorthy (1979) for Tamil Nadu soils.

The Fe-P fraction is the most abundant fraction in *Kole* soils. The mean Fe-P in surface soil is 298.9 ppm and in subsurface layer it is 254.3 ppm. It contributes to a mean value of 34.2 percent of the total pool of P. The predominance of Fe-P in soils may be attributed to the low pH and high content of sesquioxides as reported by Chu and Chang (1960). The present findings are in conformity with the findings of Kothandaraman and Krishnamoorthy (1979) for Tamil Nadu soil and also with results obtained by Aiyer and Nair (1979) for Kerala soils. Fe-P was negatively correlated with coarse sand (r = -0.5614) and fine sand (r = -0.4945) positively correlated with silt (r = 0.4603); clay (r = 0.5233);

sesquioxides (r = 0.6709); total Aluminium content (r = 0.5524) and Total Fe content (r = 0.7352). A positive relationship of Fe-P with other forms of P was also observed; the r values being 0.0602 for saloid-P, 0.4087 for Al-P, 0.1807 for Red-P and 0.3343 for occluded-P.

Red-P is the second most abundant fraction in Kole soils. The mean Red-P in surface soil is 240.2 ppm and in the subsurface layer it is 150.4 ppm. It contributes to a mean value of 22.5 percent in the total pool of P. The present findings are in conformity with the work of Vijayachandran and Raj (1978) who reported that in the acid soils of South India, upto 40 percent of all P may be reductant soluble. Highly weathered soils according to Chang and Jackson (1958) always contained appreciable amounts of Red-P. They have also observed that the existence of Red-P was due to the iron oxide precipitate found on the surface of iron and aluminium particles formed during weathering by the hydrolysis of ferric iron. The finding that the acid soils of Kerala contain a reasonably high proportion of Red-P is in conformity with the results obtained by the above workers. It is observed that Red-P is negatively correlated with coarse sand (r = -0.1400); clay (r = -0.0060) and with Ca-P (r = -0.1249) and it is positively correlated with fine sand (r = 0.0288); silt (r = 0.1255); sesquioxides (r = 0.2985);

Total Al content (r = 0.3589) and with Total Fe content (r = 0.0089); Red-P also shows a positive correlation with saloid-P, Al-P, Fe-P and organic-P.

The content of occluded-P varied from 5.6 to 33.3 ppm with a mean value of 14.2 ppm. In the surface layer samples occluded-P contributed 1.89 percent and in subsurface layer samples it contribute 2.00 percent of total-P which is in conformity with earlier findings of Aiyer and Nair (1979) and Jose (1973) for neutral and alkaline soils of South India. Statistical analysis shows that there is significant difference in occluded-P content between surface and subsurface layer samples (Appendix I).

It was also observed that occluded-P was negatively correlated with coarse sand (r = -0.0125); silt (r = -0.1402) and clay (r = -0.0431) when the surface layer samples alone were statistically analysed. Occluded-P was positively correlated with sesquioxides content (r = 0.3785); total Al content (r = 0.1044); total Fe content (r = 0.0402); Fe-P (r = 0.3343); Red-P (r = 0.4432); Ca-P (r = 0.1639) and with organic-P (r = 0.3624).

The Ca-P fraction varied from 6.2 to 195.0 ppm with a mean value of 44.9 ppm and accounted for an average of 5.02 percent of total-P. The acid nature of soils may be the reason for the low contribution of Ca-P to total-P. The Ca-P content in surface and subsurface layer soils is not statistically significant but in general the lower layer contains more of this fraction when compared to the upper layer. Chang and Jackson (1958) noticed that in calcareous soils or soils which had not weathered much, most of the inorganic P was present as Ca-P. Jose (1973) observed that in neutral and alkaline soils of South India, the Ca-P was the most dominant fraction and it increased with increase in pH, which tends to support the observations made for the acidic <u>Kole</u> soils. The present findings are in conformity with work of Aiyer and Nair (1979). From the correlation studies it is revealed that Ca-P is the only fraction which has a significant positive correlation with CaO content ($r = 0.6046$). The pH, silt, clay, organic carbon and CEC are positively correlated with Ca-P. The same fraction is negatively correlated with coarse sand ($r = {}^{-}0.3897$); fine sand ($r = {}^{-}0.6317$) and occluded-P ($r = {}^{-}0.0543$). Similar results have been obtained by Jose (1973) and Sharma et al. (1979).

The mean organic-P in the surface soil was 354.6 ppm and in the subsurface layer it was 184.8 ppm. It contributes to a mean value of 31.36 percent in pool of total-P. Brito-Mutunayagam and Koshy (1951) observed that organic phosphorus constituted one of the largest fractions in the acid soils of Kerala. Singh et al. (1979) observed in the soils of Western Uttar Pradesh that organic-P constituted 22 to 45 percent of total-P. The acid soils of Kerala showed a wide variation in organic-P ranging from 0.8 to 42.4 percent of total-P as reported by Koshy and Brito-Mutunayagam (1961).

From the 't' value (Appendix I) it may be observed that there was significant difference in organic-P content between the surface and subsurface layers. This must be due to the distribution pattern of organic carbon in the soils because, organic matter and organic-P were closely related to each other. Moreover, from the correlation studies it was observed that there was a significant positive correlation between organic carbon and organic-P (r = 0.5622). This fraction was negatively correlated with coarse sand (r = $^{-}$0.1641); fine sand (r = $^{-}$0.2572) and with silt (r = $^{-}$0.0421). Similar results were observed by Jackman (1955) and Mehta et al. (1971). Similarly organic-P was also positively correlated with clay (r = 0.2288); pH (0.2739); total sesquioxides (r = 0.0129); available P_2O_5 (r = 0.2717) and CaO content (r = 0.3842).

From the present study it was also observed that the

P fractions increase substantially as the total-P increases. The correlation coefficients between total-P and the various fractions for all locations considered together have ranged between 0.3502 and 0.7081. No significant relationship could be found between total-P content and saloid-P and also between total-P and Al-P.

II. Fixation and availability of phosphorus

(a) Phosphorus fixing capacity of soils

Phosphorus fixation is the process whereby readily soluble phosphorus is changed to less soluble forms by reaction with inorganic and organic components of the soil, with the result the phosphorus becomes restricted in its mobility in the soil and suffers a decrease in its availability to plants. The fixation of applied phosphates is generally considered to be the main cause for its low availability. Research on soil phosphate is complicated by the fact that the phosphate ions form a multitude of compounds of low solubility and often of highly variable composition.

This study revealed that the applied water soluble phosphates were rapidly converted to unavailable forms. Of the soils analysed the mean phosphorus fixing capacities were 61.07 percent and 63.40 percent respectively for the

Table 11 Relationship between phosphorus fixing capacity and other soil characters

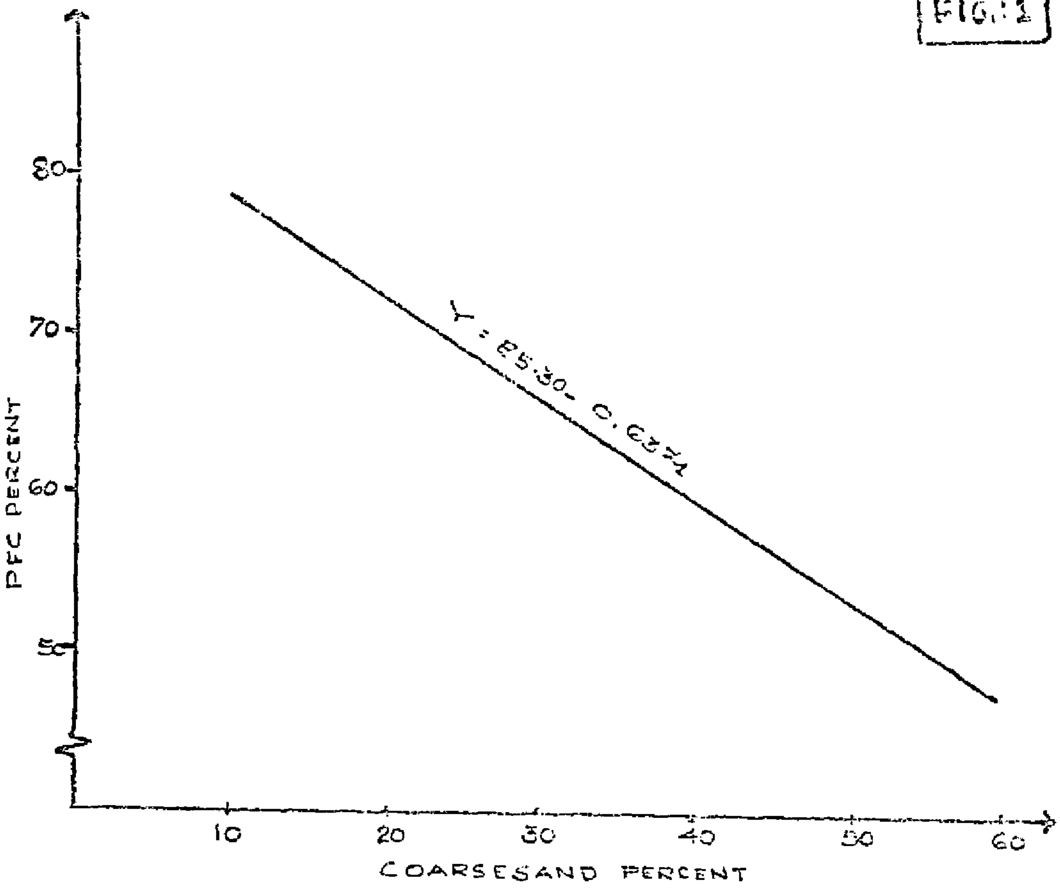
Sl. No.	Variables		Correlation coefficient	Regression equation
	X (no. of samples)	Y		
1	Coarse sand (30)	PFC	-0.7135**	Y = 85.30-0.633x1
2	Fine sand (30)	PFC	-0.1631	Y = 68.04-0.40x2
3	Silt (30)	PFC	0.4301*	Y = 43.42+0.76x3
4	Clay (30)	PFC	0.5286**	Y = 50.49+0.49x4
5	pH (30)	PFC	-0.2765	Y = 109.13-10.49x5
6	Organic carbon (15)	PFC	0.5944**	Y = 27.70+19.46x6
7	Sesquioxides (30)	PFC	0.2811	Y = 50.89+0.78x7
8	Al-content (30)	PFC	0.3300*	Y = 51.28+0.28x8
9	Fe-content (30)	PFC	0.5964**	Y = 39.39+0.60x9
10	CaO content (30)	PFC	-0.3800*	Y = 72.89-0.41x10

** Significant at 1% level

* Significant at 5% level

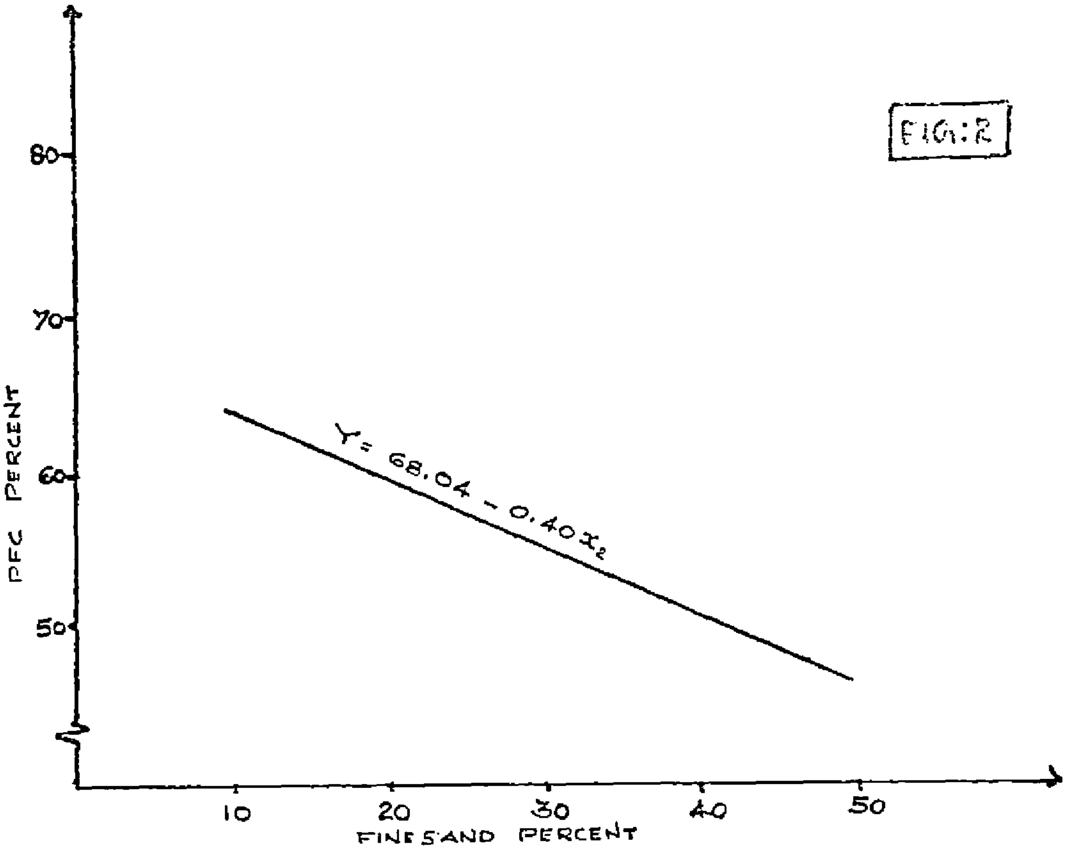
CORRELATION OF PFC TO COARSE SAND

FIG: 1



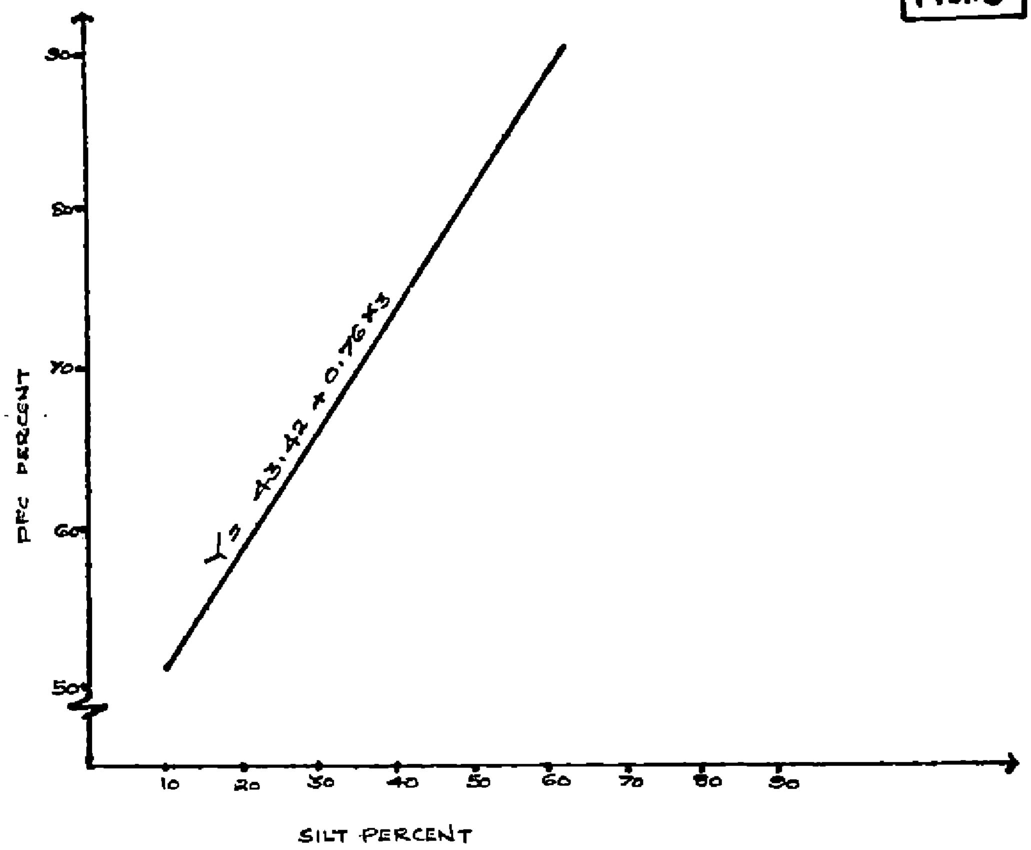
CORRELATION OF PFC TO FINE SAND

FIG: 2



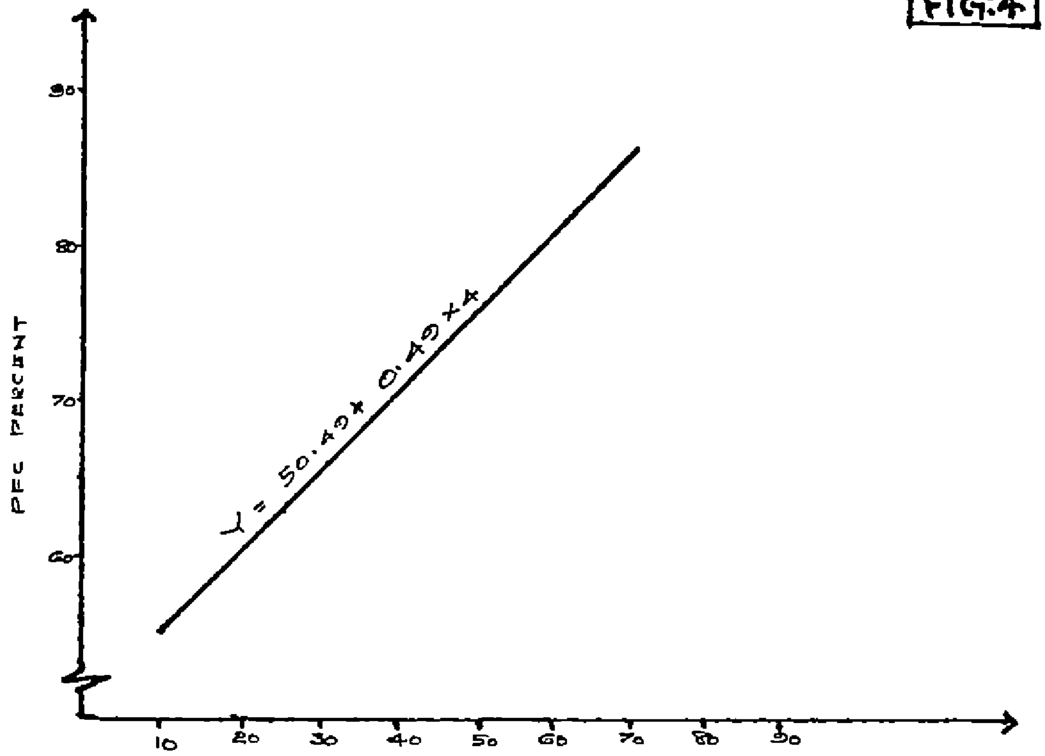
CORRELATION OF PFC TO SILT

FIG:3



CORRELATION OF PFC TO CLAY

FIG:4



CORRELATION OF PFC TO pH

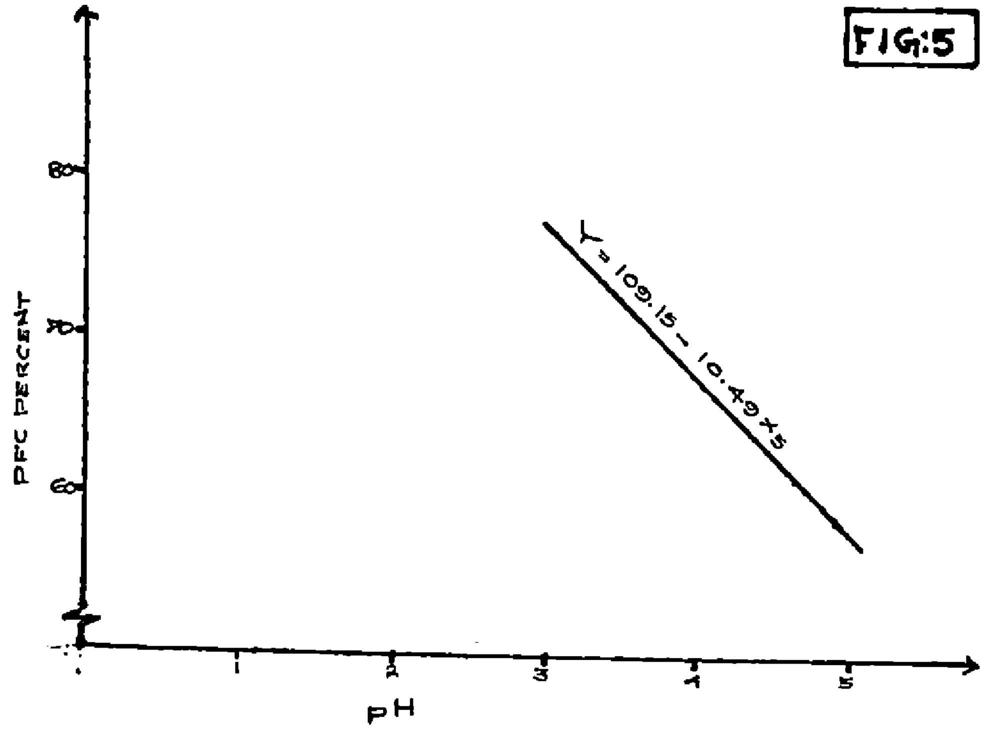


FIG:5

CORRELATION OF PFC TO ORGANIC-C

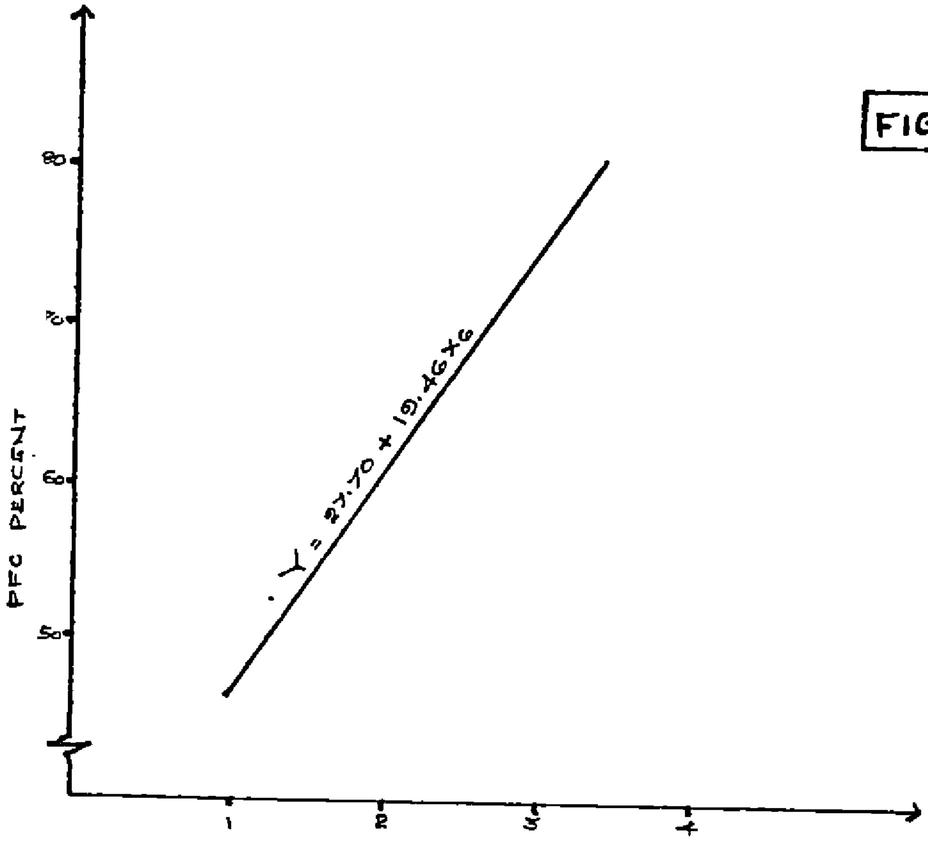


FIG:6

CORRELATION OF PFC TO SESQUIOXIDES

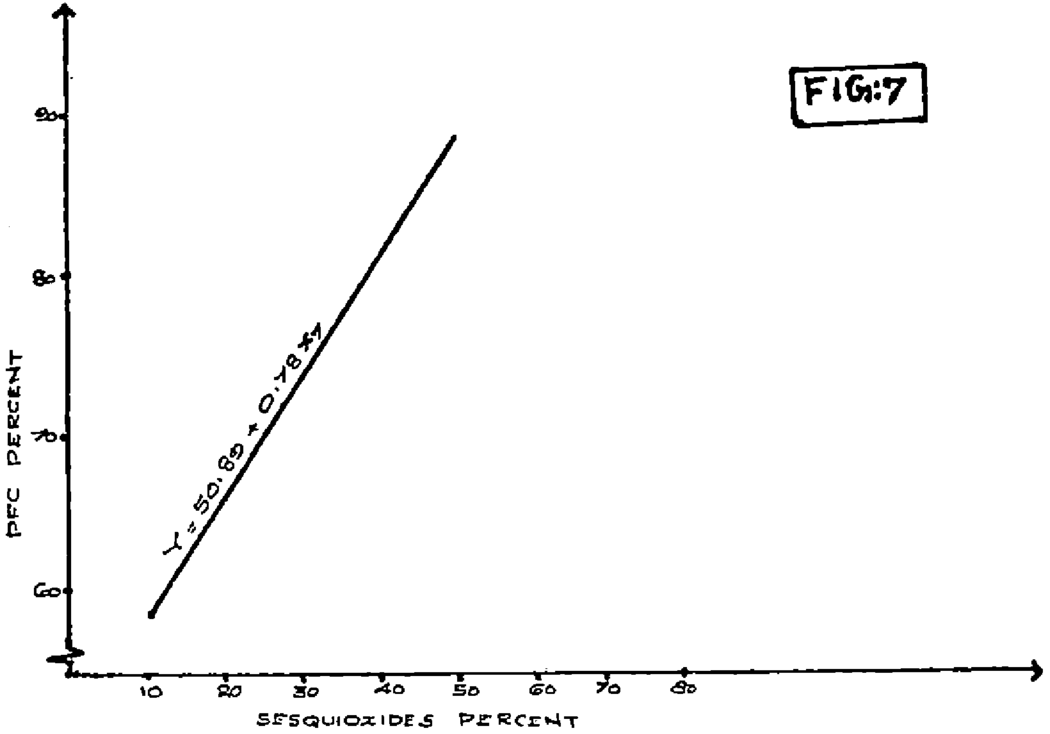


FIG:7

CORRELATION OF PFC TO TOTAL ALUMINIUM

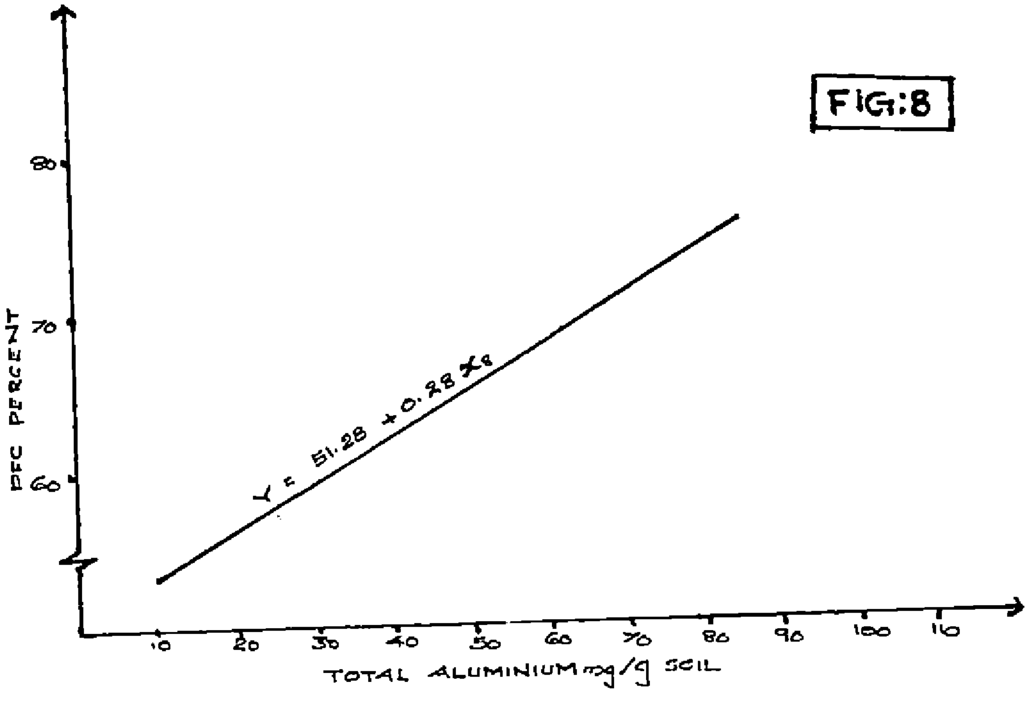
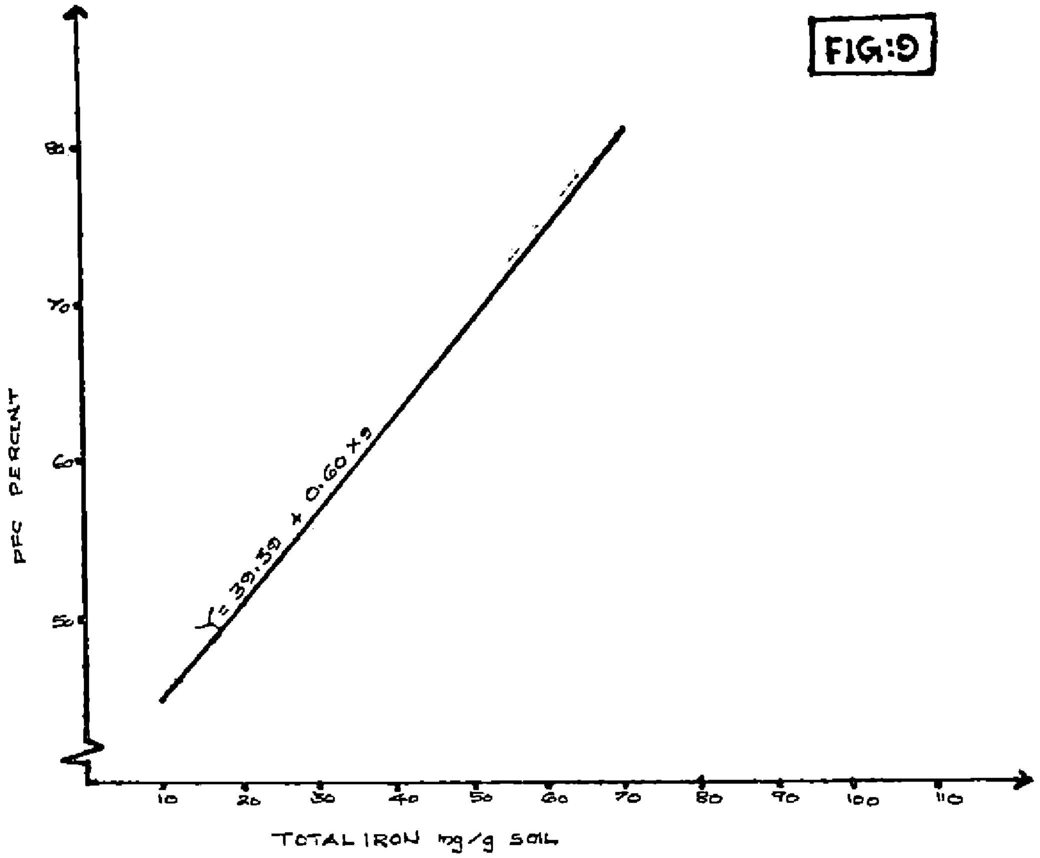


FIG:8

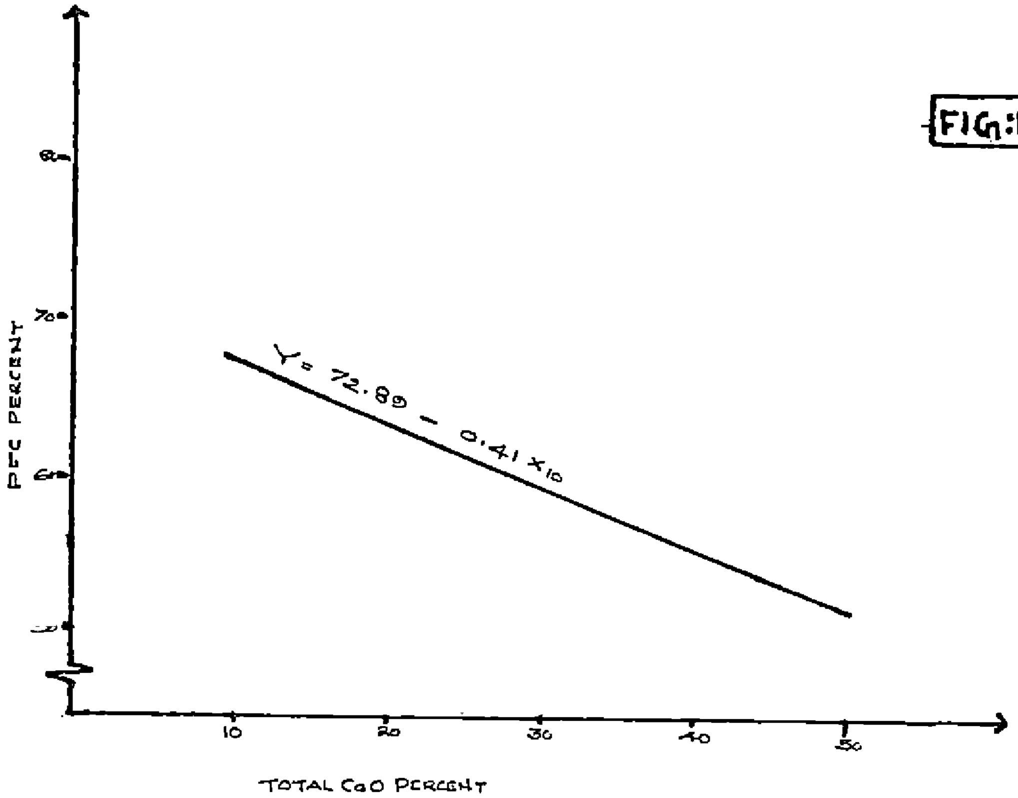
CORRELATION OF PFC TO TOTAL IRON

FIG:9



CORRELATION OF PFC TO TOTAL CaO

FIG:10



surface and subsurface layers (Table 5). The phosphorus fixing capacities reported for the Kole soils of Kerala is lower than the fixing capacities reported for laterite soils (Madhusoothanan Nair, 1978). The Kole soils contain lower amounts of clay, total iron, organic matter and total sesquioxides, compared to some high P fixing soils. Datta and Srivastava (1963), as well as Nad et al. (1975) had observed that the amount of clay, free oxides of iron, total sesquioxides and organic matter content are some of the dominant factors contributing towards a higher P fixing capacity.

Correlation studies (Table 11) with P fixation and soil properties indicate that significant positive correlations were obtained between P fixation and total iron, clay, silt, total aluminium, total sesquioxides and organic matter. Contrary to this, there was highly significant negative correlation between P fixation and sand as expected. The relationships between phosphorus fixation and different soil parameters are shown graphically (Figures 1 to 10).

Higher correlation of iron ($r = 0.5964$) and clay ($r = 0.5286$) with P fixation shows that these are the most active components in the fixation of P in soils as pointed out by Rajagopal and Idrani (1963) and Nad et al. (1975). The lack of significant correlation of P fixation with pH and $CaCO_3$ content is not easily understandable but it is possibly due to the narrow range of these characteristics in the soils studied. Raychaudhuri and Mukherjee (1941) also could not find any correlation between pH and the amount of P fixed while Kanwar (1955) observed that removal of aluminium and iron oxides resulted in the decrease of P retained by the soil. The results obtained in the present study also very clearly show the importance of iron in the fixation of P irrespective of the soils. The content of iron and clay appeared to be the dominant soil characteristics influencing the extent of fixation of applied phosphorus.

These results suggest that while recommending P doses from soil testing laboratories, the clay and iron contents of the soil or at least the clay content should be determined to get an idea of the extent of fixation of the applied P.

(b) Relative amounts of added P reverted to different chemical forms of soil P.

This study was conducted to determine the relative amounts of added phosphate reverted to different forms of soil phosphorus. For this purpose, the fractionation of soil phosphorus before and after treatment with 40 mg P_2O_5 per 100 g of soil (174.7 ppm of P) was done. This helped to understand the distribution and reversion pattern of applied P_2O_5 in these soils.

The soils investigated varied in the nature and the distribution of the various phosphorus fractions. Phosphorus was present in the soil mainly in the form of Fe-P. The next largest fraction was that of Red-P followed by Ca-P, Al-P, occluded-P and saloid-P.

Fractionation after treatment indicated that the P_2O_5 applied as KH_2PO_4 was recovered in all inorganic forms of soil phosphorus via saloid-P, Al-P, Fe-P, Red-P, occluded-P and Ca-P. Addition of phosphate resulted in considerable increase in saloid-P. The mean percentage conversion of added phosphate to this fraction was 37.39 and 27.64 percent respectively for surface and subsurface soils. The subsurface soils recorded lower conversion of added P_2O_5 into saloid-P because they contain higher amounts of iron and aluminium than surface soils. Kar and Chakravarthi (1969) studied the availability and fixation of applied phosphorus in Indian acid soils and revealed that about 30 to 50 percent of added soluble phosphate was found to get fixed. Analysis showed that out of the 100 ppm P applied 50 to 70 percent was reverted to loosely bound saloid-P and also showed appreciable increase in Al-P, Fe-P, reductant soluble Fe-P and to a lesser degree occluded-P. The level of Ca-P was unaffected.

Next to saloid-P, the percentage recovery of added P was in the form of Al-P. The mean percentage conversion of added phosphate into this fraction was 30.63 and 27.13 respectively for the surface and subsurface soils. Sharma et al. (1980) studied the transformation of added P into inorganic P fractions in acid soils and found that most of the added P was transformed into Al-P, Fe-P and very little to Ca-P fractions at one day interval. The added P which was transformed into Al-P increased upto seven days and later decreased slowly upto 90 days of incubation. The present study is in conformity with the above finding. In this study reversion of added phosphorus into Fe-P was less than that of Al-P, which might be due to the in sufficiency of the time between the addition of phosphorus and the fractionation of soil phosphorus. Khana and Mahajan (1971) reported that more than half of the conversion of added phosphate in acid soil was in the form of Al-P (47 to 73 percent) at pH 4.7, followed by Fe-P which accounted for 17 to 34 percent.

The fixation of added phosphorus in the form of Red-P was also quite considerable. The mean percentage of conversion to this fraction was 10.43 and 15.74 respectively for the surface and subsurface soils. Only a small portion of the added P was converted to occluded-P and the mean values for the surface and subsurface soils were 3.98 and 6.31 percent respectively. The higher percentage recovery of these two fractions in the subsurface layer soils may be due to the higher amounts of the sesquioxides of Fe, Al present in this layer. This finding is in conformity with that of Kar and Chakravarthi (1969).

The reversion to Ca-P occurred only to a small extent. Kar and Chakravarthi (1969) in their study of five West Bengal acid soils with pH varying from 4.3-6.3 observed that phosphate addition caused an appreciable increase in Al-P and Fe-P and to a lesser degree to occluded Al-P. Ca-P was unaffected except in a soil having a pH of 6.18. Similar results have also been reported by Nambiar (1962).

There is no significant change in organic-P fraction due to phosphorus addition. However data reveal that a small part of organic-P got mineralized to inorganic forms consequent on treatment.

c. Availability of added phosphatic fertilizers

Any form of phosphate applied to the soil undergoes a series of changes and excepting a nominal fraction, plants absorb phosphorus from the reaction products, the chemistry of which is yet to be clearly understood. Mandal (1975) observed that soil phosphorus has continued to be an enigma to the soil scientists. The more soluble phosphates are transformed into a series of reaction products of iron manganese, aluminium, calcium etc. depending upon the soil reaction and these reactions are very rapid and take place within a few days. Jung (1973) observed that citrate soluble and water soluble phosphates when applied to soil did not differ much in their reaction products but differed in their reaction rates in soil. The present study was conducted to compare the relative efficiency of two phosphatic fertilizers namely superphosphate and Mussoorie rockphosphate in the <u>Kole</u> soils. The effect of these two fertilizers on available P_2O_5 content of the soil at different days of incubation is graphically presented in Fig. 11 (Table 12). Application of superphosphate and Mussoorie rockphosphate has significantly increased the available P_2O_5 over the control (Appendix IV). Superphosphate maintained a higher amount of available P_2O_5 during the initial periods of incubation. This may be due to its highly water soluble nature. Available P_2O_5 content in the soil due to this source of phosphorus increased upto the 7th day and then decreased sharply. Mandal and Khan (1972) reported that when very soluble phosphates were added to an acid soil the fixation of phosphate took place as rapidly as the phosphate was diffused through out the soil and come in contact with colloids.

Table 12 Mean values of available P_2O_5 in soil due to treatments

P_2O_5/100 g of soil (mg)

Treatments	Periods								Mean
	1 hour B_1	1 day B_2	7 days B_3	14 days B_4	28 days B_5	42 days B_6	56 days B_7	70 days B_8	
A_1 Superphosphate	19.0	21.2	23.1	18.9	16.9	14.6	13.9	13.9	17.7
A_2 Mussoorie rock-phosphate	12.3	14.9	18.4	20.4	21.0	17.6	15.3	15.2	16.9
A_3 Control	3.0	3.7	4.5	4.4	3.7	3.2	3.1	3.0	3.6
Mean	11.4	13.2	15.3	14.6	13.9	11.8	10.8	10.7	

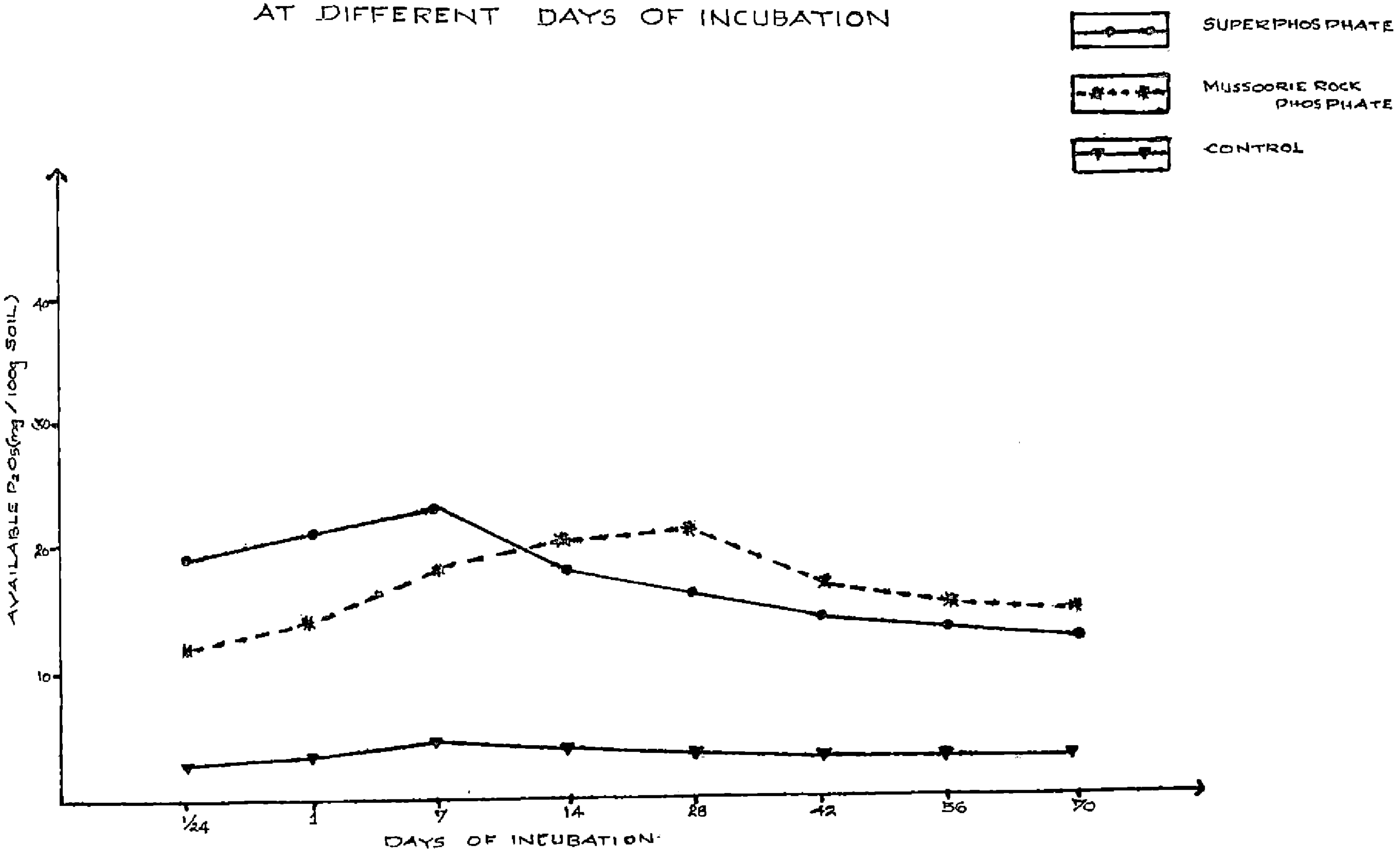
CD-A-2.0228

CD-B-0.6780

CD-AB-1.1743

EFFECT OF SUPERPHOSPHATE AND MUSSOORIE ROCK PHOSPHATE AT 40 mg P_2O_5/100 g SOIL ON AVAILABLE P_2O_5 CONTENT OF SOIL AT DIFFERENT DAYS OF INCUBATION

FIG:11



Mussoorie rockphosphate treatment, on the other hand, maintained only a lesser amount of available phosphate in the initial period. This is due to its water insoluble nature. Because of the acidic nature of the soil, solubility of Mussoorie rockphosphate increased gradually upto 28th day and decreased thereafter. But it still maintained a higher amount of available P_2O_5 than superphosphate. Eventhough statistical analysis showed that there was no significant difference between these fertilizers, the results suggest that in such acidic lowland rice soils, rockphosphate will be more advantageous than superphosphate as phosphatic fertilizer.

d. Relative amounts of native phosphorus in clay and silt

Soil texture is one of the main characters of the soil which averts a general influence on most of the other soil properties. The individual separates, silt or clay, which differ in their physico-chemical and other properties have different effects on the course and direction of the soil forming processes. One of the objects of the present study was to find out the relative amounts of native phosphorus associated with the two size fractions of soil ie. clay and silt. The average total native phosphorus associated with clay ranged from 2204 ppm to 22701 ppm with an average of 9509 ppm for the surface soil. In the subsurface layer this value ranged from 2036 to 9904 ppm with an average of 4563 ppm. Williams and Saunders (1956) have reported that for the surface soils, total P_2O_5 in the clay ranged from 5500 to 12,500 ppm. For the subsurface soil this value had a minimum of 580 ppm and a maximum of 8100 ppm. Krivosheyen (1981) reported that soil separates of various sizes differ considerably from each other in their phosphorus contents. Clay and fine silt particles have the highest contents of phosphorus. This pattern holds throughout the profile although the content of phosphorus decreases noticeably with depth. From the present study it is revealed that the amount of P_2O_5 in the clay decreases markedly with depth. The 't' test showed that there was significant difference in the amounts of native phosphorus associated with clay between the two layers of the soil.

When compared with clay the silt fraction contained a lesser amount of total native phosphorus (Appendix III b). A similar finding has been reported by Williams and Saunders (1956). Hanley and Murphy (1970) and Krivosheyen (1981). The average total native phosphorus associated with the silt ranged from 645 to 3373 ppm in the subsurface layer. In the surface layer samples this value varied between 1097 and 2540 ppm with a mean value of 1738 ppm. Williams and Saunders

(1956) reported that for surface soils the total P_2O_5 in the silt varied from 1910 to 4700 ppm. For the subsurface soil this value ranged between 650 and 3240 ppm. Koshy and Brito-Mutunayagam (1965) found that total P_2O_5 associated with silt varied from 370 to 3110 ppm in Kerala soils. The present study is in conformity with the above findings. Eventhough there was difference in this value between the two layers, 't' test showed that there was no significant difference in the amounts of phosphate associated with silt fractions between the two layers (Appendix II a).

Contributions of fractions to soil values

The F value concept was introduced by Williams and Saunders (1956) to denote the quantity of phosphorus present in a given particle size fraction in one gram of oven dry soil. Thus F values combine the phosphorus contents of the fractions and particle size composition of the soil (Table 9).

$$\text{F value (ppm)} = \frac{\text{Percent of mechanical fraction} \times \text{ppm of } P_2O_5 \text{ in fraction}}{100}$$

The F value of clay ranged from 216 ppm in the subsurface layer of Mullaseri to 2192 ppm in surface layer of Manakkody-Varyam. For the surface layer samples the average F value was 1156 ppm and the same for the subsurface was

678 ppm (Table 10).

Similarly, the P value of silt ranged from 92 ppm in the subsurface layer of Thekke Konjira to 828 ppm in the surface layer of Manaloor. The average P value for silt in surface layer samples was 437 ppm and for the subsurface layer samples it was 283 ppm. From the mean value it is observed that the P value of clay as well as that of silt decreased with depth. The mean percentage contributions of clay fraction to total phosphorus were 47.5 and 43.4 percent respectively for the surface and subsurface soils. The corresponding values for silt were 19.4 and 19.0 percent respectively. Williams and Saunders (1956) found that the clay fraction contribute to 6.0 - 62.0 percent of total P_2O_5 while the silt fraction contribute to 10 - 36 percent of the total P_2O_5. John and Gardner (1971) also reported that the clay fraction contributed the maximum towards total soil phosphorus. The phosphate associated with silt and clay actually accounted for nearly 40 - 90 percent of the total-P of soils.

e. Added phosphate retained by clay and silt

Added phosphate showed a tendency to be fixed in greater proportion in the clay fractions (Appendix III b).

This is because, the clay fraction contains more of sesquioxides. Also the clay particles are on an average only one-tenth the size of silt particles and if surface adsorption is also part of the true mechanism of phosphate fixation, a larger proportion of the added phosphate must be retained by the clay fraction because it has greater surface area. Moreover many workers have reported on the importance of clay in P fixation. Nad et al. (1975) reported that as a single factor, clay seemed to be the most important soil characteristic influencing P fixation in soils.

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSIONS

An investigation of the distribution, fixation and availability of phosphorus in the surface (0-20 cm) and subsoils (20-40 cm) of 15 locations in the Kole area of Trichur district of Kerala State was carried out in relation to the physico-chemical properties. The main findings of the study are summarised below:

(1) Total P_2O_5 content varied from 0.13 to 0.36 percent in the surface soils with an average of 0.23 percent. In the subsurface layers the variation was from 0.09 to 0.24 percent with an average of 0.16 percent. There was significant difference between the surface and subsurface layers in the total P_2O_5 content.

(2) Total P_2O_5 was significantly and negatively correlated with coarse sand and fine sand, and positively correlated with organic carbon, clay and silt. All inorganic fractions were significantly and positively correlated with total P_2O_5.

(3) The available P_2O_5 content varied from 7 to 50 ppm, the average being 29.0 ppm in the surface layer and 23.5 ppm in the subsurface layers. The maximum accumulation was found in the surface soils.

(4) From correlation studies it was observed that available P_2O_5 was negatively correlated with silt, clay, sesquioxides, total aluminium, total iron and the phosphorus fixing capacity of the soil. It was positively correlated with organic carbon, coarse sand and fine sand. Of the various fractions, saloid-P was significantly and positively correlated to available P_2O_5.

(5) Saloid-P was found to be the smallest fraction in these soils. It ranged from 3.0 to 17.9 ppm in all the soils, the average being 9.2 ppm in the surface layer and 6.1 ppm in the subsurface layer. Between the surface and subsurface soils there was significant difference in saloid-P content. When expressed as percent of total P_2O_5 this fraction constituted only 0.96 and 0.94 percent respectively in the surface and subsurface soils.

(6) Al-P content varied from 6.8 to 71.2 ppm, with averages of 35.2 and 21.5 ppm in the surface and subsurface layers respectively. Between the two depths, there was significant difference in the proportion of this fraction. The mean percentage contribution of Al-P to total-P was 3.64 and 3.50 respectively in the surface and subsurface layers.

(7) Fe-P values in this soil ranged from 137.8 and 549.2 ppm, the averages being 298.9 and 254.3 ppm. It was

the most abundant P fraction this soil. Between the two layers there was significant difference in Fe-P content. The mean contribution of Fe-P to total-P was 29.64 percent and 38.76 percent respectively for the surface and subsurface samples. Fe-P is negatively correlated with coarse sand and fine sand and positively correlated with silt, clay and the sesquioxides.

(8) Red-P varied from a minimum of 18.3 ppm to a maximum of 443.4 ppm with averages of 240.2 and 150.4 ppm respectively for the surface and subsurface soils. Statistical analysis showed that there was no significant difference for this fraction between the two layers. The extent of contribution of Red-P to total-P was 24.05 and 21.03 percent for the surface and subsurface layers respectively.

(9) Occluded-P ranged between 5.6 and 33.3 ppm in all the samples, the averages being 18.2 and 10.2 ppm for the surface and subsurface layers respectively. Between the two depths there was significant difference in occluded-P. The mean percentage contribution of this fraction to total-P in these soils was 1.89 and 2.00 respectively for the surface and subsurface layers.

(10) Ca-P content ranged between 6.2 and 195.0 ppm with averages of 41.7 and 48.1 ppm in the surface and subsurface soils respectively. Between the two depths there was no

significant difference in the value of this fraction. The average contribution of Ca-P to total-P was 4.80 and 5.20 percent for the surface and subsurface soils respectively. From correlation studies it was revealed that Ca-P was positively and significantly correlated to CaO. It was positively but insignificantly correlated to pH, silt, clay, organic matter and CEC and negatively correlated with coarse sand and fine sand.

(11) Organic-P in the soils varied between a minimum of 110.3 and a maximum of 555.2 ppm with averages of 354.6 and 184.8 ppm in the surface and subsurface soils respectively. The 't' test indicated a significant difference between the surface and subsurface layers for this fraction. The average contribution of organic-P to total-P was 35.83 and 26.88 percent for the surface and subsoils respectively. There was a significant positive correlation between organic-P and organic carbon. It was negatively correlated with coarse sand, fine sand and silt.

(12) The phosphorus fixing capacity of these soils ranged from 15 to 88 percent with averages of 61.07 and 63.40 percent respectively in the surface and subsurface soils. There was no significant variation in phosphorus fixing capacity between the two depths.

(13) Correlation studies indicate a significant positive correlation between P fixation and total iron, total aluminium, total sesquioxides, clay, silt and organic matter.

(14) Fractionation of soil after P treatment indicated that the phosphorus applied as KH_2PO_4 was recovered in all inorganic forms of soil phosphorus, viz., saloid-P, Al-P, Fe-P, Red-P, occluded-P and Ca-P. A small part of organic-P got mineralized to inorganic forms consequent on the treatment.

(15) From the incubation study it was revealed that both superphosphate and Mussoorie rockphosphate are equally good in these soils.

(16) The amount of native phosphorus associated with clay ranged between 2036 and 22701 ppm with the averages of 9509 and 4563 ppm respectively for the surface and subsoils. The amount of native phosphorus in silt varied between 645 and 3373 ppm, averages being 1738 and 1364 ppm in the surface and subsurface soils. The result suggests that the clay fraction contain more phosphorus than silt.

(17) Amount of added phosphate retained by clay ranged from 3099 to 37622 ppm with averages of 17299 and 9115 ppm

respectively in the surface and subsurface soils. This value in silt ranged from 1247 to 6090 ppm with averages of 3136 and 2573 ppm respectively for the surface and subsoils. The relative phosphorus retention capacities of silt and clay were examined statistically and it was found that there was significant difference between clay and silt for this character.

REFERENCES

Abdul Hameed. 1975. Fertility investigations in the kole soils of Kerala. M.Sc.(Ag.) Thesis, Kerala Agricultural University.

Aiyer, R.S. and Nair, C.S. 1979. Phosphate fraction of Kerala rice soils in relation to their occurrence and pedogenesis. Agric. Res. J. Kerala 17(1): 39-43.

Al-Abbas and Barber, S.A. 1964. A soil test for phosphorus based upon fractionation of soil phosphorus. I. Correlation of soil P fractions with plant available P. Soil Sci. Soc. Am. Proc. 28: 218-221.

Allaway, W.H. and Rhoades, H.F. 1951. Forms and distribution of phosphorus in the horizons of some Nebraska soils in relation to profile development. Soil Sci. 72: 119-128.

Anonymous. 1938. Soil survey of Trichur and Thalapalli taluks. Report on soil survey of Cochin State: 1-3.

Appett, H. and Sehalscha, E.B. 1970. Effect of added phosphate on the inorganic phosphorus fractions of soils derived from Volcanic ash. Soil Sci. Soc. Amer. Proc. 34: 599-602.

Atanasiu, N. 1971. A comparative study on the effect of water and citrate soluble phosphatic fertilizer on yield and uptake on tropical and subtropical soils. J. Indian Soc. Soil Sci. 19: 119-127.

*Atanasiu, N., Westiphal, A., Zuofa, K. 1978. The fertilizer effect and residual effect of phosphate with differing solubilities on tropical and subtropical soils. Zutshrift fur Ackae pflanzenban. 146(4): 266-283.

Bapat, M.V. and Bedekar, V.G. 1965. Fertilizer phosphorus in fractions of soil phosphorus. J. Indian Soc. Soil Sci. 13: 237-239.

Bapat, M.V., Padole, C.C., Totely, N.G. and Bedekar, V.G. 1965. Forms of phosphorus in Vidarbha soils. *J. Indian Soc. Soil Sci.* **13**: 31-36.

Bates, J.A.R. and Baker, T.C.N. 1960. Studies on a Nigerian Soil II. The distribution of phosphorus in profile and in various soil fractions. *J. Soil Sci.* **11**: 257-265.

Bhajan Singh, Bhumbla, D.R. and Randhawa, N.S. 1979. Relative contribution of different fractions of soil phosphorus to plant phosphorus. *Bull. Indian Soc. Soil Sci.* **12**: 385-389.

Bray, R.H. and Kurtz, L.T. 1945. Determining total, organic and available forms of phosphate in soils. *J. Soil Sci.* **12**: 286-293.

Brito-Mutunayagam, A.P.A. and Koshy, M.M. 1951. Chemical nature and distribution of phosphorus in soils of Travancore-Cochin. *Bull. Cent. Res. Inst. Univ. Travancore* **2** (1) A: 63-76.

Chai Moo Cho and Cladwell, A.C. 1959. Forms of phosphorus and fixation in soils. *Soil Sci. Soc. Amer. Proc.* **23**: 459-461.

Chang, S.C. 1965. Application of phosphorus fractionation to the study of chemistry of available soil phosphorus. *Soil Sci.* **101**(6): 459-464.

Chang, S.C. and Chiang, C.T. 1953. The availability of various phosphatic fertilizers for rice on main soil groups of Taiwan. *Soils and Fert.* 90-91.

Chang, S.C., Chu, W.K. and Erh, K.T. 1966. Determination of reductant soluble phosphate in soils. *Soil Sci.* **102**: 44-85.

Chang, S.C. and Jackson, M.L. 1957. Fractionation of soil phosphorus. *Soil Sci.* **84**: 133-144.

Chang, S.C. and Jackson, M.L. 1958. Soil phosphorus fractions in some representative soils. J. Soil Sci. 9: 109-119.

Cholitkal, V. and Tyner, E.H. 1971. Inorganic phosphorus fractions and their relation to some indices of phosphorus availability for some low land rice soils of Thailand. Proc. Int. Symp. Soil Fert. Evaln. New Delhi, India. 1: 7-20.

*Chu, W.K. and Chang, S.C. 1960. Abstr. Soil Fert. 24: 555-557.

Chu, W.K. and Chang, S.C. 1966. Soil surface activity of inorganic soil phosphorus. Soil Sci. 101(6): 459-464.

Coleman, R. 1942. The adsorption of phosphate by Kaolinitic and montmorillonitic clays. Soil Sci. Soc. Am. Proc. 7: 134-138.

Coleman, R. 1944 a. Phosphorus fixation by the coarse and fine clay fractions of kaolinitic and monmorillonitic clays. Soil Sci. 58: 71-79.

Coleman, R. 1944 b. The mechanism of phosphate fixation by montmorillonitic and kaolinitic clay. Soil Sci. Soc. Am. Proc. 9: 72-78.

Coleman, N.T., Thorup, J.T. and Jackson, W.A. 1960. Phosphate sorption reactions that involve exchangeable aluminium. Soil Sci. 90: 1-7.

Cuttle, S.P. 1983. Chemical properties of upland peats influencing the retension of phosphate and potassium ions. J. Soil Sci. 34: 75-82.

Danilo Lopez-Hernandez and Burnham, C.P. 1982. Phosphate retension in some tropical soils, in relation to soil taxonomic classes. Commun. Soil Sci. Plant Anal. 13(7): 573-583.

Dashrath Singh, Mannikar, N.D. and Srivas, N.C. 1976 a. Comparative performance of indigenous rockphosphate and superphosphate with or without phospho bacterins. J. Indian Soc. Soil Sci. 24: 182-185.

Dashrath Singh, Mannikar, N.D. and Srivas, N.C. 1976 b. Phosphate fertilizer value of indigenous rockphosphate and superphosphate for Lucerne and their residual effect on Guar. J. Indian Soc. Soil Sci. 24: 186-191.

Datta, N.P. and Srivastava, S.C. 1963. Influence of organic matter on the intensity of phosphate bonding in some acid soils. J. Indian Soc. Soil Sci. 11: 189-194.

Dean, L.A. 1937. Distribution of forms of soil phosphorus fractions. Soil Sci. Soc. Amer. 2: 223-228.

Dhawan, S., Sethi, S.P. and Mathur, C.M. 1969. Phosphate fixing capacity of Rajastan soils. J. Indian Soc. Soil Sci. 17: 487-491.

Dolui, A.K. and Gangopadhyay, S.K. 1984. Fixation of phosphate in relation to properties of some red and lateritic soils of West Bengal. Indian J. Agric. Chem. 17(2): 177-182.

*Dyer, B. 1894. On the analytical determination of probably available plant food in soils. Trans. J. Chem. Soc. (London) 65: 115-167.

Fassbender, H.W. 1968. Phosphorus fixation in tropical soil. Agric. Digest. 18: 20-28.

Fox, R.L., Hasan, S.M. and Jones, R.C. 1971. Phosphate and sulphate sorption by Ratosols. Proc. Int. Symp. Soil Fert. Evaln. 1: 857-864.

Frageria, N.K. and Barbosa Filbo, M.P. 1987. Phosphorus fixation in Oxisols of Central Brazil. Fertilizers and Agriculture. 94: 33-35.

Freisen, D.K., Juo, A.S. and Miller, M.H. 1980. Liming and lime-phosphorus-zinc interactions in two Nigerian Ultisols. 1. Interactions in the soil. Soil Sci. Soc. Am. J. 44: 1221-1226.

Fried, M. and Dean, L.A. 1952. A concept concerning the measurement of available soil nutrients. Soil Sci. 73: 263-271.

Fuller, W.H. and Mc George, W.T. 1951. Phosphates in Calcareous Arizona soils II organic phosphorus content. Soil Sci. 71: 45-49.

*Gardner, T. 1930. Die binding der phosphorassure im Erdholden. Vest Landets. Forst, Forsokstation, Meddelese 14, Bergen.

Ghani, M.O. and Aleem, S.A. 1943. Fractionation of soil phosphorus I. The distribution of some different forms of phosphorus in some Indian soils. Indian J. Agri. Sci. 13: 283-286.

Godfrey, C.L. and Rieckon, F.F. 1954. Distribution of P in some genetically related loess derived soils. Soil Sci. Soc. Amer. Proc. 18: 80-84.

Gupta, A.P. 1965. Studies on the distribution fixation and availability of phosphate in soils of sugarcane growing tracts of Bihar and Uttar Pradesh. Agra Univ. J. Res. 14: 191-194.

Gupta, A.P. and Sen, S.C. 1964. Phosphate studies in sugarcane soils of Bihar. Distribution of available phosphorus at different depths in soil profiles and the effect of different soil factors on its availability. Indian Sug. 14: 551-554.

Halstead, R.L. 1967. Chemical availability of native and applied phosphorus in soils and their textural fractions. Soil Sci. Soc. Amer. Proc. 31: 414-419.

Hanley, P.K. and Murphy, C.D. 1970. Phosphate forms in particle size separates of Irish Soils in relation to Drainage and parent materials. Soil Sci. Soc. Amer. Proc. 34: 587-590.

Hassan, M.A. 1980. Characteristics of laterite soils in ribbon valleys and corresponding uplands of Kerala. Agric. Res. J. Kerala. 18(1): 14-22.

Haynes, R.J. 1983. Effect of lime and phosphate applications on the adsorption of phosphate sulphate and molybdate by a spodosol. *Soil Sci.* **135**(4): 221-227.

Hibbard, P.L. 1931. Chemical methods for estimating the availability of soil phosphates. *Soil Sci.* **31**: 437-466.

Hibbard, P.L. 1935. Factors influencing phosphate fixation in soils. *Soil Sci.* **39**: 337-358.

Hooker, M.L., Peterson, G.A., Sander, D.A. and Daigges, L.A. 1980. Phosphate fraction in calcareous soils as altered by lime and amounts of added phosphate. *Soil Sci. Soc. Amer. J.* **44**: 269-277.

Hsu, P.H. 1965. Fixation of phosphate by aluminium and iron in acidic soils. *Soil Sci.* **99**: 398-402.

Hsu, P.H. and Jackson, M.L. 1960. Inorganic phosphate transformations by chemical weathering in soils as influenced by pH. *Soil Sci.* **90**(1): 16-25.

Hundal, H.S., Arora, B.R. and Sekhon, G.S. 1979. Efficiency of phosphatic fertilizers differing in water soluble phosphorus on rice. *J. Indian Soc. Soil Sci.* **27**: 330-333.

Hundal, H.S. and Sekhon, G.S. 1976. Comparative effectiveness of nitric phosphate as a source of fertilizer phosphorus to Berseem. *J. Indian Soc. Soil Sci.* **24**: 73-77.

*Islam, A. and Khan, K.H. 1967. Influence of phosphorus fixing agents on the formation of inorganic phosphates in the soils on the addition of phosphatic fertilizer. *Pakistan J. Soil Sci.* **3**: 32-43.

Jackson, M.L. 1973. *Soil Chemical Analysis.* Prentice Hall of India Pvt. Ltd., New Delhi.

*John, M.K. and Gardner, E.N. 1971. Forms of phosphorus in a sequence of soils developed on Freser River alluvium. *Can. J. Soil Sci.* *5*: 363-367.

Jose, A.I. 1973. Studies on soil phosphorus in the South Indian soils of neutral to alkaline reactions. Ph.D. Thesis. Tamil Nadu Agric. Univ. Coimbatore.

*Jung, J. 1973. *Proc. FAI Symposium on Use of NPK - Complex Fertilizers based on Nitrophosphate process*. Fertilizer association of India, New Delhi.

Kabeerathumma, S., Mohankumar, B. 1986. Efficiency of rock-phosphate as a source of phosphorus to sweet potato. *J. Indian Soc. Soil Sci.* *34*: 806-809.

*Kaila, A. 1956. Phosphorus in various depths of virgin peat. *Pand. Ch. Absts.* *51*(5): 3895-3899.

Kanwar, J.S. 1955. Phosphate retension in some Australian soils. *Soil Sci.* *82*(1): 43-50.

Kanwar, J.S. 1956. Phosphate fixation in some Australian soils. *Soil Sol.* *82*: 43-50.

Kanwar, J.S. and Grewal, J.S. 1960. Phosphate fixation in Punjab soils. *J. Indian Soc. Soil Sci.* *7* 135-42.

Kar, A.K. and Chakravarthy, S.N. 1969. Availability and fixation of applied phosphate in some Indian acid soils. *J. Indian Soc. Soil Sci.* *17*: 47-49.

Kar, A.K. and Hussain. 1971. Evaluation of iron phosphate as a source of P in rice soils. *J. Indian Soc. Soil Sci.* *25*: 91-93.

Khana, S.S. and Mahajan, K.K. 1971. A study of the behaviour of added phosphates in soils of variable physico-chemical properties. *Proc. Int. Symp. Soil Fert. Evaln.* New Delhi, India. *1*: 725-736.

Koshy, M.M. 1971. Organic phosphorus in relation to the organic carbon and nitrogen contents of some Kerala soil types. *Agric. Res. J. Kerala.* *9*(2): 94-95.

Koshy, M.M. and Brito-Mutunayagam, A.P.A. 1961. Fixation and availability of phosphorus in soils of Kerala. Agric. Res. J. Kerala. 1: 70-78.

Koshy, M.M. and Brito-Mutunayagam, A.P.A. 1965. The mechanism of phosphorus fixation in soils and the nature of retained phosphates. Agric. Res. J. Kerala. 3: 32-39.

Kothandaraman, G.V. and Krishnamoorthy, K. 1977. Distribution of inorganic phosphorus fractions in Tamil Nadu Soils. Madras Agric. J. 64: 516-521.

Kothandaraman, G.V. and Krishnamoorthy, K. 1979. Forms of inorganic phosphorus in Tamil Nadu Soils. Bull. Indian Soc. Soil Sci. 12: 244-247.

Krivosheyen, M.P. 1981. Content of humus, nitrogen and phosphorus in the separates of distinct soils in the southern foot hills of the Western tarbagaty. Soviet Soil Sci. 3: 95-98.

Kumaraswamy, S. and Dhanapalan Mosi, A. 1969. Studies on fixation and availability of phosphorus in the alkaline soils of Tamil Nadu. Madras Agric. J. 56: 315-319.

Kurtz, T., Deturk, E.E. and Bray, R.H. 1946. Phosphorus adsorption by Illionis soils. Soil Sci. 61: 111-124.

Laveerty, J.C. and Mc Lean, E.O. 1963. Factors affecting yields and uptake of phosphorus by different crops. Soil Sci. 91: 166-171.

Leaver, J.P. and Russel, E.W. 1957. The reaction between phosphate and phosphate forming soils. J. Soil Sci. 8: 113-126.

Madhusoodhanan Nair, K. 1978. Studies on increasing the efficiency of rockphosphate in Kerala soils. M.Sc.(Ag) Thesis, Kerala Agricultural University.

Madhusoothanan Nair, K. and Padmaja, P. 1983. Phosphorus fixing capacity of major rice soils of Kerala. Agric. Res. J. Kerala. 21(1): 63-65.

Mahapatra, I.C. and Patrick, W.M. Jr. 1971. Evaluation of phosphate fertility in water-logged soils. Proc. Int. Symp. Soil Fertalata Evaln. New Delhi, India. 1: 53-61.

Mandal, L.N. and Khan, S.K. 1972. Release of phosphorus from insoluble phosphatic materials in acidic low land rice soils. J. Indian Soc. Soil Sci. 20: 19-25.

Mandal, L.N. and Mandal, K.C. 1973. Influence of organic matter and lime on the transformation of applied phosphate in acid lowland rice soils. J. Indian Soc. Soil Sci. 21: 57-62.

Mandal, S.C. 1975. Phosphorus management of our soils. J. Indian Soc. Soil Sci. 23: 141-157.

*Mathan, K.K. 1964. Study of distribution, availability and fixation of phosphorus in Nilgiris Soils. M.Sc.(Ag.). Dissertation Univ. Madras.

*Mc. George, W.T. and Breazeale, J.F. 1931. The relation of phosphate availability, soil permeability and CO_2 to the fertility of Calcareous soils. Arizona Agr. Exp. Sta. Tech. Bull. 36: 73-78.

Meelu, O.P., Rana, D.S., Sharma, K.N. and Raghubir Singh. 1977. Comparative efficiency of different complex phosphatic fertilizers. J. Indian Soc. Soil Sci. 25: 374-378.

Mehta, P.M., Patel, J.M., Patel, M.L. and Bafna, A.M. 1979. Forms of phosphorus in profiles of Deep Black soils of Heavy Rainfall Area of Gujarat. Bull. Indian Soc. Soil Sci. 12: 249-258.

*Metzger, W.H. 1940. Significance of adsorption or surface fixation by some soils of the praire group. J. Am. Soc. Agron. 32: 513-525.

Metzger, W.H. 1941. Phosphorus fixation in relation to iron and aluminium of the soil. J. Am. Soc. Agron. 33: 1093-1099.

Mishra, B. and Gupta, R.D. 1978. Evaluation of Mussoorie rockphosphate as phosphorus source for maize in acid soils of Kumaon soils. Indian J. Agric. Sci. 48: 239-244.

Mishra, B., Mishra, N.P. and Sharma, R.D. 1980. Direct and residual effect of Mussoorie rockphosphate applied in conjunction with pyrites or superphosphate on Maize-wheat rotation in Sub-montane soils. Indian J. Agric. Sci. 50: 691-697.

Misra, S.H. and Ojha, S.K. 1969. P distribution in black and red soils of U.P. Madras Agric. J. 56: 455-462.

Motsara, M.R. and Datta, N.P. 1976. Management of acid soils by the use of basic slag and rockphosphate. Bull. Indian Sci. Soil Sci. 11: 277-282.

Murphy, W.F. 1939. The role of kaolinite in phosphate fixation. Hilgardia 12: 343-382.

Nad, B.K., Goswami, N.N. and Leelavathi, C.R. 1975. Some factors influencing the phosphorus fixing capacity of Indian soils. J. Indian Soc. Soil Sci. 23: 319-327.

Nair, S.P. and Aiyer, R.S. 1966. Studies on the factors governing the available phosphorus status of acid soils of Kerala State. Agric. Res. J. Kerala. 4(2): 61-67.

Nambiar, P.K.N. 1962. Studies on the fractions of soil phosphorus and the absorption and retension of ammonium nitrogen in Kerala soils. M.Sc. Thesis submitted to the University of Kerala.

Pareek, B.L. and Mathur, C.M. 1969. Available and total phosphorus status of soils of Rajastan. J. Indian Soc. Soil Sci. 17: 147-149.

Parfitt, R.L. 1978. Anion adsorption by soils and soil materials. Adv. Agron. 30: 1-50.

Patel, D.K. and Vishwanath, D. 1946. Comparative studies on Indian soils. XI. Phosphate fixation capacities of soils. Indian J. Agric. Sci. 16: 428-434.

Patel, J.M. and Mehta, B.V. 1962. Vertical distribution of total and available phosphorus in some typical soil profiles of Gujarat. Indian J. Agric. Sci. 32: 178-188.

Pathak, A.N., Shrikhande, J.G. and Mukerjee, S.K. 1950. Phosphate fixation in alluvial soils. Curr. Sci. 19: 290-291.

Pearson, R.W., Spry, R. and Pierre, W.H. 1940. The vertical distribution of total and dilute acid-soluble phosphorus in twelve Iowa soil profiles. J. Amer. Soc. Agron. 32: 683-696.

Perkins, A.T., Dragsdo, R.D. and Bhangoo, M.S. 1957. Reactions between phosphates and kaolinitic decomposition products. Soil Sci. Soc. Am. Proc. 21: 154-157.

Peterson, G.W. and Corey, R.B. 1966. A modified Chang and Jackson procedure for routine fractionation of soil-P. Proc. Soil Sci. Soc. Am. 30: 563-565.

Piper, C.S. 1966. Soil and plant analysis. University of Adelaide, Australia.

*Rajgopal, C.K. and Idrani, M.A. 1963. J. Indian Soc. Soil Sci. 11: 141-146.

Raghupathy, B. and Raj, D. 1973. Availability fluctuations of soil phosphorus fraction during paddy growth under flooded conditions. Madras agric. J. 60(1): 17-22.

Ramamurthy, B. and Velayutham, M. 1976. Soil fertility theory and practice. J.S. Kanwar Ed. Indian Council of Agricultural Research, New Delhi, p.156.

Rastogi, R.C., Misra, B. and Ghildyal, B.P. 1976. Effect of pyrites and organic matter on the release of P from rockphosphate. J. Indian Soc. Soil Sci., 24: 175-181.

Raychaudhuri, S.P. and Landey, R.J. 1960. Effect of soil reaction on the availability of phosphorus and potash. J. Ind. Soc. Soil Sci. 8: 171-175.

Raychaudhuri, S.P. and Mukerjee, M.K. 1941. Studies on Indian red soils II. Fixation of phosphate. Indian J. Agric. Sci. 11: 205-219.

Raychaudhuri, S.P. and Mukherjee, M.K. 1963. Indian contribution to study of phosphate fixation by soils, clay, minerals, hydrous oxides and lime. J. Indian Soc. Soil Sci. 11: 195-201.

*Runge, E.C.A. & Riecken, F.F. 1966. Proc. Soil Sci. Soc. Am. 30: 624.

Russel, E. and Russel, E.W. 1932. Soil conditions and plant growth. 8th Ed.

*Sharma, P.K. 1967. The phosphorus status of the soils of Kangra and Kulu Districts of Himachal Pradesh. M.Sc. Thesis, PAU, Ludhiana, Hissar.

Sharma, P.K. and Tripathi, B.R. 1984. Phosphorus availability indices in relation to phosphorus fractions in some Himalayan acid soils of north-west India. J. Indian Soc. Soil Sci. 32: 292-298.

Sharma, P.K., Verma, S.P. and Bhumbla, D.R. 1980. Transformation of added P into inorganic P fractions in some acid soils of Himachal Pradesh. J. Indian Soc. Soil Sci. 28: 450-453.

Sharma, R.C., Sud, K.C. and Swaminathan, K. 1979. Phosphorus forms in brown hill soils of Simla district and their availability to potato. Bull. Indian Soc. Soil Sci. 12: 259-264.

Singh, B. and Mehrotra, N. 1978. A note on comparative availability of phosphorus from rockphosphate, superphosphate alone and with pyrites in alluvial soil. Madras Agric. J. 65: 678-680.

Singh, D. and Das, B. 1945. Phosphate studies on the Punjab soils. *Ind. J. Agric. Sci.* **13**: 134-141.

Singh, D. and Datta, N.P. 1973. Effect of particle size of rockphosphate on their fertilizer value for direct application to the soil. *J. Ind. Soc. Soil Sci.* **21**: 315-318.

Singh, R.S. and Dixit, N.K. 1983. Transformation of inorganic phosphorus in soils growing rice. *J. Indian Soc. Soil Sci.* **31**: 298-301.

Singh, R.N., Sahi, B.P., Diwakar, D.P.S. 1986. Forms of phosphorus in finer mechanical separates of soils developed on different parent material and their genetic relationship. *J. Indian Soc. Soil Sci.* **34**: 476-83.

Singh, R.S. and Ram, N. 1977. Inorganic transformation of added water soluble phosphorus in soils of Uttar Pradesh. *J. Ind. Soc. Soil Sci.* **24**: 53-56.

Singhania, R. and Goswami, N.N. 1978. Transformation of applied phosphorus in soils under rice. Wheat cropping sequence. *Plant Soil.* **50**: 527-535.

Singhania, R.A. and Goswami, N.N. 1979. Relationship between available phosphorus and phosphate fractions in soil. *Bull. Indian Soc. Soil Sci.* **12**: 377-384.

Stout, P.R. 1939. Alteration in the crystal structure of clay minerals as a result of phosphat fixation. *Soil Sci. Soc. Am. Proc.* **4**: 177-182.

Sudhir Agrawal, Singh, T.A. and Bhardwaj, V. 1987. Inorganic soil phosphorus fractions and available phosphorus as affected by long term fertilization and cropping pattern in Nainital Tarai. *J. Indian Soc. Soil Sci.* **35**: 25-28.

Thakur, R.S., Besen, D.C. and Dubey, S.M. 1975. Transformation of applied P under waterlogged conditions in rice culture. J. Indian Soc. Soil Sci. 23: 391-507.

Tandon, H.L.S. 1980. Soil fertility and fertilizer use research on wheat on India review. Fert. News 25: 45-52.

Tuner, R.C. and Rice, H.M. 1952. Role of fluoride ion in release of phosphate adsorbed by aluminium and iron oxide. Soil Sci. 74: 141-148.

Venkataramana Reddy, R. 1967. Fraction and availability studies on soil inorganic phosphorus in Mysore State soils. M.Sc.(Ag.) Dissertation Univ. Madras.

Venugopal, V.K. 1969. Cation exchange studies in Kerala soils. M.Sc.(Ag.) Thesis, University of Kerala.

*Vijayachandran, P.K. 1966. Studies on soil phosphorus. Ph.D. Thesis, Univ. Madras.

Vijayachandran, P.K. and Raj, D. 1978. Available and forms of P in typical South Indian acid soils and their relationships. Proc. Natn. Symp. plantation crops.

Williams, E.G. and Saunders, W.M.H. 1956. Distribution of phosphorus in profiles and particle-size fractions of some Scottish soils. J. Soil Sci. 7(1): 91-108.

Wright, J.B. and Peach, M. 1960. Characterisation of phosphate reaction products in acid soils by application of solubility criteria. Soil Sci. 90: 32-44.

Yadavanshi, H.S., Kamala Kanwar and Kamlesh Singh. 1986. Transformation of different sources of phosphate and their uptake by wheat in an Alfisol. J. Indian Soc. Sci. 34: 291-296.

*Yuvan, T.L., Robertson, W.K. and Nellar, J.R. 1960. Forms of Newly fixed phosphorus in three acid soils. Soil Sci. Soc. Amer. Proc. 24: 447-450.

* Originals not seen

APPENDICES

APPENDIX I

T-value of surface and subsurface characters

No.	Characters	X Mean	Y Mean	T-value
1	Coarse sand (%)	36.72	36.2	0.204
2	Fine sand (%)	13.94	15.34	-1.101
3	Silt (%)	25.08	24.73	0.126
4	Clay (%)	21.79	25.31	-0.809
5	pH	4.63	4.31	2.644*
6	Organic carbon (%)	1.72	1.12	2.58*
7	Total P_2O_5 (%)	0.23	0.16	3.142*
8	Sesquioxides (%)	14.67	14.47	0.275
9	Total aluminium (mg/g)	44.33	33.82	1.342
10	Total iron (mg/g)	36.20	39.46	-0.918
11	CaO (%)	0.133	0.107	1.831
12	PFC (%)	61.07	63.40	-0.850
13	Available P_2O_5 (ppm)	29.00	23.5	1.712
14	Saloid-P (ppm)	9.2	6.1	2.575*
15	Al-P (ppm)	35.2	21.5	2.373*
16	Fe-P (ppm)	298.9	254.3	2.369*
17	Occluded-P (ppm)	18.2	10.2	3.259*
18	Red-P (ppm)	240.2	150.4	1.935
19	Ca-P (ppm)	41.7	48.1	-0.80
20	Organic-P (ppm)	354.6	184.8	2.883*

X - surface mean

Y - subsurface mean

$T_{(0.05)} = 2.145$

* Significant at 5%

APPENDIX II

ANOVA TABLE

Source	DF	SS	MSS	F
Replication	14	3098.61	221.3293	3.781278*
A	2	15153.39	7576.694	129.4433**
Error 1	28		58.53293	
B	7	999.00	142.7145	53.00237**
AB	14	1220.078	87.14844	32.36588**
Error 2	294		2.692602	
Total	359	22901.62		

* Significant at 0.05%

** Significat at 0.01%

APPENDIX III(a)

Mean P_2O_5 content in clay and silt in two depths before and after treatments

(P_2O_5 ppm)

Details	Mean values		't' value
	Surface	Subsurface	
<u>Before treatment</u>			
Clay	9509	4563	3.143*
Silt	1738	1364	1.807
<u>After treatment</u>			
Clay	17299	9115	2.76*
Silt	3136	2573	1.18

* Significant at 5% level

APPENDIX III(b)

Comparison between the clay and silt for P_2O_5 content before and after treatment

Details	Mean P_2O_5 content in		't' value
	Clay ppm	Silt ppm	
Before treatment	7035.80	1550.97	7.33*
After treatment	12559.07	2888.03	7.81*

APPENDIX-IV. Correlation between different soil properties

	Coarse sand	Fine sand	Silt	Clay	pH	Organic carbon	Total P_2O_5	Sesqui-oxides	Total Al content	Total Fe content	Available P_2O_5	CaO	Saloid-P	Al-P	Fe-P	Red-P	Occluded-P	Ca-P	Organic-P	
se sand	1.0000																			
sand	0.2500	1.0000																		
	¯0.5536	¯0.3806	1.0000																	
	¯0.7072	¯0.5134	0.1222	1.0000																
	0.0464	¯0.0675	¯0.2633	0.0979	1.0000															
nic ion	¯0.4577	¯0.1247	0.0345	0.3287	¯0.0321	¯1.0000														
l	¯0.4637	¯0.4631	0.3217	0.4278	0.4260	0.4994	1.0000													
ui- les	¯0.6857	¯0.3425	0.4280	0.5709	0.3978	0.0659	0.5025	1.0000												
l Al- ent	¯0.3572	¯0.5112	0.4220	0.3106	0.3034	0.2967	0.5585	0.3632	1.0000											
l Fe- ent	¯0.6619	¯0.4684	0.5794	0.6399	0.0995	0.0912	0.4058	0.7047	0.4759	1.0000										
lable	¯0.2397	0.2047	¯0.1906	¯0.2994	¯0.1076	0.3095	0.1821	¯0.4216	¯0.0788	¯0.4322	1.0000									
	¯0.0085	¯0.4285	¯0.0596	0.1348	0.4081	0.2301	0.4289	0.2748	¯0.0563	0.0798	0.1320	1.0000								
oid-P	0.0329	0.0230	¯0.0364	¯0.1095	0.0144	0.4296	0.3853	¯0.1969	0.0553	¯0.1866	0.7734	0.2039	1.0000							
P	¯0.2566	¯0.1800	0.1317	0.2361	0.1240	0.4455	0.3502	0.1271	0.3654	0.3165	0.2889	0.0957	0.4885	1.0000						
P	¯0.5614	¯0.4945	0.4603	0.5233	0.3592	0.2298	0.7081	0.6709	0.6524	0.7352	¯0.1306	0.3319	0.0602	0.4087	1.0000					
-P	¯0.1400	0.0288	0.1255	¯0.0060	0.2642	0.2328	0.6043	0.2985	0.3589	0.0089	0.3538	0.0539	0.3488	0.1120	0.1807	1.0000				
luded-P	¯0.0125	0.1069	¯0.1402	¯0.0431	0.5728	0.1682	0.4856	0.3785	0.1044	¯0.0402	0.0623	0.3503	0.1431	0.1787	0.3343	0.4432	1.0000			
P	¯0.3897	¯0.6317	0.4127	0.4826	0.1694	0.1109	0.4863	0.4318	0.0440	0.5384	¯0.0341	0.6046	0.1340	0.1680	0.6896	¯0.1249	¯0.0543	1.0000		
anic-P	¯0.1641	¯0.2572	¯0.0421	0.2288	0.2739	0.5622	0.7073	0.0129	¯0.3156	¯0.0256	0.2717	0.3842	0.3678	0.0850	0.1837	0.2724	0.3624	0.2115	1.0000	
	¯0.7342	¯0.3039	0.1269	0.7882	¯0.0099	0.3597	0.2151	0.5150	0.1545	0.4610	¯0.3586	¯0.0085	0.1861	0.0670	0.3814	¯0.2108	¯0.0778	0.3252	0.1392	1

THE DISTRIBUTION FIXATION AND AVAILABILITY OF PHOSPHORUS IN THE KOLE SOILS OF KERALA

By

SHEELA S.

ABSTRACT OF A THESIS
submitted in partial fulfilment of the
requirements for the degree
MASTER OF SCIENCE IN AGRICULTURE
Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
College of Agriculture
Vellayani, Trivandrum
1988

ABSTRACT

An investigation of the distribution, fixation and availability of phosphorus in the surface (0-20 cm) and subsoils (20-40 cm) of 15 locations in the Kole area of Trichur district of Kerala was carried out in relation to their physico-chemical properties.

The surface and subsurface layers showed significant difference in total P_2O_5. In all soils except in the soil from Kanjani area total phosphorus decreased markedly with depth. The subsurface layer of Kanjani contained higher amounts of total P_2O_5 which may be due to the accumulation of organic-P in this layer. Total P_2O_5 was significantly and negatively correlated with coarse sand and fine sand and significantly and positively correlated with clay, silt and organic carbon. All inorganic fractions were positively and significantly correlated with total P_2O_5. In the case of available P_2O_5, the maximum accumulation was found in the surface layer except in the Kanjani area. The variation in available P was not in direct proportion to the total P content.

Fractionation study showed that saloid-P was the smallest fraction in these soils. In all locations saloid-P

decreased with depth except at Kanjani which might be due to accumulation of organic matter in the subsurface layer. Al-P was the third most abundant fraction in these soils next to Fe-P and Red-P. Fe-P fraction was the most widely distributed fraction. The predominance of Fe-P in these soils may be attributed to the low pH and high content of sesquioxides. The second most abundant fraction was the Red-P. Occluded-P and Ca-P have not contributed much to the pool of total-P. Of the six inorganic fractions studied saloid-P, Al-P, Fe-P and occluded-P showed significant differences between the two depths.

The phosphorus fixing capacity of these soils ranged from 15.0 to 88.0 percent with averages of 61.1 and 63.4 percent respectively in the surface and subsurface soils. Correlation study indicated a significant positive correlation between P fixation and total iron, total aluminium, total sesquioxides, clay, silt and organic matter.

Fractionation of the soil after P treatment indicated that the phosphorus applied as $KH_2 PO_4$ was recovered in all inorganic forms of soil phosphorus, viz., saloid-P, Al-P, Fe-P, Red-P, occluded-P and Ca-P. A small part of the organic-P also got mineralized to inorganic forms.

The availability of P from the two phosphatic fertilizers viz., superphosphate and Mussoorie rockphosphate was studied. It was revealed that both fertilizers were equally effective in these soils.

The distribution of native phosphorus in clay and silt was also investigated. Statistical analysis showed that there was significant difference between clay and silt for this character and that the clay contained more phosphorus than silt. The studies on the amounts of added phosphorus retained by clay and silt revealed that these fractions differ widely in the P retention capacity and that the clay retained more phosphorus than silt.