BEHAVIOUR OF PHOSPHORUS IN SELECTED SOIL TYPES OF KERALA

By

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THESIS

Submitted in partial fulfilment of the
requirement for the degree

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
COLLEGE OF HORTICULTURE
Vellanikkara - Thrissur

1993

DECLARATION

I hereby declare that this thesis entitled "**Behaviour of phosphorus in selected soil types 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.

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CERTIFICATE

Certified that this thesis entitled "**Behaviour of phosphorus in selected soil types of Kerala**" is a record of research work done by **Sri.A.P.Vijayan**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

DR.SUMAM SUSAN VARGHESE
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CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Mr.A.P. Vijayan**, a candidate for the degree of Master of Science in Agriculture with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled **"Behaviour of phosphorus in selected soil types of Kerala"** may be submitted by Mr.A.P.Vijayan in partial fulfilment of the requirement for the degree.

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ACKNOWLEDGEMENT

My profound and unreserved gratitude goes to **Dr.Sumam Susan Varghese,** Associate Professor, Department of Soil Science and Agricultural Chemistry and Chairperson of my Advisory Committee for her expert counsel and unfailing help throughout the course of this investigation. Her expert guidance and unfailing patience helped me a lot that I owe to her beyond words.

I am obliged to **Dr.A.I.Jose,** Professor and Head, Department of Soil Science and Agricultural Chemistry for the help and co-operation received from him during the entire programme.

I am grateful to **Dr.N.P.Chinnamma,** Professor, Department of Soil Science and Agricultural Chemistry for the uninterrupted support and guidance given to me throughout my course period.

It is with immense pleasure that I thank to **Smt.T.K.Indira Bai,** Assistant Professor, Department of Agricultural Statistics for the guidance and wholehearted help extended to me in the statistical analysis.

I am very much grateful to **Dr.P.K.Sushama,** Associate Professor, Department of Soil Science and Agricultural Chemistry for her timely advice and other helps which enabled me for the successful completion of this study.

I wish to express my sincere thanks to all the staff members of the Department of Soil Science and Agricultural Chemistry for the timely and wholehearted co-operation and assistance they always accorded me during the course of this study.

My profound gratitude is placed on record to **Sri.P.Prabhakaran**, Professor and Head, Department of Agricultural Statistics, **Smt.K.A.Mercy**, Assistant Professor, **Smt.V.J.Joicy** and **Sri.C.Ajith** of the same Department for their generous help rendered to me in using computer for the successful statistical analysis.

I am thankful to **Dr.C.C.Abraham**, Associate Dean, College of Horticulture for his help and many acts of kindness during the course of research work.

My classmates and friends were of immense help to me during the entire period of the study. I am happy to place on record my sincere thanks for the willing assistance rendered wholeheartedly by Homey Cheriyan, Jomon Joseph, P.Muraleedharan, K.S.Saphena, C.Sivakumar, S.Jyothimani, Dr.D.Prema and E.S.Mini.

At this moment, I remember with love and gratitude the constant encouragement and inspiration given to me by my beloved parents, brothers and sisters.

Thanks are also due to Sri.K.A.Joy for the neat and prompt typing of the thesis.

Above all, I bow my head before God Almighty, whose blessings were with me at every inch of the way, enabling me to undertake this venture successfully.

Vellanikkara,
17-09-1993.

A.P.VIJAYAN

To my father

CONTENTS

ABBREVIATIONS

S-P	- Saloid bound phosphorus
Al-P	- Aluminium bound phosphorus
Fe-P	- Iron bound phosphorus
Ca-P	- Calcium bound phosphorus

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Introduction

INTRODUCTION

The significant role of phosphorus in sustaining and building up of soil fertility, particularly under intensive system of agriculture has been amply demonstrated from the results of large number of studies carried out all over the world. The dynamics of phosphorus transformation in the soil system and its fixation and release characteristics have been the subject of numerous research investigations. But in actual practice the most pertinent issue is to know how much of phosphorus can be made available to the growing crop from the native soil pool.

The knowledge of the various forms of P present in soil and the condition under which they become available to plants is a pre-requisite for assessing the availability of P to the crop. The availability of P to the plants is assessed by using chemical extractants because of their easiness in application though they are empirical in nature.

The phosphate availability in soils is intimately related to the physico-chemical laws which controls the equilibrium attained in a soil under a given set of conditions. The phosphate potential, equilibrium phosphate potential and buffering capacity are reported as better indices of P availability.

The concept of quantity-intensity relationship has proved as a useful guide in understanding the phosphorus supply to plant ration in the solution or the resulting degree of saturation.

Phosphorus sorption behaviour of soil is important in determining the availability of phosphorus from the fertilizers to the plant roots. Since different forms of soil P have different solubilities, the availability and uptake of P largely depends on the amounts of different fractions present in soil. If the existing soil testing methods are made to tap in the same proportional amounts of nutrient from the different forms as the plants, their suitability for assessing the fertility status of soil can be improved. Keeping these points in view, the present investigation was undertaken for the selected soil types of Kerala with the following objectives.

(1) To assess the different inorganic P-fractions of different types of soils and to get an idea of their relative contribution to the plant available phosphorus.

(2) To study the suitability of extractants for the selected soil types.

(3) To study the Q/I relationships of phosphorus as a method to estimate the nutrient requirement by plants.

(4) To study the adsorption-desorption characteristics in selected soil types of Kerala.

Review of Literature

REVIEW OF LITERATURE

The complex nature of soil phosphorus and its pattern of availability have become, the subject of continuous research for soil scientists all over the world. The complex nature of phosphorus tried to understand by various workers are reviewed under phosphorus forms in soil, its methods of extractions, uptake relationships to forms of phosphorus, different extraction methods, phosphate potential, equilibrium phosphate potential, differential phosphate buffering capacity and Q/I relationship, adsorption and desorption characteristics, and soil properties and phosphorus content.

1. Forms of phosphorus in soil

1.1. Forms of phosphorus in different soil types

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

The abundance of iron and aluminium phosphates in Kerala soils were reported by Nambiar (1963).

In an investigation conducted by Rajukkannu and Ravikumar (1975) Fe-P fraction was found to be prime source of available P to the plants. They got lower values of Fe-P in black soil and higher in alluvial and laterite soils. Kothandaraman and Krishnamoorthy (1979) reported that in the soil types of Tamil Nadu, P fractions viz., Al-P, Fe-P, Reductant soluble-P and occluded P were relatively more in high altitude laterite soils, but Ca-P dominated in black and alluvial soils.

Sheela (1988) studied distribution of phosphorus in Kole soils of Kerala and reported the abundance of Fe-P.

Doddamani and Rao (1988) revealed that Ca-P was the dominant mineral form of phosphorus in vertisols and inceptisols and constituted 19.5 and 11.5 per cent of the total P.

Viswanathan and Doddamani (1991) reported that Ca-P is the dominant mineral form of phosphorus in vertisols. They also reported that soil pH had negative and significant correlation with Al-P and Fe-P.

1.2. Forms of phosphorus in relation to soil test methods

In soils dominated by iron phosphate the values for available phosphorus determined by Olsen, Peech, Bray's No.1, No.2, No.4, Truog and North Carolina methods are all mutually correlated. In soils dominated by Ca-P and Fe-P, Olsen, Peech and Bray No.4 correlated mutually. For calcium phosphate dominating soils Olse and Bray No.1 and the method of Bray No.2 and No.4, North Carolin and Truog are respectively highly correlated (Chang and Juo, 1962).

Relationship between inorganic phosphate fractions and available phosphorus was studied through multiple correlation and regression technique on four major soils viz., alluvial, black, red and laterite by Singania and Goswami (1979). Available P extracted by Olsen gave correlation with all the P fractions (Al-P, Fe-P, Ca-P, Reductant soluble-P). Al-P is the main source of Olsen and Bray-P in black and alluvial soils and it is Fe-P in laterite and red soil.

Sharma and Tripathi (1984) reported that Olsen's extractant removed most of its P from Al-P fraction followed by Ca-P fraction. The multiple regression analysis showed that about 65.7 per cent variation in Olsen P was accounted by the variation in Al-P fraction alone.

Khadtar et al. (1991) studied the availability of phosphorus in rice growing lateritic soils. The extractants of Olsen's and Bray P_2 methods removed dominantly the Al-P and Fe-P fractions respectively.

In rice soils of Tamil Nadu Al-P and Fe-P contribute dominantly to the labile P pool accounting for 85-96 per cent of the Olsen P and Bray No.1-P, Ca-P fraction appeared to contribute very little to the P extracted by these methods. Olsen and Bray No.1 extractants were found to be more consistant in extracting P from specific P fractions in all the soils than the other three extractants of Truog, Mehlich and Morgan (Kumaraswamy and Sreeramulu, 1991).

Verma et al. (1991) reported that Olsen-P is closely and positively related with Al-P, Fe-P and Ca-P in Karail soils, red, alluvial and Tarai soils.

While studying the distribution of phosphorus fractions in vertisols, Viswanathan and Doddamani (1991) reported greater availability of Ca-P in calcareous soils.

1.3. Forms of phosphorus in relation to yield and uptake

Thakur et al. (1977) conducted a pot culture experiment with rice soils of Madhya Pradesh to study the correlation coefficient with inorganic P fractions and total P uptake. The total P uptake correlated with Al-P (r = 0.753) and Fe-P (r = 0.677). The grain yield also correlated with Al-P (r = 0.584) and Fe-P (0.563).

Patiram et al. (1990) in their studies on acid soils of Sikkim reported that Al-P contributed more towards P availability to maize than Fe-P and Ca-P.

Kumaraswamy and Sreeramulu (1991) while investigating P fractions and uptake by rice in Tamil Nadu soils reported that in Kodveri and Vayalogum soil series, 82 to 89 per cent of the P uptake by the rice crop was accounted by Fe-P and Al-P with greater contribution from Fe-P. In Kolathur and Madukkur soil series 77 to 84 per cent of the uptake by crop was from Al-P.

2. P extraction methods

2.1. Different extractants used

A number of laboratory indices of absorption of soil phosphorus by plants have been suggested. Different extractants which are getting importance and still in use are those with one or more solutions. These solutions will dissolve that fractions of phosphorus which are considered available to plant roots. The different extractants cover water, dilute acids, alkali, salt solutions and combinations of these solutions.

Water has been suggested as an extractant for available phosphorus in soil by Puri and Asghar (1936), Burd and Murphy (1948), Thompson et al. (1960) and Van Diest (1963) used CO_2 solution as an extractant.

One of the first extractants used for the estimation of available phosphorus was 1 per cent citric acid solution (Dyer, 1894). The Dyer's method was adopted by Jones (1949), Balasubramaniam (1966), Ahmed et al. (1967) and Misra and Ojha (1969).

Mineral acids like sulphuric acid, hydrochloric acid and nitric acid have also been used. Truog (1930) extracted soils with 0.002 N H_2SO_4 (buffered to pH 3 with $(NH_4)_2SO_4$). Olsen (1946) used 0.7 N HCl as extractant. Nelson et al. (1953) used 0.05 N HCl + 0.025 N H_2SO_4 as phosphate extractant.

Mathew (1979) found that resorption of P from the solution can be effectively prevented by employing organic acids and thus the amount of P extracted by the mineral acid could be increased by the presence of organic acids notably oxalic acid and he used 0.06 N H_2SO_4, 0.06 N HCl and 0.05 N oxalic acid.

Bray and Kurtz (1945) used 0.5 M NH_4F and 0.1 N HCl as an extractant.

Dupuis (1950) extracted soil phosphorus using 0.3 M NH_4F and 0.025 N HCl.

Datta and Kamath (1959) used 0.03 M NH_4F and 1 per cent EDTA as the extractant of soil phosphorus.

Das (1930) used 1 per cent K_2CO_3 at pH 8.5 as an extractant for soil phosphorus.

Olsen et al. (1954), Webber and Mattingly (1970) and Bowman and Cole (1978) used 0.5 M $NaHCO_3$ adjusted to 8.5 pH as a suitable extractant for available phosphorus in soil.

Jones (1949) used 0.5 N NaOH as an extractant. Saunder (1956) used hot 0.1 N sodium hydroxide as an extractant. 0.3 N NaOH + 0.5 N sodium acetate was used by Al-Abbas and Barber (1964).

2.2. Evaluation of methods

Nair and Aiyer (1966) studied the available P extracted with the different extractants and plant uptake in rice soils of Kerala.

They found that Olsen's extract gave better correlations than Bray No.1 and Saunders.

Jose (1972) compared several methods of measuring available P in soils of South India and reported that anion exchange resin and isotopic dilution technique gave highly correlated values with P uptake by ragi plants. Among the chemical extractants, Bray No.1, Al-Abbas, Barber and Olsen reagents gave close correlation with plant uptake studies.

Mohan (1978) reported the suitability of double acid mixture consisting of 0.05 N HCl and 0.02 N H_2SO_4 as a suitable extractant for available P in Kerala soils.

Mathew (1979) revealed that Bray No.1 could not estimate 'RA-value' of the soil i.e., total available phosphate reserve, soil.

Durgadevi (1986) reported that Mathew's triacid extractant could release relatively large amounts of P from soils containing very little as well as very high amounts of P. She established the suitability of Bray No.1 as an extractant for .ilable P and got significant correlation with uptake studies in Kerala soils.

Khadtar *et al*. (1991) reported that the Olsen P and Bray-P_2 methods were superior to Truog P and Bray P for predicting available P for rice in lateritic soils.

3. Phosphate potential

The ability of a soil to supply phosphate to plants depends upon two properties; one the ease with which phosphate may be removed, and 2nd the ability of soil to maintain phosphate against its depletion. Schofield has proposed the phosphate potential ½ pCa + pH_2PO_4 as a measure of easiness of removal of phosphate by plants.

Bjerrum and Gjaldback (1919) the equilibrium relation found for soil containing $CaCO_3$ as

$$pH - 0.5\ pCa = pCO_2 + 5.02$$

where pCO_2 is the negative logarithm of the carbondioxide pressure in atmosphere.

Aslyng (1950) recommended a 10^{-2} M $CaCl_2$ solution and two soil/liquid ratios for this solution. A 10^{-2} M $CaCl_2$ is a sufficiently high concentration to keep the soil flocculated and thus obtain a clear filtrate and not too high for application of activity coefficients. The Ca ion is normally the dominating exchangeable cation and the Cl^- ion has no significant influence on the phosphate potential. The equilibrium between liquid and soil is obtained almost instantaneously.

Schofield (1955) introduced the concept of phosphate potential in soil science as a measure of the work needed to withdraw the phosphate from the pool by plant roots. The activity of $H_2PO_4^-$ and HPO_4^{2-} in the solutions are depending on the pH and temperature.

The (negative) potential of monocalcium phosphate in the soils is obtained by calculating from the pH and concentrations of Ca and P in the equilibrium solution the value of $\frac{1}{2}$ pCa + pH_2PO_4.

The determination of the phosphate potential was investigated by Lemare (1960), White and Beckett (1962), Beckett and White (1964) and Larsen (1965).

Barrow (1966) studied plant uptake of P and P potential as a measure of predicting P availability using soft brome. The progressive uptake of P could be described by

$$\text{Uptake} = 0.0375\ (t-21)\ (1-b)\ (8.92 + 0.0043t + \text{Potential})^2$$

where (1-b) is an index of buffering capacity

t - days after sowing

Sengupta (1966) observed phosphate potential to be a better method for available phosphate measurement than the conventional methods in the case of soils not grouped on the basis of their clays.

Bagchi and Chakravarti (1972) showed that in Nadia soils the lime potential remained more or less constant though pH of the suspension varies with dilution.

Sengupta (1975) observed Schofield's phosphate potential showed little or no significance when correlated with P concentrations in 60 days old oat plants.

Elrashidi and Larsen (1978) studied effect of phosphate withdrawal by plant and by an anion exchange resin on the phosphate potential of soil and the results showed that phosphate depletion either by plants or anion exchange resin did not change the phosphate potential of soil.

Typical alluvial, black, red and laterite soil types of Karnataka were characterised for phosphate potential by Doddamani (1982) and the data on P values revealed that pP of black and alluvial soils was higher than that in red and laterite soils. The higher pP values in black and alluvial soils may be attributed to the high soil pH, which reduced the concentration of $H_2PO_4^-$ at higher pH and high organic matter in alluvial soils.

Polyzopoulos _et_ _al_. (1982) correlated phosphate potential with P uptake by rye grass in pot culture experiment in different Alfisols. Prakash (1988) studied the phosphate potential in Karnataka soils and reported a high correlation between available P and phosphate potential.

Sushama (1990) made extensive studies on coastal laterites of Karnataka and reported that the $H_2PO_4^-$ concentration increased due to low pH and it inturn reduced the P potential. The Io (related to the available P) was negatively and significantly correlated with soil pH and available P. This indicates that the concentration of P in soil solution would increase with an increase in soil solution pH and available P.

4. Equilibrium phosphate potential

Ramamoorthy and Subramanian (1960) introduced the concept of equilibrium phosphate potential (EPP) and determined it in a P solution of such a concentration that there is no loss or gain of P when it was shaken with soil. They concluded that EPP was a better estimate of the chemical potential of the phosphate in the original soil than the Schofield's P potential (pP). White and Beckett (1962), Sengupta (1966), White and Haydock (1967) and Sarkar (1971) had made extensive studies of equilibrium phosphate potential.

Sarkar and Hetram (1974) observed that there is a fall in EPP immediately after P application and increased considerably after 45 days of fertilizer application. Sengupta (1975) reported that phosphate potential (Schofields) showed little or no significance while equilibrium phosphate potential (EPP) showed high level of significance when correlated with P concentration in oat plants.

Stadler and Stewart (1977) observed that in soils where intensity was not controlled by quantity, the intensity factor alone and in soils where intensities were controlled by quantity, quantity/ intensity factor correlated with the available P to the plants.

Biswas et al. (1979) studied EPP of a loamy sand (pH 8.2) and measured after two cycles of crop rotation in a multiple cropping system. They noted that P fertilization increased the intensity of P. The available P and EPP were significantly correlated with P uptake by maize grain and stover but not with their P content.

Keramidas and Polyzopoulos (1983) studied a number of phosphorus intensity indices. Simple intensity indices such as P concentration in either $CaCl_2$ or H_2O extracts proved as good as more elaborate ones.

Black soils showed higher EPP values than the alluvial and the red soils (Lakshmi <u>et</u> <u>al</u>., 1987). They also noticed that relationships of EPP were highly significant and positive with pH, $CaCO_3$ and exchangeable calcium where as they were negative with oxides of aluminium and manganese.

Patiram and Rai (1987) reported that liming consi[illegible]ol reduced the EPP and concluded that EPP could be a factor go[illegible]ing the available P compounds.

Patiram <u>et</u> <u>al</u>. (1990) while studying the acid soils of Sikkim reported equilibrium phosphate potential as a good availability index with respect to maize and they got a threshold value of 7.2.

5. Adsorption and desorption of phosphorus

The phosphate adsorption is regarded as a typical physical and chemisorption reaction.

Olsen and Watanabe (1957) showed that adsorption of phosphorus by soil followed the Langmuir isotherm more closely than with Freundlich isotherm. They worked out two constants of P adsorption maxima and bonding energy of soils on the basis of Langmuir adsorption isotherm.

Woodruff and Kamprath (1965) reported that the soils with a high sesquioxide had a large adsorption maxima.

Barrow and Shaw (1975) reported that the amount of phosphate desorbed decreased as the period of prior contact between soil and phosphate increased.

Gupta _et_ _al_. (1977) reported that sorption capacity appears to be related to surface area, clay and Fe_2O_3 contents respectively. The $CaCO_3$ content decreased the exchangeability of sorbed P and helped in removing P from solutions.

Kothandaraman and Krishnamoorthy (1978) showed that P adsorption was characterised by an initial fast reaction followed by a slow process in all the soils studied.

P adsorption maxima was positively correlated with total sesquioxides, silt, organic carbon, clay content, free iron oxide and negatively correlated with soil pH (Sundararajan and Kothandaraman, 1978).

The phosphate adsorption by the oxisol upto an equilibrium phosphate concentration of 85 ppm P could be described with the help of Langmuir or Freundlisch adsorption isotherm model indicating that a monolayer of phosphate is formed on the particle surface. The estimated maximum surface saturation was 89.2 µg P/g. The rate constant of adsorption remained more or less same irrespective of phosphate concentration in free solution upto 200 ppm P. (Mohapatra _et_ _al_., 1979).

Vig _et_ _al_. (1979) reported that the rapid P desorption process was due to the dissolution of amorphous P compounds and the slow desorption process by the dissolution of crystalline P compounds.

Loganathan and Fernando (1980) reported that the sorption maxima were significantly correlated with per cent clay and silt.

Smyth and Sanchez (1980) found that previous application of P to a soil reduced P adsorption and increased the retention of cations on the soil complex compared to addition of amendments.

Laverdiere and Karam (1984) noticed that the P sorption data conformed to the linear form of the Langmuir and Freundlich equations.

Manikandan and Sastry (1984) reported that an increased soil solution ratio increased the amount of phosphate sorbed by soils. With increasing salt concentrations the amount of phosphate sorbed also increased.

The fraction of added phosphate recovered with phosphate sorption capacity but not with the maximum buffering capacity.

The formation of calcium phosphate compounds during sorption may be the reasons for the non linearity of the Langmuir isotherm plot (Hundal, 1988).

Mehadi and Taylor (1988) indicated that P adsorption was an endothermic process and suggested that P was held more tightly to the surface of soil.

Singh et al. (1990) reported that phosphorus adsorption of salt affected soils at field capacity depends on the time of contact between soil and added P. They also reported that P adsorption is less at lower concentrations.

Patiram and Prasad (1991) reported that application of phosphate increased the dry matter yield and uptake of P linearly in acid soils having high adsorption coefficients. The adsorption maxima and the energy of adsorption were inversely related to native P uptake and accounted for 92.3 per cent variability. The per cent adsorption, saturation of adsorption maxima and adsorption maximum saturation index had highly positive relationship with P uptake.

Singh et al. (1991) suggests that phosphorus adsorption by salt affected soils increased with increasing concentration of phosphate in solution. Hyperbolic relationship between adsorbed and adsorbed per equilibrium P concentration and deviation in Langmuir isotherm from linear relationship suggests the presence of two or more energetically different reactive sites in the soils.

6. Differential phosphate buffering capacity and Q/I relationships

Beckett and White (1964) suggested phosphate buffering capacity to predict the availability of phosphorus to plants and there by the fertilizer requirements. The Q/I relationships define the ability of a soil to maintain phosphate availability during periods of depletion short enough for the whole demand to fall on the phosphate already labile at the on set of depletion. The form of Q/I relations may also be interpreted to provide information on the transfer of phosphate from non labile to labile forms.

Jensen (1970) introduced the concept of differential phosphate buffering capacity (DPBC). It was determined as a quantity and intensity relationship

Differential phosphate buffering capacity is the necessary amount of phosphate to be added or removed per gram of soil inorder to obtain a certain alteration of the phosphate potential (Sarkar and Hetram, 1974). The accuracy in predicting P availability can be increased to a small extent by considering the Intensity and Capacity factors together (Holford and Mattingly, 1976). The level of Q or I varied with the buffering capacity of the soil. They could correlate P availability to plants with buffering capacity of soil.

Holford (1977) reported that there was marked variability in phosphate buffering when expressed as a good index of phosphorus availability. Maximum buffering capacity is highly correlated with $CaCO_3$, surface area, Fe content and pH of the soil.

Elrashidi and Larsen (1978) found that, the labile phosphate removed by plants appeared to be replaced by the mobilization of the non-labile phosphate fraction in the soil. The constancy of the phosphate potential indicated that the concentration of phosphate in the soil solution was controlled by the solubility of sparingly soluble soil phosphates.

Mittal et al. ,(1983) conducted green house study in Haryana soils to understand Q/I relationships and supply parameter values. The supply parameter values increased with P levels and had a wide range of variation. These showed positive and significant correlation with P uptake. The relative values of Q were higher for the soils which had lower values of supply parameters.

Brar et al. (1986) studied the adsorption of P in Punjab soil to determine the relationship between quantity, intensity and buffering capacity factors of soil P and the growth and P uptake of wheat. They concluded that the supply parameter was a better predictor of P supply than any one of the factors alone.

Lakshmi et al. (1987) reported that the buffering capacity tended to increase with clay content.

Patiram and Rai (1987) showed that liming decreased the EPP and DPBC although later was not consistent.

Phosphorus uptake by rye grass from four soils of Sri Lanka was significantly correlated with the P intensity and quantity measurements by Kumaraganga and Keerthisinge (1988). Multiregression indicated that at equal quantity levels, increasing buffering capacity tends to increase P uptake, suggesting that the quantity parameters was buffered by maximum buffering capacity.

Patiram (1990) reported that the Io (phosphate potential at Q = 0) was negatively and significantly correlated with soil pH and available P. This indicated that the concentration of P in soil solution could increase with an increase in soil solution. It also increase with soil pH and available P.

Patiram and Prasad (1991) stated that the uptake of P in maize was correlated negatively with differential buffering capacity (DBC) of P. The calculated supply parameters $[Cq/(k_1k_2)^{\frac{1}{2}}]$ and equilibrium soil solution P increased with increasing P levels and their variations were wide and it correlated positively with P uptake.

7. Soil properties and P content in soils

Jose (1972) observed that alluvial soils contain more labile phosphorus than red and black soils.

More *et al.* (1978) reported that there is significant negative correlation between pH and P fixation. They also reported that sand content did not bear any relation but P fixing capacity of soils is very much dependent on soil characteristics, as a single factor clay is the most influencing factor.

More *et al.* (1979) got significant negative correlation of available phosphorus and total phosphorus with calciu [illegible] bonate. While pH, organic carbon and clay content did not bear any relationship with available phosphorus in the soils, the availability of phosphorus was highly correlated with total phosphorus content in the soils.

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

Sah and Mikkelsen (1986) opined that temperature and prior flooding reduced soil P concentration but the effect of latter was dominant.

The positively correlated relationship of saloid-P with coarse particles in kole soils of Trichur was reported by Sheela (1988).

Singh *et al.* (1990) stated that labile and surface P increased and phosphate potential decreased with increased level of P, pH, ESP and SAR, showed negative correlation with labile and surface P and positive correlation with phosphate potential.

According to Verma *et al.* (1991), calcium carbonate and pH were negatively related with Olsen P. However, the relationship was non-significant in red, alluvial and Taraisoils and significant in Karael soils.

Viswanathan and Doddamani (1991) observed that soil pH had negative and significant correlation with Al-P. This may be due to low Al activity at higher pH. Fe-P also had negative and significant correlation with pH.

Materials and Methods

MATERIALS AND METHODS

For the study of the behaviour of phosphorus in selected soil types of Kerala, 100 surface soil samples belonging to five types were selected from various districts of Kerala. The five soil types selected were laterite, brown hydromorphic, coastal alluvium, Kuttanad alluvium and black soil. The details of soils collected are given in Table 1.

Surface soils of 0-15 cm depth were collected during summer. The samples were air dried in shade, gently powdered, passed through a 2 mm sieve and stored in properly labelled bags.

The following analyses were undertaken using these selected soils.

1. pH
2. Electrical conductivity
3. Particle size analysis
4. Sesquioxides
5. Alkaline earth CO_3
6. Organic carbon
7. Total nitrogen
8. Total phosphorus
9. Total potassium
10. Available nitrogen
11. Available phosphorus
12. Available potassium

Table 1(a). Location of the soil samples (Laterite soil)

Sl.No.	Sample No.	Place of collection	District
1	L_1	Ollur	Trichur
2	L_2	Potta	,,
3	L_3	Vellangallur	,,
4	L_4	Kadukutty	,,
5	L_5	Unnikulam	Kozhikode
6	L_6	Naduvannur	,
7	L_7	Kakkodi	,,
8	L_8	Elanji	Ernakulam
9	L_9	Kuttipuram	Malappuram
10	L_{10}	Valanchery	,,
11	L_{11}	Vatamkulam	,,
12	L_{12}	Kottakal	,,
13	L_{13}	Pulamenthol	,,
14	L_{14}	Kooriyadu	,,
15	L_{15}	Panambra	,,
16	L_{16}	Elakkadu	Idukki
17	L_{17}	Vaduvakkadu	,,
18	L_{18}	Ulleri	Kozhikode
19	L_{19}	Parappukkara	Trichur
20	L_{20}	Kannambra	Palghat

Table 1(b). Location of the soil samples (Coastal alluvium)

Sl.No.	Sample No.	Place of collection	District
1	C_1	Karuvatta	Alappuzha
2	C_2	Ochira	,,
3	C_3	Chertala	,,
4	C_4	Athiyad	,,
5	C_5	Mararikulam	,,
6	C_6	Nattika	Trichur
7	7	Pattanakad	Alappuzha
8	8	Charamangalam	,,
9	9	Kodanthenathu	,,
10	10	Haripad	,,
11	11	Kayamkulam	,,
12	12	Krishnapuram	,,
13	13	Kulasekharapuram	,,
14	14	Karunagappilly	Kollam
15	C_{15}	Olekettiyambalam	Alappuzha
16	C_{16}	Mavelikkara	,,
17	C_{17}	Cheriyazhiykal	,,
18	C_{18}	Chettikulangara	Kollam
19	C_{19}	Kaitha North	,,
20	C_{20}	Punnakumblam	,,

Table 1(c). Location of the soil samples (Brown hydromorphic)

Sl.No.	Sample No.	Place of collection	District
1	BH_1	Farooq Chungam	Kozhikode
2	BH_2	Arangottukara	Trichur
3	BH_3	Nenmenikkara	,,
4	BH_4	Mulamkunnathukavu	,,
5	BH_5	Kombazhi	Palghat
6	BH_6	Elavanchery	,,
7	BH_7	Ottupara	Trichur
8	BH_8	Kadangode	,,
9	BH_9	Mullurkkara	,,
10	BH_{10}	Alathur	Palghat
11	BH_{11}	Kaiparambu	Trichur
12	BH_{12}	Vadakkenchery	Palghat
13	BH_{13}	Nelluvai	,,
14	BH_{14}	Muthuppana	Ernakulam
15	BH_{15}	Annamanada	Trichur
16	BH_{16}	Kandanessery	,,
17	BH_{17}	Pattikad	,,
18	BH_{18}	Edarikkode	Malappuram
19	BH_{19}	Chovvannur	Trichur
20	BH_{20}	Atholi	Kozhikode

Table 1(d). Location of the soil samples (Kuttanad alluvium)

Sl.No.	Sample No.	Place of collection	District
1	K_1	Veliyanadu	Alappuzha
2	K_2	Mampuzhakari	,,
3	K_3	Muttar	,,
4	K_4	Nedumudi	,,
5	K_5	Ramankari	,,
6	K_6	Thakazhi	,,
7	K_7	Moncombu	,,
8	K_8	Pulinkunnu	,,
9	K_9	Thalavady	,,
10	K_{10}	Nelamperur	Kottayam
11	K_{11}	Thottappally	Alappuzha
12	K_{12}	Ambalapuzha	,,
13	K_{13}	Vaikom	Kottayam
14	K_{14}	Vechoor	,,
15	K_{15}	Thannirmukkam	Alappuzha
16	K_{16}	Udayanapuram	,,
17	K_{17}	Changanachery	Kottayam
18	K_{18}	Kattikkunnu	,,
19	K_{19}	Thottakam	,,
20	K_{20}	Thalayazham	,,

Table 1(e)'. Location of the soil samples (Black soil)

Sl.No.	Sample No.	Place of collection	District
1	B_1	Kozhinjampara	Palghat
2	B_2	Elappilly	,,
3	B_3	Kulukkapara	,,
4	B_4	Panikkakalam	,,
5	B_5	Athikodi	,,
6	B_6	Athikodi North	,,
7	B_7	Venthapalayam	,,
8	B_8	Kozhipara	,,
9	B_9	Chunnambukalthodu	,,
10	B_{10}	Ozhalappathy I	,,
11	B_{11}	Kozhinjampara (proper)	,,
12	B_{12}	Parassikkal	,,
13	B_{13}	Vadakarappathy	,,
14	B_{14}	Sathram	,,
15	B_{15}	Nalleppilly	,,
16	B_{16}	Menonpara	,,
17	B_{17}	Muttakkal	,,
18	B_{18}	Chammanampathy	,,
19	B_{19}	Ozhalappathy II	,,
20	B_{20}	Devarajankotta	,,

13. Fractionation of soil inorganic phosphorus
14. Phosphate potential
15. Equilibrium phosphate potential
16. Differential phosphorus buffering capacity and Quantity-Intensity relationship of P
17. Phosphorus adsorption-desorption characteristics
18. Plant uptake studies of P

1. pH

The pH of 1:2.5 soil water suspension was measured using a pH meter.

2. Electrical conductivity

Electrical conductivity of the soil solution (1:2.5) was determined using a digital conductivity bridge.

3. Particle size analysis

Particle size analysis of the soil was carried out by the International Pipette method after oxidation of the organic matter with hydrogen peroxide. Cementing agents were removed by treating with 2 N HCl and 1 N sodium hydroxide which brought about proper dispersion of the clay (Piper, 1942).

4. Organic carbon

Organic carbon was determined by Walkley and Black's wet digestion method as described by Jackson (1958).

5. Sesquioxides

The sesquioxide in the perchloric acid digest was precipitated with excess of ammonium hydroxide in the presence of ammonium chloride and filtered through ashless filter paper. 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, 1942).

6. Alkaline earth carbonate (free $CaCO_3$)

Free $CaCO_3$ content of soil was determined by acid neutralization method as outlined by Piper (1942).

7. Total nitrogen

Total nitrogen for each soil type was determined by micro-kjeldhal method as given by Hesse (1972).

8. Total phosphorus

For the determination of total phosphorus, soil was predigested with concentrated HNO_3 and evaporated to dryness and again digested with $HClO_4$ until a white residue was left. The residue was filtered and made to known volume. Total phosphorus was then estimated by vanadomolybdophosphoric yellow colour method as described by Olsen and Sommers (1982).

9. Total potassium

The total K content of acid digest was determined by flame photometric method (Hesse, 1972).

10. Available nitrogen

Available nitrogen was determined by alkaline permanganate method as suggested by Subbiah and Asija (1956).

11. Available phosphorus

The available phosphorus was determined using three different extractants viz., Bray No.1 (Jackson, 1958); Olsen's reagent (Hesse, 1972) and Mathew's triacid mixture (Mathew, 1979).

Bray No.1 method: Soil (5 g) was equilibrated for 5 minutes in 0.03 $\underline{N}$ NH_4F + 0.025 $\underline{N}$ HCl (50 ml), filtered through Whatman No.40 filter paper and the P content was estimated.

Olsen's method: Soil (5 g) was equilibrated for 30 minutes in 0.5 $\underline{M}$ $NaHCO_3$ (100 ml) filtered through Whatman No.40 filter paper and the P concentration was determined.

Mathew's triacid method: Soil (5 g) was equilibriated for 30 minutes in 50 ml Mathew's triacid mixture (0.06 $\underline{N}$ H_2SO_4 + 0.06 $\underline{N}$ HCl + 0.05 $\underline{N}$ oxalic acid) and filtered through Whatman No.40 filter paper and the concentration of P was estimated.

Phosphorus content of the solution was determined colorimetrically using L-ascorbic acid as the reductant as described by Watanabe and Olsen, 1965.

12. Available potassium

Available K was found out using equilibrium extraction method in 1 N NH_4OAc as given by Hesse (1972).

13. Fractionation of soil inorganic phosphorus

For the fractionation of soil inorganic phosphorus, procedure given by Chang and Jackson (1957) as modified by Peterson and Corey (1966) was followed. The following fractions were determined.

(a) Saloid bound-P (S-P): This was extracted by shaking 0.5 g of the soil with 25 ml of 1N NH_4Cl for 30 minutes. Phosphorus in centrifugate was then estimated colorimetrically using L-ascorbic acid as reductant.

(b) Aluminium bound-P (Al-P): The soil saved after extraction of S-P was shaken with 25 ml of 0.5 N NH_4F (pH 8.2) for one hour and then centrifuged. Phosphorus in the extract was estimated colorimetrically using boric acid to prevent the interference of fluoride ions and using L-ascorbic acid as reductant.

(c) Iron bound-P (Fe-P): The soil saved from above was washed twice with 12.5 ml of saturated NaCl solution and centrifuged and decanted. The soil was then shaken with 25 ml of 0.1 N NaOH for 4 hours and then centifuged. After flocculation of organic matter in the extracts with a few drops of concentrated H_2SO_4 and centrifuging, P was estimated in the clear extract colorimetrically.

(d) Calcium bound-P (Ca-P): After extraction of iron bound-P, the soil in the centrifuge tube was washed twice with 12.5 ml each of saturated NaCl solution. The washed residue was then shaken for one hour with 0.5 N H_2SO_4, centrifuged and phosphorus was estimated colorimetrically.

(e) Organic and other unidentified forms of P (Org-Un P): This was calculated by substracting the sum of four forms of P viz., S-P, Al-P, Fe-P and Ca-P from total soil phosphorus.

14. Phosphate potential

The phosphate potential was determined by the method explained by Aslyng (1954). Fifty ml of 0.01 M $CaCl_2$ was added to 20 g of soil in a 100 ml capacity test tube and shaken for 30 seconds. The pH of the suspension was found immediately using glass electrode assembly. The suspension was then filtered through Whatman No.40 filter paper and the phosphorus concentration in the filtrate was determined colorimetrically by sulfomolybdenum blue colour method at 660 nm. The concentration of Ca in the filtrate was determined by titration with EDTA. The phosphate potential is defined by the equation

$$\text{Phosphorus potential (pP)} = \tfrac{1}{2}\,\text{pCa} + \text{pH}_2\text{PO}_4$$

where, $\frac{1}{2}$ pCa = $\frac{1}{2}$ ($\log_{10}$ conc. Ca + $\log_{10}$fi)

where, concentration Ca = molar concentration of calcium in the filtrate

fi = Activity coefficient

The activity of anion is equal to the concentration of the ion multiplied by an activity coefficient f, which is expressed by

$$-\log_{10}\text{fi} = Z^2 A \sqrt{I}$$

where, Ionic strength $I = 0.5 \sum C_i Z_i^2$

$A = 0.5$ (constant)

C_i = Molar concentration of ions in the solution

Z_i = Valency of the particular ion

From the total concentration of phosphate, the values of pH_2PO_4 was calculated by using the equation

$$\text{pH}_2\text{PO}_4 = \text{pP} + \text{P}\left[\frac{H}{K^H + H}\right]$$

where, pP = ($\log_{10}$(P)

P = Total concentration of inorganic P in the solution (dm^{-3})

$\text{P}\left[\frac{H}{K^H + H}\right]$ = Correction factor worked out by Aslyng (1954) and it is the proportion of H_2PO_4/P at different pH

15. Equilibrium phosphate potential (EPP)

EPP determination was done by the procedure given by White and Beckett (1964) and Beckett and White (1964) with some modification as suggested by Jensen (1970).

Three gram of soil was shaken with 30 cm^3 of 1 x 10^{-2}M $CaCl_2$ solution containing known P concentration in the form of KH_2PO_4. The concentration that consist of 0, 0.5, 1.0, 2.0 and 2.5 $\mu g\ ml^{-1}$ were used for equilibrium. The suspension were shaken for two hours on horizontal shaker and then centrifuged at 3000 rpm for three minutes. The pH of the supernatent solution was measured after 5 minutes. The total inorganic P in the solution was estimated colorimetrically using L-ascorbic acid as reductant. Ca concentration in the centrifugate was determined using EDTA titration method. The shaking, centrifuging, colourimetric P determination, Ca and pH determination were done at room temperature.

The amount of phosphate (Δ P) gained or lost by the soil in coming to equilibrium with each solution was calculated from the loss or gain of phosphate by the solution. For each soil sample value Δ P was plotted against the corresponding value of phosphate potential. The intercept of line on x axis gives the equilibrium phosphate potential (EPP).

16. Differential phosphorus buffering capacity (DPBC) and Quantity-Intensity relationship of P

The differential phosphate buffering capacity (DPBC) of the soil was determined by following equation.

$$DPBC = \frac{\Delta Q}{\Delta I} Io$$

where, Io - Phosphate potential at Q = 0

Q - Amount of phosphate gained or lost

I - Change in phosphate potential

DPBC values are always be positive since the numerical value of I decreases when Q increases.

17. Phosphate adsorption desorption characteristics

i) Adsorption studies

Three gram of soil was equilibrated for six days at room temperature with 30 ml of 1 x 10^{-2} $\underline{M}$ $CaCl_2$ containing graded amounts of KH_2PO_4 with P concentration ranging from 50 µg ml^{-1} to 400 µg ml^{-1} for black soil and coastal alluvium and for laterite, Kuttanad alluvium and brown hydromorphic soils 100 µg ml^{-1} to 1000 µg ml^{-1} The levels were fixed based on the preliminary investigation. Two drops of toluene were added for sample to supress the microbial activity during equilibration period. Equilibration was done in centrifuge tubes for six days. During this period the tubes were shaken for 30 min twice daily (Fox and Kamprath, 1970).

After equilibration, the samples were centrifuged at 2500 rpm for 5 minutes. The P in the supernatent liquid was estimated by the L-ascorbic acid blue colour method. The P sorbed was calculated by the difference in P concentration orginally present in equilibrating solution and after equilibration.

The sorption data for the soils were fitted to the linear form of the simple Langmuir equation, which is as follows.

$$\frac{C}{X/m} = \frac{1}{k}\frac{1}{b} + \frac{C}{b}$$

where C = concentration of P in the equilibrium solution (μg/ml)

X/m = amount of P sorbed (μg/g)

b = Langmuir sorption maximum (μg/g)

k = constant related to bonding energy

The reciprocal of the slope was calculated to obtain the P adsorption maximum and the constant 'k' was calculated by dividing the slope with the intercept.

ii) Desorption studies

Soil was incubated as for the adsorption studies and the P desorbed for four washings with 0.01 M $CaCl_2$ was calculated. Number of washings were fixed as four because the quantity of phosphorus desorbed after the third washings remained constant and insignificant (Biddappa, 1976).

18. Uptake studies of P

For the determination of plant available phosphorus, a laboratory experiment by modified Neubauer seedling method was done. As suggested by Mathew (1979) rice seedlings were grown for longer period for complete exhaustion of phosphorus. Weighed exactly 100 g soil samples into a 11 cm diameter and 7 cm depth dishes and mixed thoroughly with 50 g acid washed sand and 100 rice seedlings were made to feed exhaustively for 38 days. Sufficient quantities of N and K were applied through solution. The phosphorus uptake was calculated from the dry weight and total phosphorus content of the seedlings.

19. Statistical analysis

The data were examined statistically making use of the principles of correlation and regression as described by Panse and Sukhatme (1967)

Results and Discussion

RESULTS AND DISCUSSION

The present study was formulated to understand the phosphorus status and availability in different soil types of Kerala viz., laterite, coastal alluvium, brown hydromorphic, Kuttanad alluvium and black soil. The fractions of phosphorus, the different extraction methods, the adsorption desorption characteristics, phosphate potential, equilibrium phosphate potential and differential phosphate buffering capacity were used as tools to study the phosphorus supplying capacity of the soils and the reliability of these methods in predicting the phosphorus supplying capacity was also examined.

1. Laterite soil

1.1. General characteristics (Table 2)

The soils belonging to these type were only slightly acidic and recorded a mean pH of 5.44. The electrical conductivity was only 0.12 dS m^{-1}. The particle size analysis showed that the fine fraction (clay + silt) contributed 34.90 per cent. Organic carbon content was medium with an average value of 1.05 per cent. The mean values for total nitrogen, phosphorus and potassium were 0.22 per cent, 991.7 ppm and 2250 ppm respectively. These soils recorded a mean sesquioxide content of 36.03 per cent.

The data on total phosphorus, available phosphorus and fractions of phosphorus are presented in Table 3. The total phosphorus

Table 2. General characteristics of the different soil types, mean values

Soil type	EC dS m^{-1}	pH	Particle size analysis Sand %	(Clay + silt) %	Total nutrients N (%)	P (ppm)	K (ppm)	Organic carbon %	R_2O_3 %
Laterite	0.12	5.44	65.10	34.90	0.22	991.70	2250.00	1.05	36.03
Coastal alluvium	0.08	5.87	83.14	16.86	0.16	217.50	562.50	0.37	4.08
Brown hydromorphic	0.09	5.35	62.00	38.00	0.20	677.90	1250.00	0.75	21.62
Kuttanad alluvium	0.37	5.21	60.98	39.02	0.32	750.40	812.50	1.58	12.97
Black soil	0.25	8.30	59.81	40.19	0.14	658.60	2187.50	0.82	14.35

Table 3. Total phosphorus, available phosphorus and fractions of phosphorus in laterite soils, ppm

Sample No.	Total P	Available P Bray No. 1	Saloid P	Al-P	Fe-P	Ca-P	Organic and unidentified forms of P
L_1	780.50	56.00	13.05	113.05	65.08	86.45	502.87
L_2	1327.10	1.05	8.08	65.20	57.00	90.25	1106.17
L_3	501.80	1.00	4.75	32.30	43.20	15.20	406.35
L_4	468.30	49.00	4.75	26.60	37.50	43.70	355.75
L_5	602.10	5.00	9.03	5.70	5.70	46.55	535.12
L_6	724.80	3.00	18.05	8.08	4.28	303.05	391.34
L_7	669.00	36.00	5.70	28.03	47.50	56.05	531.72
L_8	646.70	0.00	2.38	8.08	20.90	16.15	599.19
L_9	1014.70	1.00	2.38	7.13	25.05	19.00	961.14
L_{10}	1493.80	14.00	6.18	26.13	104.60	61.75	1293.34
L_{11}	1103.90	16.00	1.43	37.05	61.45	23.75	980.22
L_{12}	1806.30	7.03	2.85	74.81	107.35	28.50	1592.79
L_{13}	1226.60	37.00	1.43	42.75	79.80	121.60	980.92
L_{14}	1092.70	6.00	2.38	58.90	85.98	32.30	913.14
L_{15}	925.50	1.00	6.18	43.94	39.90	12.83	822.65
L_{16}	1315.70	12.00	3.33	52.25	62.23	242.25	955.64
L_{17}	1059.30	12.50	1.43	49.40	121.13	17.10	870.24
L_{18}	755.50	8.00	1.43	27.55	80.75	21.85	623.92
L_{19}	1226.50	0.00	2.85	65.08	88.83	266.00	803.74
L_{20}	1092.70	0.00	4.75	21.38	96.90	48.45	920.52
Mean	991.67	13.28	5.12	39.69	61.85	77.64	807.37

content of the laterite soils selected for the present study varied from 468.3 ppm to 1806 ppm with a mean value of 991.67. The mean available P content was only 13.28 ppm and accounted for 1.34 per cent of the total phosphorus.

Among the various inorganic P fractions studied, the maximum content was recorded for Ca-P followed by Fe-P with mean values of 77.64 and 61.85 ppm. The content of Al-P and saloid-P were 39.69 and 5.12 ppm respectively.

Percentage contribution of various inorganic phosphorus fractions to total phosphorus is given in Fig.1. It showed that the contributions for each fraction was 7.8 per cent for Ca-P, 6.2 per cent for Fe-P, 4.0 per cent for Al-P and 0.5 per cent for saloid-P. All these inorganic fractions together contribute only 18.5 per cent of the total phosphorus.

2. Coastal alluvium

2.1. General characteristics (Table 2)

The pH values of these soils varied from 4.8 to 8.15 with a mean value of 5.87. Electrical conductivity recorded an average value oof 0.08 dS m^{-1}. The texture was loamy sand and the fine fractions contributed only 16.86 per cent whereas the sand fraction

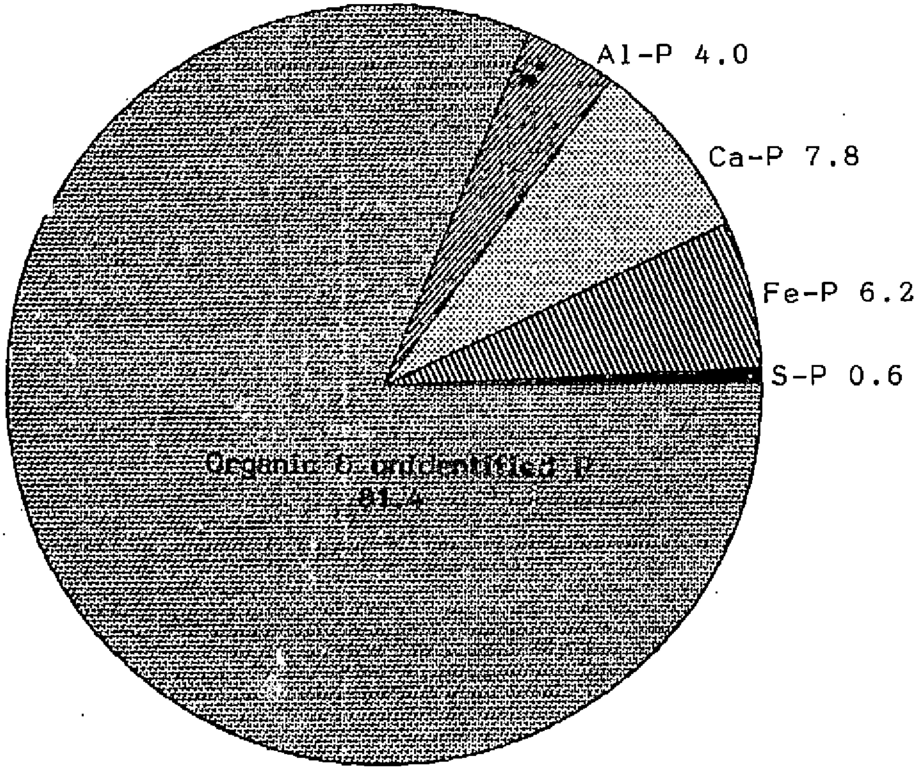

Fig. 1. P fractions in laterite soil, %

contributed 83.14 per cent. Organic carbon content was the lowest compared to other soil types. It recorded a mean value of 0.37 per cent only. The sesquioxide content of these soils was the lowest among the soil types studied. It varied from 0.40 to 7.60 with a mean value of 4.08 per cent. The mean values of total nitrogen, phosphorus and potassium were 0.16 per cent, 217.50 ppm and 562.50 ppm respectively.

2.2. Total, available and fractions of phosphorus

The total phosphorus content of the coastal alluvium ranged from 111.30 ppm to 567.40 ppm which was the lowest among the soil types studied. The available P content was high, 43.95 ppm and it came to 11.44 per cent of the total phosphorus. The data on various fractions of phosphorus in coastal alluvium are given in Table 4.

From the data it can be seen that among the different inorganic fractions studied, the Fe-P recorded the maximum content (36.24 ppm) followed by Al-P, Ca-P and saloid-P. The low content of Saloid-P may be attributed to the transformation of soluble forms of P into relatively less soluble forms with lapse of time. Nair (1986) made studies on soils of Kerala and reported saloid-P as the smallest and Fe-P as the dominant inorganic fraction.

The percentage contribution of different inorganic fractions to the total phosphorus is shown in Fig.2. Among the fractions

Table 4. Total phosphorus, available phosphorus and fractions of phosphorus in coastal alluvium, ppm

Sample No.	Total P	Available P (Bray No.1)	Saloid P	Al-P	Fe-P	Ca-P	Organic and unidentified forms of P
C_1	267.00	10.00	1.43	15.20	28.98	6.65	214.74
C_2	211.40	29.00	1.90	21.38	28.03	7.60	152.49
C_3	211.40	45.00	2.38	18.05	24.70	5.23	161.04
C_4	278.10	50.00	1.90	35.15	33.73	7.60	199.72
C_5	166.90	95.00	3.38	28.03	22.80	6.18	106.56
C_6	567.40	70.00	25.25	101.65	53.68	37.05	349.77
C_7	178.00	37.00	19.00	39.90	32.75	16.15	70.17
C_8	133.50	38.00	4.75	20.90	28.03	5.23	74.59
C_9	122.40	49.00	3.33	8.07	16.85	5.70	88.45
C_{10}	166.90	5.00	7.60	33.25	45.60	11.40	69.05
C_{11}	111.30	54.00	1.43	12.85	21.80	5.23	69.99
C_{12}	111.50	41.00	2.85	27.08	29.93	7.13	4.51
C_{13}	267.00	95.00	4.28	38.00	46.08	11.40	57.24
C_{14}	216.90	66.00	8.08	47.50	54.15	12.35	94.82
C_{15}	267.00	29.00	5.23	57.95	23.28	4.75	175.79
C_{16}	222.50	95.00	7.60	42.75	41.80	12.35	118.00
C_{17}	200.30	7.00	2.88	22.80	29.93	5.23	139.46
C_{18}	233.60	13.00	7.60	49.40	97.38	21.38	57.84
C_{19}	166.90	39.00	1.43	20.43	24.10	5.70	115.24
C_{20}	255.90	12.00	2.85	35.63	41.38	13.30	162.74
Mean	217.54	43.95	6.04	33.80	36.24	10.38	131.58

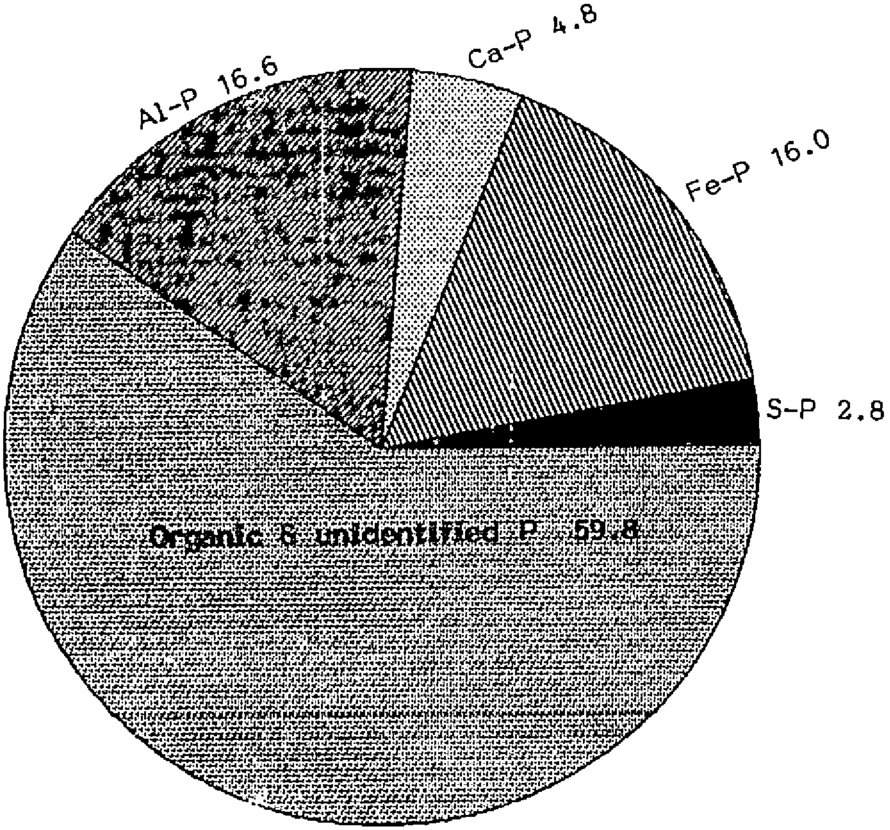

Fig. 2. P fractions in coastal aluvium, %

studied Fe-P contributed 16.90 per cent of total phosphorus, Al-P 15.50 per cent, Ca-P 4.80 per cent and Saloid-P 2.80 per cent. All together the inorganic fractions of P comes to 40.04 per cent of the total phosphorus. Compared to the laterite soil, organic and other unidentified fractions of P were low i.e., only 60 per cent, whereas in the laterite soil it was 81.30 per cent.

3. Brown hydromorphic soil

3.1. General characteristics (Table 2)

Soil reaction of this soil recorded a mean value of 5.35. Electrical conductivity of these soils was 0.09 dS m^{-1}. The finer particles (clay + silt) accounted for 38 per cent. The sesquioxide and organic carbon content of these soils were 21.62 per cent and 0.75 per cent respectively. Total nitrogen, phosphorus and potassium were 0.20 per cent, 677.90 ppm and 1250 ppm respectively.

3.2. Total, available and fractions of phosphorus

The data on total P, available P and inorganic fractions of P are presented in Table 5. Total phosphorus content varied from 334.50 to 1761.30 ppm with a mean value of 677.90 ppm. The available P content was 4.08 ppm which was only 0.60 per cent of the total phosphorus.

From the data in Table 5 it is seen that the most important inorganic fraction is Fe-P followed by Ca-P, Al-P and Saloid-P. The applied P might have got precipitated as insoluble Fe-P

Table 5. Total phosphorus, available phosphorus and fractions of phosphorus in brown hydromorphic soil, ppm

Sample No.	Total P	Available P (Bray No.1)	Saloid P	Al-P	Fe-P	Ca-P	Organic and unidentified forms of P
BH_1	669.00	3.50	2.85	36.10	79.80	54.15	496.10
BH_2	825.10	1.00	3.80	38.00	143.45	25.65	614.20
BH_3	446.00	5.00	2.85	26.60	41.80		362.87
BH_4	624.40	2.50	3.33	10.90	79.80	56.05	464.32
BH_5	601.90	8.50	4.28	38.95	57.00	52.25	449.42
BH_6	512.90	2.00	5.23	19.00	95.95	49.40	343.32
BH_7	446.00	5.00	4.75	24.70	93.10	83.60	239.85
BH_8	892.00	1.00	2.85	30.40	146.30	71.25	641.20
BH_9	334.50	6.00	4.28	33.25	78.85	105.45	112.40
BH_{10}	535.20	3.50	4.28	21.85	82.65	146.30	280.12
BH_{11}	1115.00	2.50	4.28	36.10	169.10	100.70	804.82
BH_{12}	334.50	1.50	4.28	13.30	42.75	35.15	239.02
BH_{13}	401.40	5.00	3.33	20.90	70.30	130.15	176.72
BH_{14}	579.80	0.50	4.75	24.70	128.25	97.85	324.25
BH_{15}	379.10	5.00	3.80	26.60	71.25	31.35	246.10
BH_{16}	1761.30	2.50	4.75	157.70	364.80	335.35	898.70
BH_{17}	490.60	5.00	2.85	15.20	56.05	73.15	343.35
BH_{18}	914.30	1.00	3.33	55.10	185.30	90.25	402.72
BH_{19}	1092.70	11.78	3.33	48.45	279.30	180.50	581.12
BH_{20}	602.10	8.74	3.80	22.80	64.60	36.10	474.80
Mean	677.90	4.08	3.85	35.53	116.47	88.33	436.38

accounting for its predominance among the P fractions. The percentage contribution of different fractions to the total phosphorus is shown in Fig.3.

Among the inorganic fractions studied Fe-P contributed 17.18 per cent, Ca-P 13.03 per cent, Al-P 5.24 per cent and saloid-P 0.57 per cent of the total phosphorus.

Nair (1986) and Sheela (1988) also recorded the highest content of Fe-P in this type of soils.

4. Kuttanad alluvium

4.1. General characteristics (Table 2)

The soils collected recorded a mean pH value of 5.21. The electrical conductivity was 0.37 dS m^{-1}. The soil was sandy clay loam with finer fractions (clay + silt) accounting for 39.02 per cent. Among the soil types studied Kuttanad alluvium contained more organic carbon with a mean value of 1.58 per cent. The mean sesquioxide content was 12.97 per cent.

The total nitrogen, phosphorus and potassium were 0.37 per cent, 750.40 ppm and 851.50 ppm respectively.

4.2. Total, available and inorganic fractions of phosphorus

The data on total phosphorus, available phosphorus and inorganic phosphorus fractions are given in Table 6. The total

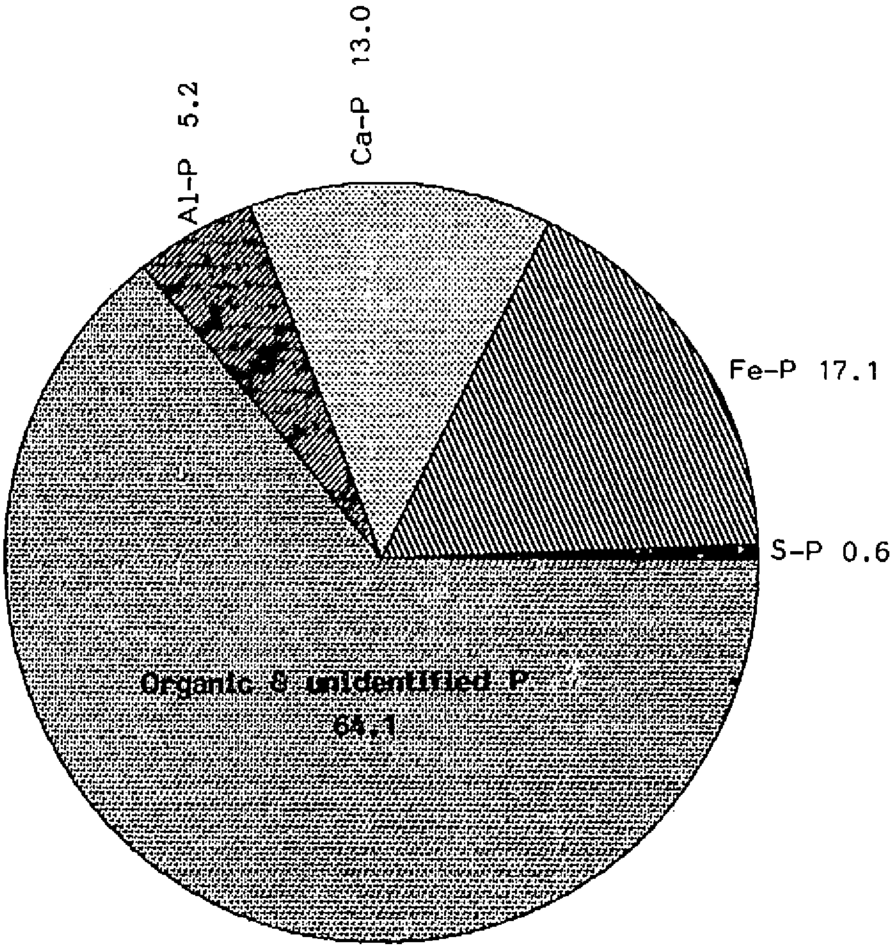

Fig. 3. P fractions in brown hydromorphic soil, %

Table 6. Total phosphorus, available phosphorus and fractions of phosphorus in Kuttanad alluvium, ppm

Sample No.	Total P	Available P (Bray No. 1)	Saloid P	Al-P	Fe-P	Ca-P	Organic and unidentified forms of P
K_1	700.90	15.00	1.43	26.60	79.33	76.00	516.97
K_2	823.30	0.00	3.33	55.81	103.08	31.38	629.70
K_3	1246.00	39.00	2.38	92.15	203.78	74.10	873.59
K_4	623.00	59.00	5.23	125.88	234.65	61.75	195.49
K_5	867.80	0.00	2.38	57.00	75.53	72.20	660.69
K_6	878.90	34.00	3.80	25.65	156.28	55.10	638.07
K_7	745.40	25.00	1.43	63.65	115.90	70.30	494.12
K_8	1101.40	29.00	10.93	107.35	142.50	134.90	705.72
K_9	1112.50	26.00	35.90	114.95	284.05	86.45	587.15
K_{10}	1490.80	28.00	3.33	171.00	326.80	81.23	908.44
K_{11}	700.90	41.00	0.00	67.45	51.30	18.53	563.62
K_{12}	689.70	62.00	5.23	89.30	51.30	6.18	537.69
K_{13}	945.60	76.00	0.00	181.45	95.95	135.85	532.35
K_{14}	300.40	50.00	2.33	71.25	35.15	10.93	180.74
K_{15}	333.80	50.00	8.08	69.35	41.80	15.68	198.89
K_{16}	367.10	66.00	3.33	106.40	56.08	22.80	178.49
K_{17}	1112.50	39.00	9.03	124.45	417.05	55.10	506.87
K_{18}	578.50	6.00	6.18	104.50	91.20	85.03	291.59
K_{19}	178.00	5.00	1.90	10.45	21.85	51.30	92.50
K_{20}	211.40	0.00	1.90	31.35	122.55	20.43	35.17
Mean	750.40	34.00	5.61	84.80	135.31	58.26	466.39

phosphorus content of Kuttanad alluvium varied from 178.00 ppm to 1490.80 ppm with a mean value of 750.40 ppm. The available P content had a mean value of 34.00 ppm which was only 4.53 per cent of the total phosphorus.

From Table 6 it can be seen that the predominant inorganic fraction is Fe-P followed by Al-P, Ca-P and saloid-P. The results proved that aluminium and iron phosphorus dominated in situations leading to acid soil reactions. Nair (1986) obtained similar results in the Kari and Kayal soils of Kuttanad.

The percentage contribution of different inorganic fractions to the total phosphorus is shown in Fig.4. Fe-P constitute 18.03 per cent, Al-P 11.03 per cent, Ca-P 7.76 per cent and saloid-P 0.75 per cent of the total phosphorus. All these inorganic fractions together contribute 37.84 per cent of the total phosphorus.

5. Black soil

5.1. General characteristics (Table 2)

Among the five soil types selected for the study, the black soil was the only one that recorded an alkaline reaction, with a mean pH value of 8.30. These soils recorded a mean electrical conductivity value of 0.25 dS m^{-1}. The organic carbon content was 0.82 per cent. The sesquioxide content was 14.35 per cent and the mean $CaCO_3$ content was 5.86 per cent. The finer particles (clay + silt) were the highest among the soil types studied with a mean value of 40.19 per cent.

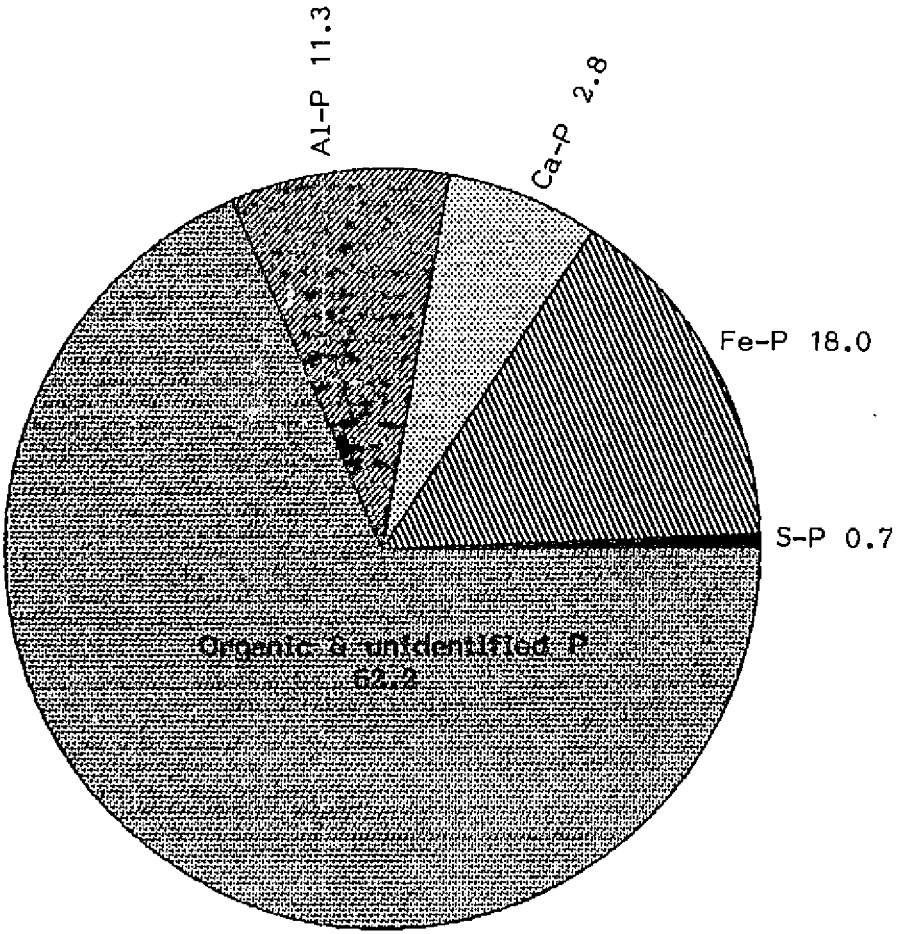

Fig. 4. P fractions in Kuttanad alluvium, %

Table 7. Total phosphorus, available phosphorus and fractions of phosphorus in black soil, ppm

Sample No.	Total P	Available P (Olsen's)	Saloid P	Al-P	Fe-P	Ca-P	Organic and unidentified forms of P
B_1	557.50	16.00	9.50	26.60	1.90	159.60	359.90
B_2	669.00	9.00	4.75	21.85	8.55	246.35	387.50
B_3	501.80	15.00	4.75	26.60	0.00	221.35	249.10
B_4	958.90	15.00	3.80	21.85	0.00	232.75	700.50
B_5	802.80	9.00	0.48	19.00	0.00	284.05	499.27
B_6	561.10	8.00	2.85	19.00	17.10	233.70	288.45
B_7	892.00	8.00	3.80	26.60	7.60	255.55	598.50
B_8	802.80	9.00	1.90	17.10	0.00	181.45	602.35
B_9	624.40	11.00	1.43	4.75	0.00	117.80	500.42
B_{10}	624.40	11.00	0.95	33.25	2.85	116.85	470.50
B_{11}	646.70	23.00	8.55	33.25	0.00	162.45	442.45
B_{12}	334.50	9.00	0.40	17.10	9.50	181.70	125.80
B_{13}	259.90	6.00	5.70	6.66	3.80	256.50	17.24
B_{14}	691.30	14.00	4.75	9.98	2.85	127.30	546.42
B_{15}	825.10	6.00	9.50	32.78	39.90	74.10	668.82
B_{16}	847.40	5.00	6.65	13.33	1.90	103.55	721.92
B_{17}	958.90	20.00	13.30	37.05	2.85	298.30	607.40
B_{18}	356.80	19.00	9.50	24.70	22.80	127.30	172.50
B_{19}	780.50	15.00	10.45	37.05	48.45	40.85	643.70
B_{20}	446.00	19.00	2.85	11.88	45.60	15.20	370.47
Mean	658.60	12.25	5.29	22.02	10.90	171.82	448.66

The recorded values for total nitrogen, phosphorus and potassium were 0.14 per cent, 658.60 ppm and 2187.50 ppm respectively.

5.2. Total, available and inorganic fractions of phosphorus

The data on total phosphorus, available phosphorus and the inorganic fractions are given in Table 7. From the table, it can be seen that total phosphorus varied between 259.90 to 958.90 ppm with a mean value of 658.60 ppm. The mean available P content was 12.25 ppm which is 1.86 per cent of the total phosphorus.

Fig.5 illustrate the percentage contribution of inorganic fractions to the total P. Among the inorganic fractions, Ca-P is the dominant fraction followed by Al-P, Fe-P and saloid-P. The highest content of Ca-P in black soils was attributed due to the calcareous nature of these soils.

Calcium-P accounted for 26.09 per cent, Al-P 3.34 per cent, Fe-P 16.66 per cent and saloid-P 0.80 per cent of the total phosphorus. The dominance of Ca-P in neutral to alkaline soils has been reported by many scientists viz., Doddamani and Rao (1988) and Viswanathan and Doddamani (1991).

6. Soil properties and inorganic fractions of phosphorus

6.1. Soil reaction (pH)

The data on pH of various soils are given in Table 8. It is evident that the black soils were alkaline with a mean pH of 8.30

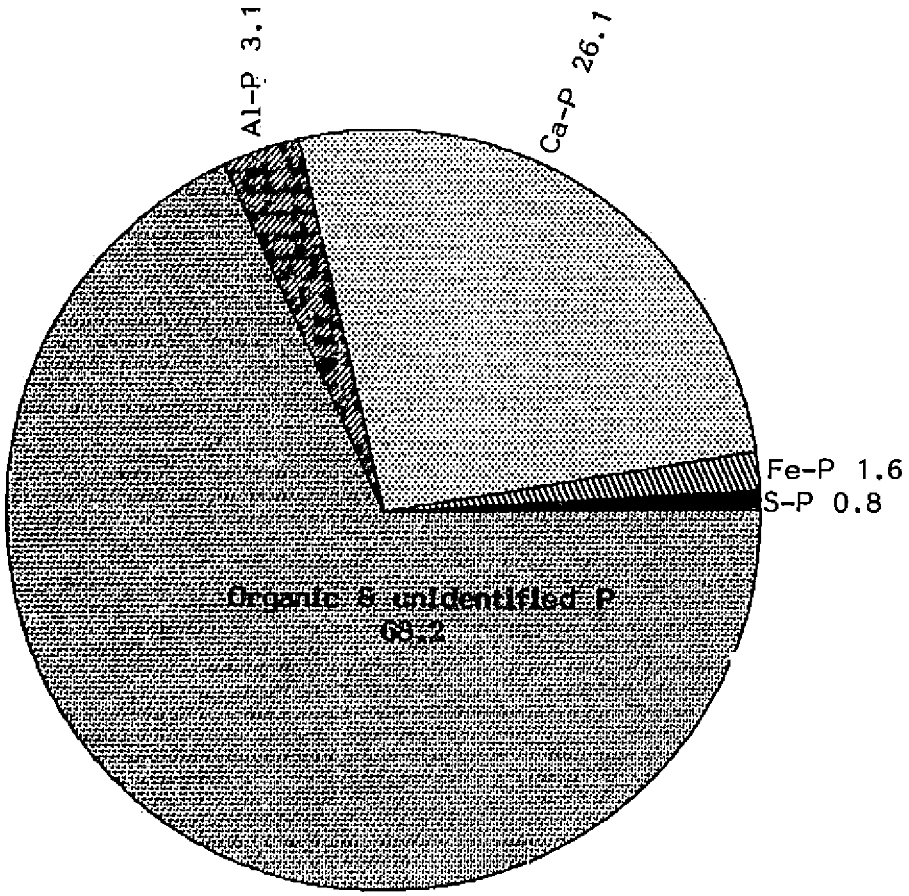

Fig. 5. P fractions in black soil, %

Table 8. Soil reaction in different soil types

Laterite		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	pH	Sample No.	pH	Sample No.	pH	Sample No.	pH	Sample No.	pH
L_{1}	5.90	C_{1}	4.80	BH_{1}	5.30	K_{1}	5.00	B_{1}	8.50
L_{2}	6.50	C_{2}	4.85	BH_{2}	5.60	K_{2}	4.35	B_{2}	8.55
L_{3}	5.00	C_{3}	5.30	BH_{3}	5.20	K_{3}	5.10	B_{3}	8.65
L_{4}	5.55	C_{4}	5.95	BH_{4}	5.35	K_{4}	5.15	B_{4}	8.55
L_{5}	5.75	C_{5}	5.60	BH_{5}	5.35	K_{5}	4.55	B_{5}	8.30
L_{6}	5.80	C_{6}	7.85	BH_{6}	5.65	K_{6}	4.10	B_{6}	7.60
L_{7}	6.20	C_{7}	6.15	BH_{7}	5.30	K_{7}	5.15	B_{7}	8.60
L_{8}	4.85	C_{8}	5.05	BH_{8}	5.00	K_{8}	4.65	B_{8}	8.35
L_{9}	4.80	C_{9}	5.20	BH_{9}	5.85	K_{9}	4.55	B_{9}	8.45
L_{10}	5.10	C_{10}	6.25	BH_{10}	5.25	K_{10}	5.45	B_{10}	8.60
L_{11}	6.10	C_{11}	5.45	BH_{11}	5.35	K_{11}	6.05	B_{11}	8.30
L_{12}	5.35	C_{12}	5.05	BH_{12}	5.55	K_{12}	5.85	B_{12}	8.20
L_{13}	5.20	C_{13}	5.70	BH_{13}	5.00	K_{13}	7.40	B_{13}	8.70
L_{14}	5.35	C_{14}	6.25	BH_{14}	4.95	K_{14}	5.85	B_{14}	8.55
L_{15}	5.00	C_{15}	5.60	BH_{15}	5.35	K_{15}	5.10	B_{15}	8.55
L_{16}	4.60	C_{16}	6.35	BH_{16}	5.40	K_{16}	5.30	B_{16}	8.40
L_{17}	5.30	C_{17}	6.00	BH_{17}	5.95	K_{17}	5.40	B_{17}	6.20
L_{18}	5.64	C_{18}	8.15	BH_{18}	5.05	K_{18}	6.50	B_{18}	8.45
L_{19}	5.65	C_{19}	5.60	BH_{19}	5.40	K_{19}	5.55	B_{19}	8.35
L_{20}	5.20	C_{20}	6.15	BH_{20}	5.15	K_{20}	3.10	B_{20}	8.20
Mean	5.20	Mean	5.87	Mean	5.35	Mean	5.21	Mean	8.30

and the other soil types were acidic in reaction. The pH ranged from 4.60 to 6.50 with a mean of 5.20 in laterite soils. In coastal alluvium it ranged from 4.80 to 8.15 with a mean value of 5.87. In case of brown hydromorphic soil the variation was very little, it ranged from 4.95 to 5.95 with a mean value of 5.35. In Kuttanad soils some of the soils were extremely acidic with a pH value as low as 3.10. The mean pH recorded for these type of soils was 5.21. In the case of laterite, brown hydromorphic and black soils none of the fractions of phosphorus correlated significantly to pH of the soil. Saxena (1973) and Viswanathan and Doddamani (1991) reported a negative correlation between pH of the soil and inorganic fractions of P.

In coastal alluvium pH significantly influenced the P content of the soil. The different inorganic fractions correlated positively with pH and the correlation coefficient for the various fractions were Fe-P 0.835**, Ca-P 0.818**, Al-P 0.760** and Saloid-P 0.658**.

In Kuttanad alluvium Al-P alone showed a siginificant and positive correlation with pH (r = 0.527*).

6.2. Electrical conductivity (EC) and inorganic fraction of P

The electrical conductivity of the soil types studied are presented in Table 9. The EC of Kuttanad soils varied widely from 0.03 dS m^{-1} to 1.64 dS m^{-1} with a mean value of 0.37 dS m^{-1}. In black soils it varied from 0.10 to 0.44 dS m^{-1} with a mean value of 0.25 dS m^{-1}. In laterites EC ranged from 0.04 dS m^{-1} to 0.39 dS m^{-1} and recorded a mean value of 0.12 dS m^{-1}. The coastal alluvium had a mean value of 0.08 dS m^{-1} (range 0.03 to 0.13 dS m^{-1}). In brown hydromorphic soils it ranged between 0.01 to 0.29 dS m^{-1} with a mean value of 0.09 dS m^{-1}.

A simple correlation analysis showed that EC had no significant relations with fractions of phosphorus in laterite, brown hydromorphic, Kuttanad alluvium and black soil.

In coastal alluvium the fractions viz., Ca-P (r = 0.570**), Al-P (r = 0.540*) and saloid-P (r = 0.450*) showed a positive and significant relationship with EC where as Fe-P failed to correlate with EC.

6.3. Organic carbon and inorganic P-fractions

Organic carbon contents of the different soils are presented in Table 10. The organic matter was also calculated and presented in Table 11.

Organic carbon content was highest in Kuttanad soils and lowest in coastal alluvium with a mean value of 1.58 per cent and 0.37 per cent respectively.

In laterite soils total P showed significant positive correlation with organic matter while none of the inorganic fractions established significant correlation with organic matter. Ruhal and

Table 9. Electrical conductivity in different soil types, dS m^{-1}

Laterite		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	EC	Sample No.	EC	Sample No.	EC	Sample No.	EC	Sample No.	EC
L_1	0.1060	C_1	0.0952	BH_1	0.1200	K_1	0.1251	B_1	0.3290
L_2	0.1643	C_2	0.0931	BH_2	0.0300	K_2	0.7000	B_2	0.2044
L_3	0.0347	C_3	0.1079	BH_3	0.1121	K_3	0.1486	B_3	0.3210
L_4	0.1597	C_4	0.0850	BH_4	0.2930	K_4	0.1803	B_4	0.2380
L_5	0.1094	C_5	0.0431	BH_5	0.0680	K_5	0.5002	B_5	0.4289
L_6	0.1487	C_6	0.1727	BH_6	0.0842	K_6	1.6140	B_6	0.1720
L_7	0.3904	C_7	0.0913	BH_7	0.0769	K_7	0.0990	B_7	0.2895
L_8	0.0558	C_8	0.0600	BH_8	0.0494	K_8	0.1601	B_8	0.2810
L_9	0.1065	C_9	0.0582	BH_9	0.0692	K_9	0.1491	B_9	0.2350
L_{10}	0.0821	C_{10}	0.0699	BH_{10}	0.1870	K_{10}	0.0849	B_{10}	0.1686
L_{11}	0.1582	C_{11}	0.1300	BH_{11}	0.0430	K_{11}	0.0469	B_{11}	0.4085
L_{12}	0.1237	C_{12}	0.0519	BH_{12}	0.0689	K_{12}	0.0333	B_{12}	0.1595
L_{13}	0.0850	C_{13}	0.0572	BH_{13}	0.0819	K_{13}	0.2873	B_{13}	0.1607
L_{14}	0.1411	C_{14}	0.0740	BH_{14}	0.0975	K_{14}	0.5800	B_{14}	0.1560
L_{15}	0.0389	C_{15}	0.0631	BH_{15}	0.0381	K_{15}	0.0900	B_{15}	0.1810
L_{16}	0.0885	C_{16}	0.0753	BH_{16}	0.1091	K_{16}	0.0407	B_{16}	0.2640
L_{17}	0.1165	C_{17}	0.0640	BH_{17}	0.0950	K_{17}	0.2899	B_{17}	0.0969
L_{18}	0.0677	C_{18}	0.1070	BH_{18}	0.0610	K_{18}	0.1224	B_{18}	0.2100
L_{19}	0.0528	C_{19}	0.0741	BH_{19}	0.0499	K_{19}	1.0396	B_{19}	0.2991
L_{20}	0.0699	C_{20}	0.0346	BH_{20}	0.0121	K_{20}	1.6114	B_{20}	0.4400
Mean	0.12	Mean	0.08	Mean	0.09	Mean	0.37	Mean	0.25

Deo (1979) reported positive correlation between total P and organic fractions in Rajasthan soils.

In all other soil types viz. coastal alluvium, brown hydromorphic soils, Kuttanad alluvium and black soil organic carbon failed to correlate with inorganic P fractions. Kanwar *et al.* (1983) reported the inconsistent effect of organic carbon on the P fractions in Alfisols and Inceptisols.

6.4. Particle size distribution and inorganic phosphorus fractions

Table 12 shows the particle size distribution of different soil types. A significant relationship between P fractions and clay + silt percentage was not established.

6.5. Sesquioxides and P fractions

The data on sesquioxides of various soils are given in Table 13. From the table it is evident that the laterite is having highest sesquioxide and least in coastal alluvium.

In a simple regression analysis Al-P showed a significant negative relationship with sesquioxides in laterite soil ($r = -0.525^*$) and black soil the relationship is positive ($r = 0.462^*$). In coastal alluvium and brown hydromorphic soils it is Fe-P which positively correlated with sesquioxides r values are 0.470^* and 0.505^*. Ca-P correlated to sesquioxides in Kuttanad alluvium whereas in all other soil types it failed to correlate.

Table 10. Organic carbon in different soil types, %

Laterite		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	OC	Sample No.	OC	Sample No.	OC	Sample No.	OC	Sample No.	OC
L_1	0.70	C_1	0.36	BH_1	0.77	K_1	2.65	B_1	1.96
L_2	0.83	C_2	0.40	BH_2	0.47	K_2	4.69	B_2	0.53
L_3	0.59	C_3	0.18	BH_3	0.72	K_3	1.59	B_3	0.57
L_4	0.39	C_4	0.29	BH_4	0.36	K_4	1.52	B_4	0.59
L_5	1.17	C_5	0.26	BH_5	0.66	K_5	1.52	B_5	0.77
L_6	1.30	C_6	0.33	BH_6	0.36	K_6	1.17	B_6	0.59
L_7	0.86	C_7	0.45	BH_7	0.41	K_7	1.85	B_7	2.94
L_8	0.88	C_8	0.80	BH_8	0.39	K_8	0.44	B_8	0.83
L_9	1.47	C_9	0.53	BH_9	0.30	K_9	1.69	B_9	0.77
L_{10}	1.49	C_{10}	0.18	BH_{10}	1.06	K_{10}	2.84	B_{10}	0.83
L_{11}	0.56	C_{11}	0.27	BH_{11}	0.72	K_{11}	0.19	B_{11}	0.59
L_{12}	2.02	C_{12}	0.35	BH_{12}	0.39	K_{12}	1.83	B_{12}	0.41
L_{13}	0.97	C_{13}	0.30	BH_{13}	0.72	K_{13}	1.04	B_{13}	0.36
L_{14}	1.47	C_{14}	0.36	BH_{14}	2.37	K_{14}	0.32	B_{14}	0.77
L_{15}	1.91	C_{15}	0.36	BH_{15}	0.36	K_{15}	0.53	B_{15}	0.12
L_{16}	1.36	C_{16}	0.47	BH_{16}	1.06	K_{16}	0.39	B_{16}	0.53
L_{17}	1.04	C_{17}	0.47	BH_{17}	0.54	K_{17}	1.65	B_{17}	0.53
L_{18}	0.92	C_{18}	0.30	BH_{18}	1.85	K_{18}	0.77	B_{18}	0.77
L_{19}	0.47	C_{19}	0.41	BH_{19}	0.67	K_{19}	0.39	B_{19}	1.12
L_{20}	0.71	C_{20}	0.30	BH_{20}	0.77	K_{20}	4.58	B_{20}	0.71
Mean	1.05	Mean	0.37	Mean	0.75	Mean	1.58	Mean	0.82

Table 11. Organic matter content in different soil types, %

Laterite		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	OM	Sample No.	OM	Sample No.	OM	Sample No.	OM	Sample No.	OM
L_1	1.21	C_1	0.62	BH_1	1.33	K_1	4.57	B_1	3.38
L_2	1.43	C_2	0.69	BH_2	0.81	K_2	8.09	B_2	0.91
L_3	1.02	C_3	0.31	BH_3	1.24	K_3	2.74	B_3	0.98
L_4	0.67	C_4	0.50	BH_4	0.62	K_4	2.62	B_4	1.02
L_5	2.02	C_5	0.45	BH_5	1.14	K_5	2.62	B_5	1.33
L_6	2.24	C_6	0.59	BH_6	0.62	K_6	2.02	B_6	1.02
L_7	1.48	C_7	0.78	BH_7	0.71	K_7	3.19	B_7	5.07
L_8	1.52	C_8	1.38	BH_8	0.67	K_8	0.76	B_8	1.43
L_9	2.53	C_9	0.91	BH_9	0.52	K_9	2.91	B_9	1.33
L_{10}	2.57	C_{10}	0.31	BH_{10}	1.83	K_{10}	4.90	B_{10}	1.43
L_{11}	0.97	C_{11}	0.47	BH_{11}	1.24	K_{11}	0.33	B_{11}	1.02
L_{12}	3.48	C_{12}	0.60	BH_{12}	0.67	K_{12}	3.15	B_{12}	0.71
L_{13}	1.67	C_{13}	0.52	BH_{13}	1.24	K_{13}	1.74	B_{13}	0.62
L_{14}	2.53	C_{14}	0.62	BH_{14}	4.09	K_{14}	0.55	B_{14}	1.33
L_{15}	3.29	C_{15}	0.62	BH_{15}	0.62	K_{15}	0.91	B_{15}	0.21
L_{16}	2.33	C_{16}	0.81	BH_{16}	1.83	K_{16}	0.67	B_{16}	0.91
L_{17}	1.79	C_{17}	0.81	BH_{17}	0.93	K_{17}	2.84	B_{17}	0.91
L_{18}	1.59	C_{18}	0.52	BH_{18}	3.19	K_{18}	1.33	B_{18}	1.33
L_{19}	0.81	C_{19}	0.71	BH_{19}	1.16	K_{19}	0.67	B_{19}	1.93
L_{20}	1.22	C_{20}	0.52	BH_{20}	1.33	K_{20}	7.90	B_{20}	1.22
Mean	1.82	Mean	0.64	Mean	1.29	Mean	2.72	Mean	1.40

the total P ($r = 0.636^{**}$). It may be due to the formation of insoluble calcium phosphates in the presence of free $CaCO_3$.

7. Relationship between total phosphorus and fractions of phosphorus

7.1. Laterite soil

In laterite soils simple regression analysis showed that only Fe-P correlated significantly to total phosphorus ($r = 0.669^{*}$). The multiple regression equation is Total P = +0.02 S-P - 0.01 Fe-P - 0.001 Ca-P + 4.08 ($R = 0.59$).

7.2. Coastal alluvium

In coastal alluvium, except Fe-P, all fractions correlated with total phosphorus. The fractions which significantly and positively correlated with total phosphorus are Saloid-P ($r = 0.623^{**}$), Ca-P ($r = 0.807^{**}$) and Al-P ($r = 0.834^{**}$).

Multiple regression analysis showed that total phosphorus is significantly influenced by the various inorganic P fractions ($R = 0.89$). The multiple regression equation is

Total P = -7.62 S-P + 3.06 Al-P - 1.57 Fe-P + 0.10 Ca-P + 105.60 ($R = 0.89^{**}$).

Table 12. Clay + silt content in selected soil types, %

Laterite		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	Clay+ silt	Sample No.	Clay+ silt	Sample No.	Clay+ silt	Sample No.	Clay+ silt	Sample No.	Clay+ silt
L_1	28.0	C_1	10.9	BH_1	44.1	K_1	29.2	B_1	65.4
L_2	24.0	C_2	8.0	BH_2	51.4	K_2	69.8	B_2	34.6
L_3	47.0	C_3	21.0	BH_3	42.3	K_3	28.0	B_3	48.8
L_4	30.0	C_4	8.0	BH_4	39.2	K_4	42.1	B_4	43.0
L_5	28.0	C_5	7.9	BH_5	37.4	K_5	42.4	B_4	45.0
L_6	39.0	C_6	18.0	BH_6	32.2	K_6	42.8	B_6	32.6
L_7	31.0	C_7	26.0	BH_7	34.8	K_7	50.1	B_7	38.2
L_8	34.6	C_8	18.9	BH_8	40.1	K_8	32.1	B_8	43.4
L_9	39.0	C_9	13.0	BH_9	22.2	K_9	37.2	B_9	43.0
L_{10}	50.0	C_{10}	8.0	BH_{10}	54.4	K_{10}	29.0	B_{10}	44.8
L_{11}	19.0	C_{11}	11.0	BH_{11}	44.4	K_{11}	32.4	B_{11}	40.4
L_{12}	28.0	C_{12}	7.9	BH_{12}	33.0	K_{12}	29.0	B_{12}	28.2
L_{13}	38.0	C_{13}	23.2	BH_{13}	39.1	K_{13}	38.3	B_{13}	46.8
L_{14}	30.0	C_{14}	32.0	BH_{14}	36.4	K_{14}	54.0	B_{14}	43.2
L_{15}	49.0	C_{15}	26.2	BH_{15}	39.2	K_{15}	48.8	B_{15}	17.8
L_{16}	32.2	C_{16}	25.8	BH_{16}	38.8	K_{16}	48.7	B_{16}	36.6
L_{17}	55.0	C_{17}	17.8	BH_{17}	39.9	K_{17}	28.0	B_{17}	26.8
L_{18}	32.0	C_{18}	10.6	BH_{18}	34.0	K_{18}	15.0	B_{18}	43.8
L_{19}	19.0	C_{19}	29.0	BH_{19}	28.1	K_{19}	23.1	B_{19}	43.4
L_{20}	45.0	C_{20}	14.0	BH_{20}	29.2	K_{20}	61.2	B_{20}	38.0
Mean	33.4	Mean	16.9	Mean	38.0	Mean	39.02	Mean	40.19

Table 13. Sesquioxide content in different soil types, %

Laterite		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	R_2O_3	Sample No.	R_2O_3	Sample No.	R_2O_3	Sample No.	R_2O_3	Sample No.	R_2O_3
L_{1}	14.3	C_{1}	6.8	BH_{1}	15.3	K_{1}	22.2	B_{1}	30.8
L_{2}	30.8	C_{2}	7.4	BH_{2}	30.4	K_{2}	20.5	B_{2}	12.0
L_{3}	45.7	C_{3}	0.4	BH_{3}	16.3	K_{3}	28.2	B_{3}	13.5
L_{4}	44.5	C_{4}	2.2	BH_{4}	11.1	K_{4}	10.9	B_{4}	12.8
L_{5}	53.0	C_{5}	1.6	BH_{5}	17.4	K_{5}	21.4	B_{5}	14.0
L_{6}	36.5	C_{6}	3.3	BH_{6}	14.4	K_{6}	23.9	B_{6}	10.7
L_{7}	39.6	C_{7}	3.6	BH_{7}	34.6	K_{7}	11.1	B_{7}	12.4
L_{8}	33.2	C_{8}	2.0	BH_{8}	31.4	K_{8}	20.7	B_{8}	15.2
L_{9}	56.2	C_{9}	1.0	BH_{9}	14.5	K_{9}	25.6	B_{9}	9.5
L_{10}	36.3	C_{10}	4.5	BH_{10}	15.7	K_{10}	8.0	B_{10}	21.0
L_{11}	30.2	C_{11}	5.6	BH_{11}	36.2	K_{11}	2.0	B_{11}	6.8
L_{12}	46.0	C_{12}	5.0	BH_{12}	13.7	K_{12}	1.5	B_{12}	10.9
L_{13}	31.6	C_{13}	3.8	BH_{13}	16.6	K_{13}	11.5	B_{13}	9.2
L_{14}	35.2	C_{14}	7.3	BH_{14}	10.8	K_{14}	3.6	B_{14}	2.9
L_{15}	42.2	C_{15}	2.6	BH_{15}	16.3	K_{15}	1.4	B_{15}	26.0
L_{16}	39.4	C_{16}	3.2	BH_{16}	29.4	K_{16}	5.4	B_{16}	14.0
L_{17}	37.5	C_{17}	2.4	BH_{17}	14.7	K_{17}	14.7	B_{17}	14.0
L_{18}	18.2	C_{18}	7.6	BH_{18}	42.6	K_{18}	8.5	B_{18}	14.3
L_{19}	15.7	C_{19}	6.0	BH_{19}	30.4	K_{19}	1.0	B_{19}	25.5
L_{20}	34.6	C_{20}	5.6	BH_{20}	20.2	K_{20}	17.0	B_{20}	13.6
Mean	36.0	Mean	4.1	Mean	21.6	Mean	13.0	Mean	14.4

7.3. Brown hydromorphic soil

Total P showed a significant positive relationship with the inorganic fractions. A simple correlation analysis showed that Fe-P ($r = 0.929^{**}$), Al-P ($r = 0.856^{**}$) and Ca-P ($r = 0.724^{**}$) are significantly related to total phosphorus. The multiple regression equation is given below:

$$\text{Total P} = -0.29 \text{ S-P} - 0.006 \text{ Al-P} - 0.002 \text{ Fe-P} + 0.006 \text{ Ca-P} + 5.19$$

$(R = 0.361)$

7.4. Kuttanad alluvium

In Kuttanad soils also total P significantly correlated to Fe-P, Al-P and Ca-P but failed to correlate with saloid-P. The correlation coefficients are Fe-P ($r = 0.704^{**}$), Ca-P ($r = 0.592^{**}$) and Al-P ($r = 0.563^{*}$).

The multiple regression equation showed that total P is significantly influenced by the various inorganic P fractions. The equation is

$$\text{Total P} = -2.39 \text{ S-P} + 0.90 \text{ Al-P} + 1.84 \text{ Fe-P} + 3.56 \text{ Ca-P} + 231.08$$

$(R = 0.81^{**})$

7.5. Black soil

None of the

total P in black soil

Table 14. Calcium carbonate content in black soil, %

Sample No.	$CaCO_3$
B_1	6.68
B_2	5.25
B_3	7.63
B_4	7.63
B_5	6.20
B_6	4.29
B_7	5.72
B_8	7.16
B_9	6.20
B_{10}	4.77
B_{11}	8.11
B_{12}	3.82
B_{13}	3.82
B_{14}	4.29
B_{15}	3.34
B_{16}	10.49
B_{17}	10.40
B_{18}	1.43
B_{19}	9.54
B_{20}	0.48
Mean	5.86

The multiple regression equation showed that Total-P is not influenced by the fractions. The multiple regression equation is,

$$\text{Total P} = 1.69\ \text{S-P} + 0.02\ \text{Al-P} + 0.16\ \text{Fe-P} + 0.08\ \text{Ca-P} + 483.22$$

$(R = 0.422)$

7.6. Comparison between soil types

The soil types varied in their different fractions and total phosphorus content.

The saloid-P content of different soil types studied are shown in Fig.6. Coastal alluvium contained maximum saloid-P (6.04 ppm) and this fraction was least in brown hydromorphic soil 3.85 ppm.

The Al-P content of the soil types is illustrated in Fig.6. The Al-P content is maximum for Kuttanad soils (84.80 ppm) and the least for black soil.

The content of Fe-P is maximum for Kuttanad alluvium and the lowest in black soil; as illustrated in Fig.6.

Among the soil types studied, black soil recorded maximum content of Ca-P (171.82 ppm) and lowest in coastal alluvium (Fig.6).

8. Different chemical extractants for phosphorus

Three different extractants were used to assess the available phosphorus in these soil types. The data are presented in Tables 15, 16, 17, 18 and 19. From the tables it is evident that Mathew's triacid mixture extracted more P than Bray No.1 or Olsen's extractant. This indicated higher extracting power of the triacid extractant. Kamalam (1988) also reported that triacid is a stronger extractant for available P than Bray No.1 extractant.

8.1. Relationship between Bray No.1 P and P fractions

None of the soils except the Kuttanad soils established significant relationship between the P fractions and Bray No.1 P. In Kuttanad soils, Bray No.1 P significantly correlated with Al-P (r = 0.66**).

The multiple regression equation between Bray No.1 P and the inorganic fractions for different soil types are given below:

Laterite soil: Bray No.1 P = 0.53 S-P + 0.28 Al-P - 0.06 Fe-P - 0.03 Ca-P + 5.64 (R = 0.42)

Coastal alluvium: Bray No.1 P = 0.97 S-P + 0.94 Al-P - 0.16 Fe-P + 0.36 Ca-P + 10.51 (R = 0.70**)

Brown hydromorphic soil: Bray No.1 P = -0.79 S-P - 0.03 Al-P - 0.005 Fe-P + 0.02 Ca-P + 6.99 (R = 0.28)

Kuttanad alluvium: Bray No.1 P = -0.28 S-P +0.50 Al-P - 0.04 Fe-P - 0.20 Ca-P + 13.25 (R = 0.79**)

Black soil: Bray No.1 P = 0.03 S-P + 0.22 Al-P + 0.16 Fe-P + 0.06 Ca-P - 8.98 (R = 0.55*)

Bray No.1 P showed highest degree of correlation with Al-P in Kuttanad soils which was due to NH_4F constituent of the extracting

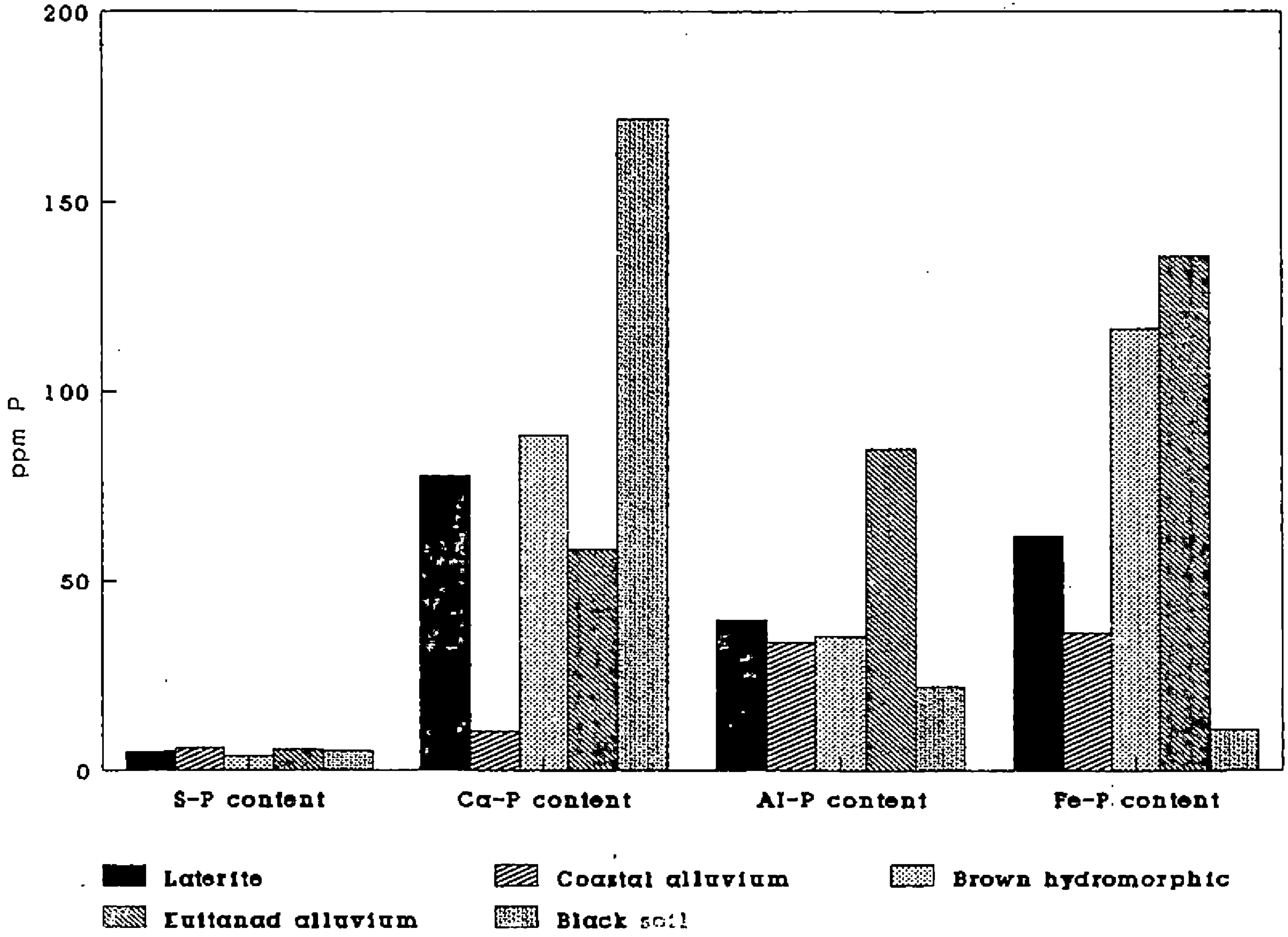

Fig. 6. P fractions in different soil types (ppm)

Table 15. Available phosphorus in laterite soil using different extractants, ppm

Sample No.	Bray No.1 P	Olsen's P	Mathews-triacid P
L_1	56.00	46.00	142.50
L_2	1.05	3.04	156.75
L_3	1.00	0.00	60.80
L_4	49.00	38.00	114.19
L_5	5.00	12.00	74.88
L_6	3.00	8.00	66.50
L_7	36.00	34.00	133.00
L_8	0.00	0.00	57.00
L_9	1.00	0.00	36.10
L_{10}	14.00	24.00	80.75
L_{11}	16.00	10.00	77.88
L_{12}	7.03	6.24	65.55
L_{13}	37.00	16.00	98.66
L_{14}	6.00	8.00	64.60
L_{15}	1.00	0.00	0.60
L_{16}	12.00	5.13	152.00
L_{17}	12.50	8.56	72.20
L_{18}	8.00	0.00	57.00
L_{19}	0.00	32.00	152.00
L_{20}	0.00	3.90	70.30
Mean	13.28	12.74	86.66

Table 16. Available phosphorus in coastal alluvium using different extractants, ppm

Sample No.	Bray No.1 P	Olsen's P	Mathew's-triacid P
C_1	10.00	7.00	28.60
C_2	29.00	7.00	22.04
C_3	45.00	8.00	30.59
C_4	50.00	12.00	55.86
C_5	95.00	13.00	19.00
C_6	70.00	17.00	44.46
C_7	37.00	11.00	82.65
C_8	38.00	15.00	19.19
C_9	49.00	16.00	44.84
C_{10}	5.00	14.00	73.15
C_{11}	54.00	9.00	3.04
C_{12}	41.00	17.00	25.64
C_{13}	95.00	11.00	52.44
C_{14}	66.00	15.00	25.46
C_{15}	29.00	40.00	96.90
C_{16}	95.00	15.00	93.10
C_{17}	7.00	7.00	51.30
C_{18}	13.00	11.00	106.40
C_{19}	39.00	12.35	26.03
C_{20}	12.00	17.86	64.60
Mean	43.95	14.46	48.26

Table 17. Available phosphorus in brown hydromorphic soil using different extractants, ppm

Sample No.	Bray No.1 P	Olsen's P	Mathew's-triacid P
BH$_{1}$	3.50	12.35	54.10
BH$_{2}$	1.00	8.69	33.06
BH$_{3}$	5.00	8.55	22.80
BH$_{4}$	2.50	10.45	36.10
BH$_{5}$	8.50	9.12	40.85
BH$_{6}$	2.00	10.83	30.40
BH$_{7}$	5.00	16.15	62.70
BH$_{8}$	1.00	10.88	45.79
BH$_{9}$	6.00	10.45	49.59
BH$_{10}$	3.50	12.92	57.95
BH$_{11}$	2.50	12.92	48.45
BH$_{12}$	1.50	9.50	0.38
BH$_{13}$	5.00	11.21	43.13
BH$_{14}$	0.50	10.26	5.89
BH$_{15}$	5.00	11.02	0.95
BH$_{16}$	2.50	43.70	42.95
BH$_{17}$	5.00	9.50	46.17
BH$_{18}$	1.00	17.67	0.76
BH$_{19}$	11.78	19.05	71.25
BH$_{20}$	8.74	8.55	32.49
Mean	4.08	13.19	36.29

Table 18. Available phosphorus in Kuttanad alluvium using different extractants, ppm

Sample No.	Bray No.1 P	Olsen's P	Mathew's-triacid P
K_1	15.00	14.06	104.50
K_2	0.00	12.02	43.70
K_3	39.00	39.14	142.50
K_4	59.00	84.55	180.50
K_5	0.00	16.34	104.50
K_6	34.00	20.90	104.50
K_7	25.00	22.42	123.50
K_8	29.00	32.68	127.30
K_9	26.00	28.69	121.60
K_{10}	58.00	75.05	180.50
K_{11}	41.00	18.24	96.90
K_{12}	62.00	30.78	115.90
K_{13}	76.00	28.88	98.80
K_{14}	50.00	13.11	96.90
K_{15}	50.00	20.90	90.95
K_{16}	66.00	14.82	82.70
K_{17}	39.00	57.00	175.80
K_{18}	6.00	9.88	161.50
K_{19}	5.00	11.78	68.40
K_{20}	0.00	0.00	44.70
Mean	34.00	27.56	113.28

Table 19. Available phsophorus in black soil using different extractants, ppm

Sample No.	Bray No.1 P	Olsen's P	Mathew's-triacid P
B_1	15.00	16.00	132.05
B_2	20.00	9.00	180.50
B_3	7.22	15.00	171.00
B_4	-	15.00	180.50
B_5	5.80	9.00	142.50
B_6	13.00	8.00	171.00
B_7	17.00	8.00	171.00
B_8	1.23	9.00	161.50
B_9	1.05	11.00	123.50
B_{10}	13.00	11.00	132.10
B_{11}	1.14	23.00	180.50
B_{12}	11.00	9.00	127.30
B_{13}	3.14	6.00	63.70
B_{14}	1.81	14.00	142.50
B_{15}	6.00	6.00	180.50
B_{16}	1.05	5.00	90.30
B_{17}	33.00	20.00	152.00
B_{18}	1.24	19.00	112.10
B_{19}	0.00	15.00	180.50
B_{20}	15.00	17.00	77.90
Mean	8.33	12.25	148.65

solution. The NH_4F constituent of Bray's extracting solution removes easily exchangeable P by its complex formation with Al-P and Fe-P whereas HCl removes the easily acid soluble phosphates that contributes to the suitability of this method for Kuttanad soils, which is acidic in reaction.

From the multipleregression equation it is seen that the highest R value is recorded for Kuttanad alluvium. It is inferred that 79 per cent variation in Bray No.1 P of these soils is explained by the inorganic P fractions.

Kumaraswamy and Sreeramulu (1991) reported that Fe-P and Al-P account for 85-95 per cent of variations in the Bray No.1 P.

8.2. Relationship between Olsen's P and P fractions

Among the five soil types studied Olsen's P correlated with Al-P (r = 0.944**), Ca-P (r = 0.895**) and Fe-P (r = 0.851**) in brown hydromorphic soils. In Kuttanad alluvium Al-P (r = 0.656**) alone correlated to Olsen's P. In acid soils sodium bicarbonate at pH 8.5 extracts the available P present in the form of Al-P or Fe-P adsorbed on clay surfaces. This could be the reason of its suitability for these acid soils. Khadtar <u>et al</u>. (1991) also reported the same.

In Black soil Saloid-P got significant correlations with Olsen's P (r = 0.468*). Sharma and Tripathi (1984) stated that Olsen's P extractant removed most of its P from Al-P fractions followed by Ca-P.

The multiple regression equation for Olsen's P vs inorganic P fractions for the different soil types are given below:

Laterite soil: Olsen P = 0.80 S-P + 0.18 Al-P - 0.16 Fe-P - 0.03 Ca-P + 5.64 $(R = 0.42)$

Coastal alluvium: Olsen P = -0.53 S-P + 0.47 Al-P - 0.16 Fe-P - 0.37 Ca-P + 10.51 $(R = 0.70^{**})$

Brown hydromorphic soil: Olsen P = 0.41 S-P + 0.16 Al-P + 0.004 Fe-P + 0.04 Ca-P + 2.27 $(R = 0.98^{**})$

Kuttanad alluvium: Olsen P = -0.58 S-P + 0.19 Al-P + 0.13 Fe-P - 0.05 Ca-P - 0.53 $(R = 0.53^{*})$

Black soil: Olsen P = 0.50 S-P + 14 Al-P - 0.09 Fe-P - 0.02 Ca P + 10.34 $(R = 0.55^{*})$

8.3. Mathew's triacid P and P fr

Mathew's triacid P showed significant relationships with inorganic P fractions in all the soil types studied except in brown hydromonphic soil.

In laterite soil Mathew's P significantly correlated to Ca-P and Fe-P the correlation coefficients were 0.612^{*} and 0.481^{*} respectively.

In coastal alluvium Mathew's triacid P significantly correlated to Fe-P $(r = 0.519^{*})$, Ca-P $(r = 0.451^{*})$ and Al-P $(r = 0.441^{*})$.

In Kuttanad alluvium, a simple regression analysis showed that Mathew's P is correlated to Fe-P (r = 0.677**) and Al-P (r = 0.617**). In Black soil only Al-P established significant correlation.

Mathew's P showed highest degree of correlation with Al-P and Fe-P because the mineral acids HCl and H_2SO_4 removed the acid soluble portion. The organic acid namely oxalic acid helped in preventing the refixation of the Al-P and Fe-P on soil colloids which helped in making the fractions available in solution. Mathew (1977) also reported the same.

The multple regression equation are given below:

Laterite soil: Mathew's P = -1.51 S-P + 0.76 Al-P - 0.13 Fe-P + 0.25 Ca-P + 53.58 (R = 0.68**)

Coastal alluvium: Mathew's P = -0.05 S-P + 0.28 Al-P + 0.64 Fe-P + 0.18 Ca-P + 13.94 (R = 0.55*)

Brown hydromorphic soil: Mathew's P = -4.99 S-P - 0.15 Al-P + 0.2 Fe-P - 0.08 Ca-P + 45.75 (R = 0.31)

Kuttanad alluvium: Mathew's P = -0.64 S-P + 0.28 Al-P + 0.20 Fe-P + 0.11 Ca-P + 59.58 (R = 0.76**)

Black soil: Mathew's P = -2.67 S-P + 2.79 Al-P + 0.09 Fe-P + 0.10 Ca-P + 78.81 (R = 0.68**)

9. Phosphate potential and P fractions

Phosphate potential values for different soil types are presented in Table 20. The mean potential values recorded for the different soil types are as follows: Coastal alluvium 6.99 (range 7.74 to 6.38); Kuttanad alluvium 7.13 (range 7.57 to 6.23); Black soil 7.50 (range 7.82 to 7.26); Laterite 7.58 (range (8.05 to 7.26); Brown hydromorphic soil 7.61 (range 8.05 to 7.07).

Comparing the range values of pP in different soil types, the Kuttanad alluvium recorded 2nd lowest value this may be due to the low pH, that increased the concentration of H_2PO_4 and it in turn reduced the phosphate potential. The findings of Doddamani (1982) also support this observation.

Among the five soil types studied none of the soils except coastal alluvium established significant relationship between P fractions and pP.

9. Equilibrium phosphate potential (EPP)

The equilibrium phosphate potential values for the different soil types are given in Table 21. The lowest EPP value was recorded in laterite soil with a mean value of 7.13 (range 7.50 to 6.74). In black soil the EPP recorded a mean value of 7.38 (range 7.91 to 6.73), coastal alluvium 7.47 (range 8.35 to 6.26), Kuttanad alluvium 7.47 (range 8.17 to 5.93) and brown hydromorphic soil 7.73 (range 7.92 to 7.36). Comparing the different soil types much variation was not observed among the soil types studied.

Among the five soil types selected for the study, negative and significant relationship was established by certain fractions of P and EPP and the correlation coefficients between EPP and Saloid-P was ($r = -0.644^{**}$) negative in coastal alluvium. In black soil EPP established a negative relationship with Ca-P ($r = -0.522^{*}$). The correlation coefficient for EPP vs Fe-P was also negative ($r = -0.445^{*}$). This indicated the decreased availability of P in these soils as EPP increased.

11. Differential phosphate potential buffering capacity (DPBC)

The value obtained for DPBC for the different soil types are given in Table 22. The values ranged between 3.4 to 56.9 mole P $\times 10^{-6}$ per gram in coastal alluvium with a mean value of 11.71 mole P $\times 10^{-6}$ per gram. In black soil the average value recorded was 17.22 mole P $\times 10^{-6}$ per gram (range 9.8 to 29.9 mole P $\times 10^{-6}$ per gram). In brown hydromorphic soil it varied from 16.6 to 38.1 with an average value of 20.99 mole P $\times 10^{-6}$ per gram. In Kuttanad alluvium and laterite soil the mean values were 63.94 (range 6.5 to 410.7) and 195.8 (range 11.3 to 1666.1) respectively. Among the soil types studied the laterite soil recorded the highest DPBC value. This may be due to the high content of sesquioxides, which provided higher P adsorption sites resulting high labile pool of P and increased buffering capacity.

Similar results were reported by Doddamani (1982) and Lakshmi _et al._ (1987). DPBC failed to establish significantly with P fractions in all the soil types studied.

Table 20. Phosphate potential values in different soil types

Laterite		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	Value	Sample No.	Value	Sample No.	Value	Sample No.	Value	Sample No.	Value
L_1	7.44	C_1	7.44	BH_1	7.42	K_1	7.25	B_1	7.43
L_2	7.26	C_2	7.73	BH_2	7.73	K_2	7.26	B_2	7.76
L_3	7.58	C_3	6.95	BH_3	7.73	K_3	7.03	B_3	7.40
L_4	7.44	C_4	6.89	BH_4	8.04	K_4	6.81	B_4	7.36
L_5	7.57	C_5	6.74	BH_5	7.56	K_5	7.57	B_5	7.51
L_6	7.76	C_6	6.48	BH_6	8.05	K_6	7.19	B_6	7.40
L_7	7.75	C_7	6.38	BH_7	8.04	K_7	7.14	B_7	7.46
L_8	7.44	C_8	6.81	BH_8	7.44	K_8	7.13	B_8	7.51
L_9	7.36	C_9	6.56	BH_9	7.44	K_9	7.44	B_9	7.40
L_{10}	7.58	C_{10}	6.79	BH_{10}	7.57	K_{10}	7.35	B_{10}	7.52
L_{11}	7.44	C_{11}	7.74	BH_{11}	7.74	K_{11}	6.78	B_{11}	7.26
L_{12}	8.05	C_{12}	7.04	BH_{12}	7.56	K_{12}	6.84	B_{12}	7.49
L_{13}	8.05	C_{13}	7.08	BH_{13}	7.56	K_{13}	6.25	B_{13}	7.68
L_{14}	7.57	C_{14}	6.78	BH_{14}	7.42	K_{14}	7.13	B_{14}	7.41
L_{15}	7.58	C_{15}	6.64	BH_{15}	7.34	K_{15}	6.88	B_{15}	7.35
L_{16}	7.56	C_{16}	6.61	BH_{16}	7.44	K_{16}	7.34	B_{16}	7.82
L_{17}	7.72	C_{17}	7.20	BH_{17}	7.56	K_{17}	7.34	B_{17}	7.64
L_{18}	7.46	C_{18}	7.13	BH_{18}	7.07	K_{18}	7.43	B_{18}	7.51
L_{19}	7.45	C_{19}	7.57	BH_{19}	7.74	K_{19}	7.43	B_{19}	7.42
L_{20}	7.58	C_{20}	7.25	BH_{20}	7.73	K_{20}	6.92	B_{20}	7.66
Mean	7.58	Mean	6.99	Mean	7.61	Mean	7.13	Mean	7.50

Table 21. Equilibrium phosphate potenital (EPP) in different soil types

Laterite		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	EPP	Sample No.	EPP	Sample No.	EPP	Sample No.	EPP	Sample No.	EPP
L_1	6.99	C_1	8.02	BH_1	7.90	K_1	8.16	B_1	7.16
L_2	6.78	C_2	8.08	BH_2	7.90	K_2	8.17	B_2	7.03
L_3	6.97	C_3	7.28	BH_3	7.90	K_3	8.17	B_3	7.03
L_4	7.25	C_4	7.51	BH_4	7.91	K_4	8.13	B_4	6.91
L_5	7.36	C_5	7.11	BH_5	7.91	K_5	7.92	B_5	7.44
L_6	7.09	C_6	6.75	BH_6	7.90	K_6	7.64	B_6	7.35
L_7	6.74	C_7	6.26	BH_7	7.92	K_7	7.92	B_7	7.26
L_8	7.21	C_8	7.20	BH_8	7.91	K_8	7.50	B_8	7.63
L_9	6.93	C_9	6.90	BH_9	7.90	K_9	7.68	B_9	7.65
L_{10}	7.32	C_{10}	7.40	BH_{10}	7.91	K_{10}	7.39	B_{10}	7.72
L_{11}	7.38	C_{11}	7.91	BH_{11}	7.90	K_{11}	7.00	B_{11}	6.73
L_{12}	7.17	C_{12}	7.72	BH_{12}	7.89	K_{12}	7.62	B_{12}	7.64
L_{13}	7.21	C_{13}	6.89	BH_{13}	7.89	K_{13}	5.93	B_{13}	7.67
L_{14}	7.11	C_{14}	6.94	BH_{14}	7.45	K_{14}	6.93	B_{14}	3.13
L_{15}	7.50	C_{15}	7.44	BH_{15}	7.41	K_{15}	6.36	B_{15}	7.71
L_{16}	7.42	C_{16}	7.51	BH_{16}	7.38	K_{16}	7.17	B_{16}	7.57
L_{17}	7.04	C_{17}	8.33	BH_{17}	7.45	K_{17}	7.07	B_{17}	6.97
L_{18}	7.12	C_{18}	7.67	BH_{18}	7.40	K_{18}	7.63	B_{18}	7.70
L_{19}	7.07	C_{19}	8.20	BH_{19}	7.43	K_{19}	7.60	B_{19}	7.48
L_{20}	6.97	C_{20}	8.35	BH_{20}	7.36	K_{20}	7.34	B_{20}	7.91
Mean	7.13	Mean	7.47	Mean	7.73	Mean	7.47	Mean	7.38

12. Desorbed P

The desorbed P in four successive washings are given in Table 23. In laterite soil the mean desorbed P was 3.68 µg/g (range 2.55 to 7.94 µg/g). In coastal alluvium 2.12 µg/g (range 0.24 to 7.03 µg/g). In brown hydromorphic soil the mean value was 0.33 µg/g (range 0.19 to 0.76 µg/g), Kuttanad alluvium 1.33 µg/g (range 0.05 to 17.48 µg/g), black soil 2.62 µg/g (range 0.53 to 6.88 µg/g). Among the five soil types studied desorbed P established significant relationship with S-P ($r = 0.865^{**}$), Al-P ($r = 0.720^{**}$) and Ca-P ($r = 0.722^{**}$) in coastal allvuium soils.

In Kuttanad alluvium Al-P ($r = 0.497^{*}$) and Ca-P ($r = 0.463^{*}$) showed significant correlation with desorbed P. In all other soil types viz., laterite, brown hydromorphic and black soil desorbed P failed to correlate with P fractions.

13. Adsorption characteristics

The adsorption characteristics studied are adsorption maximum and bonding energy constant 'K' the values of which are presented in Table 24 and 25.

The mean adsorption maximum was highest in brown hydromorphic soil 727.6 µg/g (range 438.3 to 1087.0 µg/g) followed by Kuttanad alluviumm 652.4 µg/g (range 71.3 to 1957.6 µg/g), laterite 436.0 µg/g (range 209.2 to 1182.0 µg/g), black soil 287.3 µg/g (range 133.8 to 354.5 µg/g) and coastal alluvium 113.3 µg/g (range 19.4

to 269.6 µg/g). The maximum adsorption of 1956.6 µg/g was recorded in Kuttanad alluvium and minimum of 19.4 µg/g in coastal alluvium.

High amount of free oxides of Fe and organic matter content in Kuttanad alluvium might have increased the adsorption of P in these type of soils. Sundararajan and Kothandaraman (1978) reported enormous specific surface area of the hydrated Fe and Al oxides for the high adsorption power of the soil. This may be true in case of the brown hydromorphic soils in our present study.

A simple regression analysis showed that Fe-P correlated to adsorption maximum in brown hydromorphic soils ($r = 0.640^{**}$). In all other soil types P fractions failed to correlate with adsorption maximum.

14. Phosphorus uptake

Phosphorus uptake was studied using modified Neubauer experiment using rice as test crop. The data are presented in Table 26. Maximum uptake was recorded in coastal alluvium with a mean value of 4.520 mg/pot (range 3.615 to 6.026) followed by Kuttanad alluvium 4.230 mg/pot (range 2.897 to 5.561). The mean P uptake recorded for other soil types viz., laterite, brown hydromorphic and black soil were 4.170, 4.160 and 3.720 mg/pot respectively.

14.1. Phosphorus uptake and P fractions

A simple correlation analysis showed that in coastal alluvium

Table 22. Differential phosphate buffering capacity (DPBC) in different soil types, mole p x 10^{-6} per gram

Laterite soil		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	DPBC	Sample No.	DPBC	Sample No.	DPBC	Sample No.	DPBC	Sample No.	DPBC
L_1	23.7	C_1	17.3	BH_1	16.9	K_1	32.9	B_1	24.3
L_2	24.6	C_2	56.9	BH_2	17.3	K_2	32.2	B_2	12.5
L_3	760.7	C_3	4.1	BH_3	17.6	K_3	31.0	B_3	18.3
L_4	11.3	C_4	4.1	BH_4	17.3	K_4	11.0	B_4	21.1
L_5	50.8	C_5	5.0	BH_5	16.6	K_5	48.3	B_5	16.4
L_6	350.0	C_6	10.0	BH_6	17.4	K_6	78.8	B_6	29.9
L_7	31.1	C_7	28.5	BH_7	16.9	K_7	39.6	B_7	10.8
L_8	164.9	C_8	3.5	BH_8	17.3	K_8	153.5	B_8	21.4
L_9	39.7	C_9	3.4	BH_9	17.6	K_9	63.4	B_9	15.9
L_{10}	34.7	C_{10}	5.1	BH_{10}	18.6	K_{10}	30.5	B_{10}	19.1
L_{11}	36.9	C_{11}	5.2	BH_{11}	17.8	K_{11}	6.5	B_{11}	18.3
L_{12}	40.9	C_{12}	15.5	BH_{12}	19.0	K_{12}	9.8	B_{12}	18.6
L_{13}	34.7	C_{13}	9.2	BH_{13}	19.2	K_{13}	122.9	B_{13}	17.3
L_{14}	107.5	C_{14}	6.8	BH_{14}	23.0	K_{14}	50.4	B_{14}	16.1
L_{15}	34.9	C_{15}	6.8	BH_{15}	25.6	K_{15}	410.7	B_{15}	13.4
L_{16}	45.2	C_{16}	6.3	BH_{16}	23.5	K_{16}	70.3	B_{16}	18.0
L_{17}	180.7	C_{17}	4.8	BH_{17}	23.8	K_{17}	32.6	B_{17}	9.8
L_{18}	176.4	C_{18}	5.8	BH_{18}	27.8	K_{18}	16.3	B_{18}	14.3
L_{19}	100.9	C_{19}	25.0	BH_{19}	28.4	K_{19}	7.3	B_{19}	14.7
L_{20}	1666.1	C_{20}	10.9	BH_{20}	38.1	K_{20}	32.8	B_{20}	14.2
Mean	195.8	Mean	11.71	Mean	20.99	Mean	63.94	Mean	17.22

Table 23. Phosphorus desorbed for four successive washings in different soil types, µg/g

Laterite soil		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	Desorbed P	Sample No.	Desorbed P	Sample No.	Desorbed P	Sample No.	Desorbed P	Sample No.	Desorbed P
L_1	7.22	C_1	0.912	BH_1	0.19	K_1	0.18	B_1	4.33
L_2	6.69	C_2	0.53	BH_2	0.19	K_2	0.18	B_2	3.80
L_3	2.55	C_3	1.44	BH_3	0.38	K_3	0.36	B_3	4.86
L_4	7.94	C_4	0.94	BH_4	0.19	K_4	0.90	B_4	4.52
L_5	2.70	C_5	2.70	BH_5	0.76	K_5	10.36	B_5	2.89
L_6	3.29	C_6	7.03	BH_6	0.19	K_6	0.54	B_6	2.89
L_7	3.61	C_7	5.24	BH_7	0.38	K_7	0.818	B_7	4.71
L_8	2.70	C_8	0.95	BH_8	0.76	K_8	0.36	B_8	3.42
L_9	2.66	C_9	2.70	BH_9	0.19	K_9	0.36	B_9	3.08
L_{10}	2.89	C_{10}	1.97	BH_{10}	0.19	K_{10}	0.05	B_{10}	1.82
L_{11}	3.08	C_{11}	1.10	BH_{11}	0.38	K_{11}	0.72	B_{11}	6.88
L_{12}	2.55	C_{12}	1.25	BH_{12}	0.19	K_{12}	0.38	B_{12}	0.72
L_{13}	3.08	C_{13}	0.24	BH_{13}	0.19	K_{13}	17.48	B_{13}	1.10
L_{14}	2.81	C_{14}	1.44	BH_{14}	0.19	K_{14}	0.72	B_{14}	1.10
L_{15}	3.18	C_{15}	3.99	BH_{15}	0.19	K_{15}	0.90	B_{15}	1.82
L_{16}	3.42	C_{16}	3.08	BH_{16}	0.38	K_{16}	0.54	B_{16}	1.44
L_{17}	3.80	C_{17}	0.53	BH_{17}	0.19	K_{17}	0.90	B_{17}	1.10
L_{18}	2.70	C_{18}	3.61	BH_{18}	0.76	K_{18}	0.54	B_{18}	3.27
L_{19}	3.09	C_{19}	1.25	BH_{19}	0.38	K_{19}	0.36	B_{19}	0.53
L_{20}	3.61	C_{20}	1.44	BH_{20}	0.38	K_{20}	0.54	B_{20}	1.10
Mean	3.68	Mean	2.12	Mean	0.33	Mean	1.33	Mean	2.62

Table 24. Adsorption maximum in different soil types, μg/g

Laterite soil		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	Adsorption maximum	Sample No.	Adsorption maximum	Sample No.	Adsorption maximum	Sample No.	Adsorption maximum	Sample No.	Adsorption maximum
L_1	372.25	C_1	200.52	BH_1	594.35	K_1	726.59	B_1	354.50
L_2	1182.23	C_2	269.59	BH_2	922.34	K_2	1108.57	B_2	221.71
L_3	294.20	C_3	19.35	BH_3	545.32	K_3	752.11	B_3	315.53
L_4	209.20	C_4	65.70	BH_4	655.27	K_4	454.36	B_4	812.94
L_5	337.40	C_5	47.94	BH_5	698.81	K_5	1150.22	B_5	265.86
L_6	434.78	C_6	119.50	BH_6	695.70	K_6	1379.52	B_6	223.69
L_7	385.46	C_7	51.66	BH_7	627.71	K_7	632.83	B_7	242.88
L_8	397.66	C_8	43.14	BH_8	872.45	K_8	764.06	B_8	306.23
L_9	414.52	C_9	34.08	BH_9	596.02	K_9	934.49	B_9	303.62
L_{10}	410.59	C_{10}	86.07	BH_{10}	645.08	K_{10}	594.53	B_{10}	311.31
L_{11}	371.37	C_{11}	237.31	BH_{11}	896.70	K_{11}	143.04	B_{11}	269.00
L_{12}	365.00	C_{12}	132.55	BH_{12}	438.27	K_{12}	93.27	B_{12}	248.53
L_{13}	351.19	C_{13}	101.86	BH_{13}	645.54	K_{13}	286.74	B_{13}	308.05
L_{14}	384.50	C_{14}	76.48	BH_{14}	1086.99	K_{14}	373.15	B_{14}	255.66
L_{15}	432.69	C_{15}	109.95	BH_{15}	671.64	K_{15}	131.20	B_{15}	172.97
L_{16}	217.84	C_{16}	110.433	BH_{16}	901.23	K_{16}	507.31	B_{16}	284.30
L_{17}	785.73	C_{17}	93.91	BH_{17}	485.74	K_{17}	575.84	B_{17}	133.83
L_{18}	460.70	C_{18}	106.47	BH_{18}	975.13	K_{18}	410.37	B_{18}	269.08
L_{19}	443.68	C_{19}	216.26	BH_{19}	806.71	K_{19}	71.33	B_{19}	290.77
L_{20}	468.36	C_{20}	142.38	BH_{20}	790.20	K_{20}	1957.61	B_{20}	154.66
Mean	435.98	Mean	113.26	Mean	727.56	Mean	652.36	Mean	287.26

Table 25. Bonding energy constant (K) in different soil types.

Laterite soil		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	K	Sample No.	K	Sample No.	K	Sample No.	K	Sample No.	K
L_1	0.19	C_1	0.58	BH_1	0.59	K_1	0.78	B_1	0.29
L_2	0.10	C_2	1.10	BH_2	2.68	K_2	6.31	B_2	0.13
L_3	8.37	C_3	0.23	BH_3	0.49	K_3	0.42	B_3	0.14
L_4	1.58	C_4	0.44	BH_4	0.97	K_4	0.28	B_4	0.24
L_5	21.63	C_5	2.70	BH_5	0.51	K_5	8.20	B_5	0.25
L_6	8.07	C_6	0.21	BH_6	0.63	K_6	7.71	B_6	0.45
L_7	41.84	C_7	0.79	BH_7	0.39	K_7	0.29	B_7	0.14
L_8	13.24	C_8	1.43	BH_8	2.92	K_8	0.79	B_8	0.21
L_9	100.52	C_9	-0.62	BH_9	0.57	K_9	1.77	B_9	0.21
L_{10}	32.05	C_{10}	0.33	BH_{10}	0.54	K_{10}	0.11	B_{10}	0.39
L_{11}	1.98	C_{11}	1.04	BH_{11}	2.22	K_{11}	0.04	B_{11}	0.09
L_{12}	16.70	C_{12}	0.59	BH_{12}	0.27	K_{12}	0.20	B_{12}	0.25
L_{13}	4.63	C_{13}	0.16	BH_{13}	0.50	K_{13}	0.04	B_{13}	0.15
L_{14}	9.29	C_{14}	0.48	BH_{14}	0.82	K_{14}	0.11	B_{14}	0.15
L_{15}	35.56	C_{15}	0.41	BH_{15}	0.49	K_{15}	0.19	B_{15}	0.16
L_{16}	19.13	C_{16}	0.26	BH_{16}	0.93	K_{16}	0.19	B_{16}	0.24
L_{17}	4.08	C_{17}	0.74	BH_{17}	0.22	K_{17}	0.10	B_{17}	0.12
L_{18}	5.95	C_{18}	0.32	BH_{18}	10.05	K_{18}	0.11	B_{18}	0.21
L_{19}	0.81	C_{19}	1.10	BH_{19}	0.90	K_{19}	0.90	B_{19}	0.16
L_{20}	10.57	C_{20}	0.51	BH_{20}	1.17	K_{20}	0.95	B_{20}	0.16
Mean	16.81	Mean	0.70	Mean	1.39	Mean	1.44	Mean	0.20

Table 26. Phosphorus uptake in different soil types, mg/pot

Laterite		Coastal alluvium		Brown hydromorphic		Kuttanad alluvium		Black soil	
Sample No.	Uptake	Sample No.	Uptake	Sample No.	Uptake	Sample No.	Uptake	Sample No.	Uptake
L_1	6.004	C_1	4.488	BH_1	3.825	K_1	3.112	B_1	3.220
L_2	5.706	C_2	4.290	BH_2	4.007	K_2	3.766	B_2	3.523
L_3	4.080	C_3	4.115	BH_3	3.667	K_3	4.979	B_3	3.992
L_4	5.645	C_4	4.380	BH_4	3.570	K_4	5.347	B_4	4.009
L_5	4.187	C_5	4.665	BH_5	3.589	K_5	2.899	B_5	3.367
L_6	3.585	C_6	5.233	BH_6	3.764	K_6	3.840	B_6	3.352
L_7	5.126	C_7	5.028	BH_7	3.794	K_7	4.316	B_7	3.591
L_8	4.366	C_8	4.501	BH_8	4.895	K_8	3.892	B_8	3.418
L_9	3.429	C_9	4.416	BH_9	3.496	K_9	4.630	B_9	4.061
L_{10}	3.664	C_{10}	6.026	BH_{10}	4.847	K_{10}	3.795	B_{10}	3.540
L_{11}	3.820	C_{11}	3.615	BH_{11}	3.796	K_{11}	4.942	B_{11}	3.384
L_{12}	3.429	C_{12}	4.053	BH_{12}	4.671	K_{12}	4.595	B_{12}	3.053
L_{13}	3.243	C_{13}	5.281	BH_{13}	5.428	K_{13}	5.561	B_{13}	4.317
L_{14}	3.315	C_{14}	4.401	BH_{14}	4.631	K_{14}	4.343	B_{14}	3.458
L_{15}	3.537	C_{15}	4.636	BH_{15}	3.385	K_{15}	4.466	B_{15}	3.202
L_{16}	4.806	C_{16}	4.303	BH_{16}	4.191	K_{16}	3.586	B_{16}	3.381
L_{17}	4.615	C_{17}	3.957	BH_{17}	5.215	K_{17}	5.334	B_{17}	6.467
L_{18}	3.651	C_{18}	4.988	BH_{18}	5.967	K_{18}	4.370	B_{18}	3.818
L_{19}	3.975	C_{19}	3.759	BH_{19}	3.098	K_{19}	3.226	B_{19}	4.124
L_{20}	3.206	C_{20}	4.308	BH_{20}	3.432	K_{20}	3.647	B_{20}	3.200
Mean	4.170	Mean	4.520	Mean	4.160	Mean	4.230	Mean	3.720

all the fractions viz., saloid-P (r = 0.544*), Ca-P (r = 0.541*), Al-P (r = 0.489*), and Fe-P (r = 0.470*) correlated significantly to P uptake (Fig. 7 to 10). The multiple regression equation is given below:

Uptake = 0.04 S-P - 0.001 Al-P + 0.01 Fe-P - 0.001 Ca-P + 3.95
(R = 0.61*)

In the case of Kuttanad soil Al-P alone showed a significant relationship with P uptake (r = 0.605**) (Fig.11). In all other soil types P fractions failed to correlate significantly with P uptake. The multiple regression equations with the inorganic fractions of P and the P uptake for the selected soil types studied are given below:

Laterite soil: Uptake = 0.02 S-P + 0.02 Al-P - 0.01 Fe-P - 0.001 Ca-P + 4.08 (R = 0.59)

Brown hydromorphic: Uptake = -0.29 S-P -0.006 Al-P - 0.002 Fe-P + 0.006 Ca-P + 5.19 (R = 0.36)

Kuttanad alluvium: Uptake = 0.002 S-P + 0.01 Al-P + 0.001 Fe-P + 0.005 Ca-P + 3.48 (R = 0.64)

Black soil: Uptake = 0.12 S-P - 0.005 Al-P - 0.0001 Fe-P + 0.004 Ca-P + 2.52 (R = 0.42)

Among the different soil types the maximum R value of 0.64 was recorded for Kuttanad alluvium and from that it is inferred that 64% variation in the uptake of P in Kuttanad alluvium is due to the inorganic P fractions.

14.2. Extraction methods vs. P uptake

A simple correlation analysis in laterite soil showed that Mathew's P (r = 0.680**), Bray No.1 P (r = 0.560*) and Olsen's P (r = 0.543*) correlated significantly to P uptake (Fig.12 to 14).

Mathew's triacid P alone correlated significantly to P-uptake (r = 0.482*) in coastal alluvium and the same is illustrated by Fig.15.

Bray No.1 P (r = 0.593**) Mathew's triacid P (r = 0.459*) and Olsen's P (r = 0.483*) significantly correlated to P-uptake in Kuttanad alluvium (Fig.16, 17 and 18).

In case of brown hydromorphic and black soil none of the extraction methods correlated significantly to P uptake.

From the above results it is concluded that Mathew's triacid extractant is a better extracting solution for the estimation of available P in laterite and coastal alluvium soils. For Kuttanad alluvium Bray No.1 P is the best. Suitability of this Bray No.1 P in Kuttanad soils may be due to the higher content of Al-P in this soil type. Al-P established a significant relationship with Bray No.1 P in Kuttanad soils (r = 0.66**).

14.3. Phosphate potential vs. P uptake

A simple regression analysis confirmed that phosphate potential can be used as an availability index of phosphorus. Phosphate potential negatively and significantly correlated to P-uptake in Kuttanad alluvium (r = -0.623**), coastal alluvium (r = -0.512*) and brown

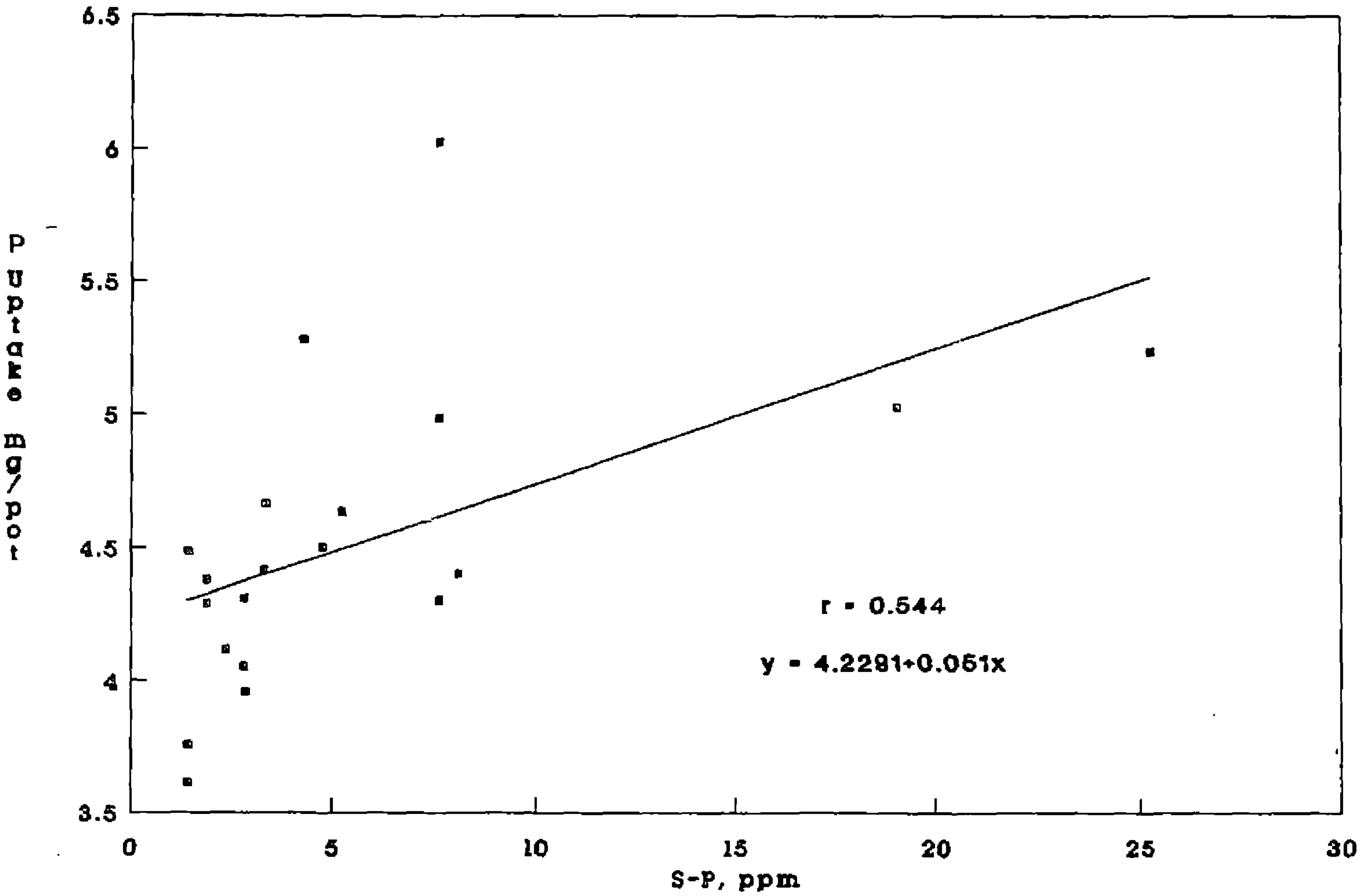

Fig. 7. Relationship between S-P and P uptake in coastal alluvium

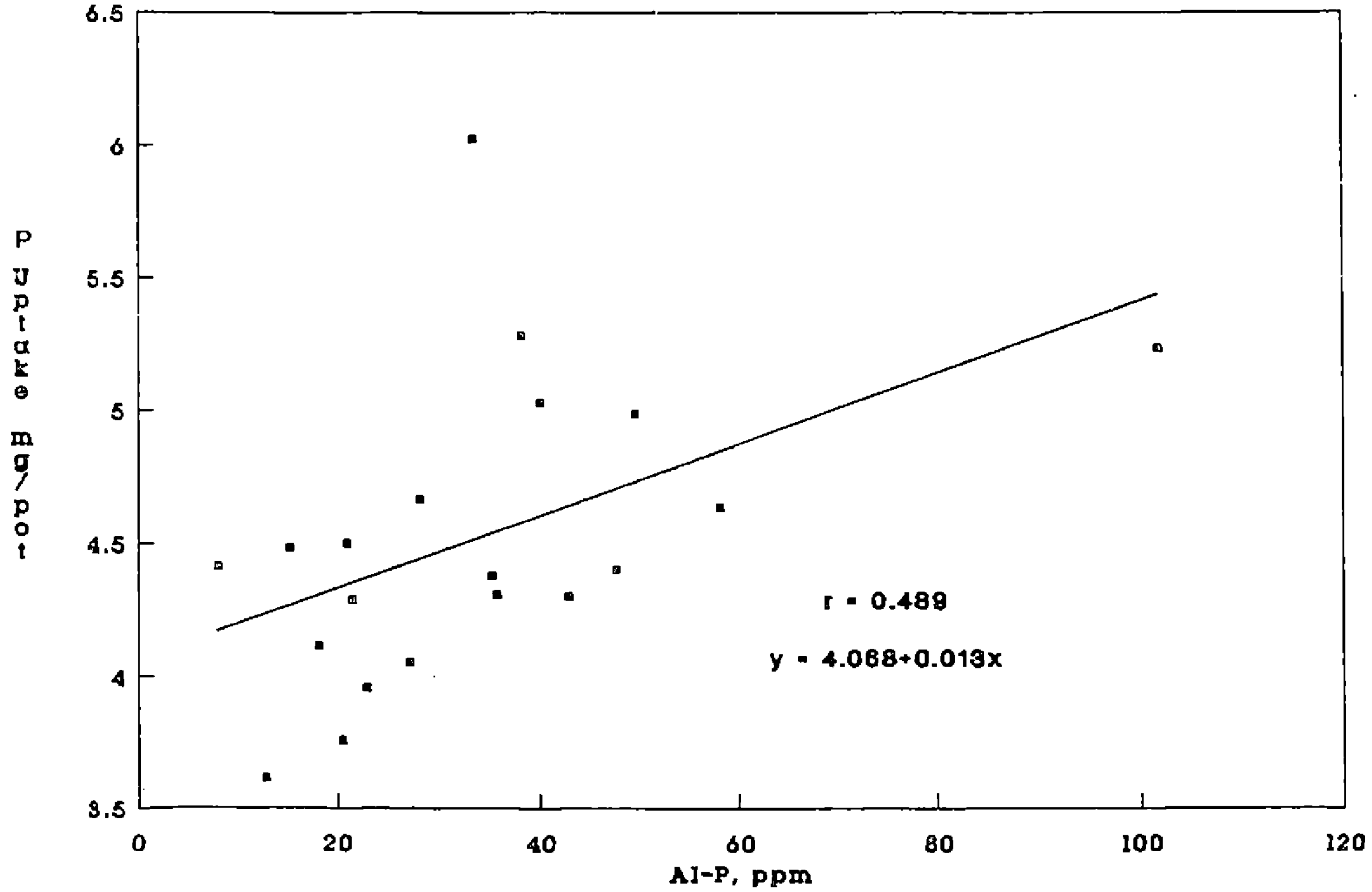

Fig. 8. Relationship between Al-P and P uptake in coastal alluvium

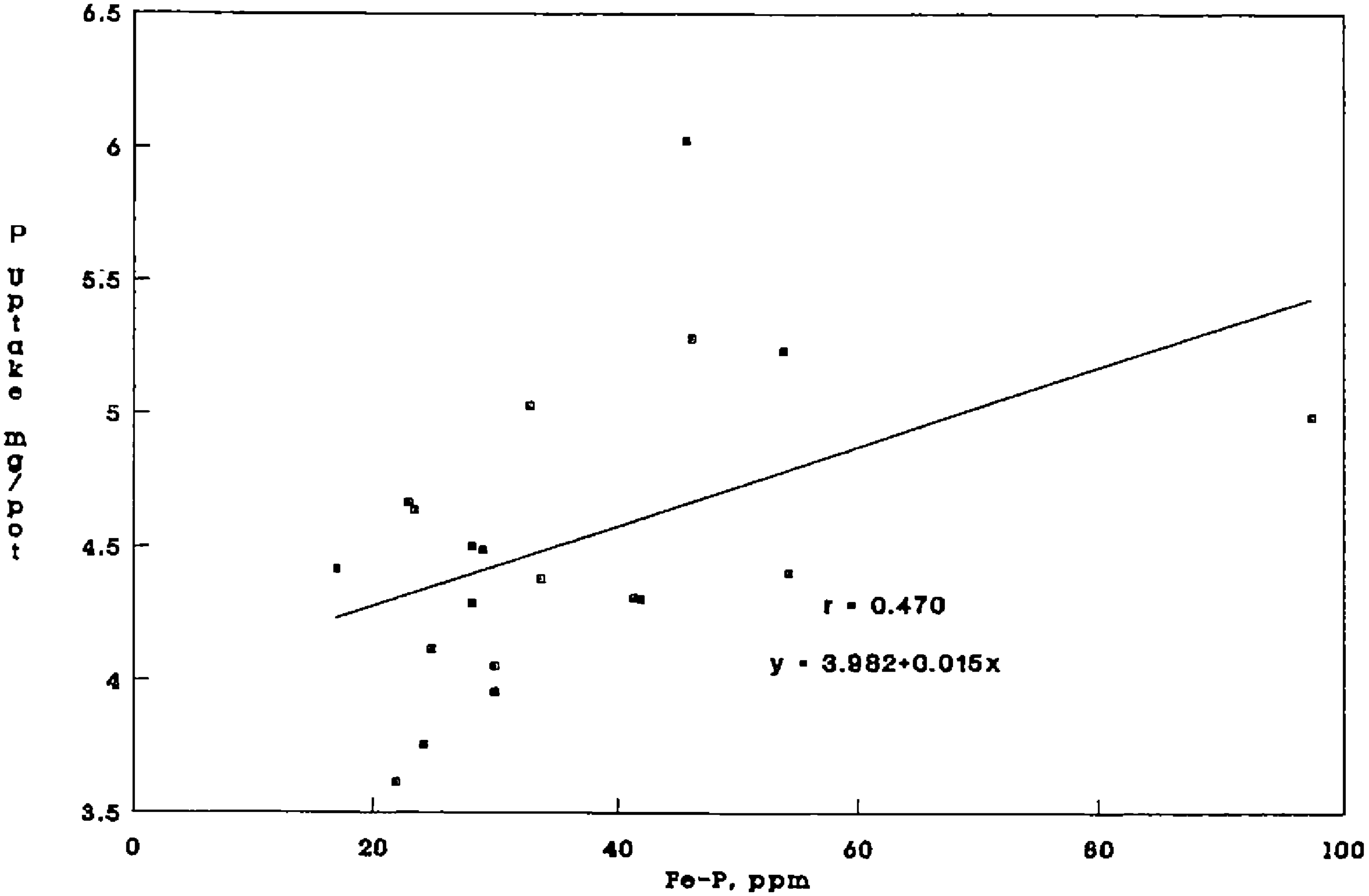

Fig. 9. Relationship between Fe-P and P uptake in coastal alluvium

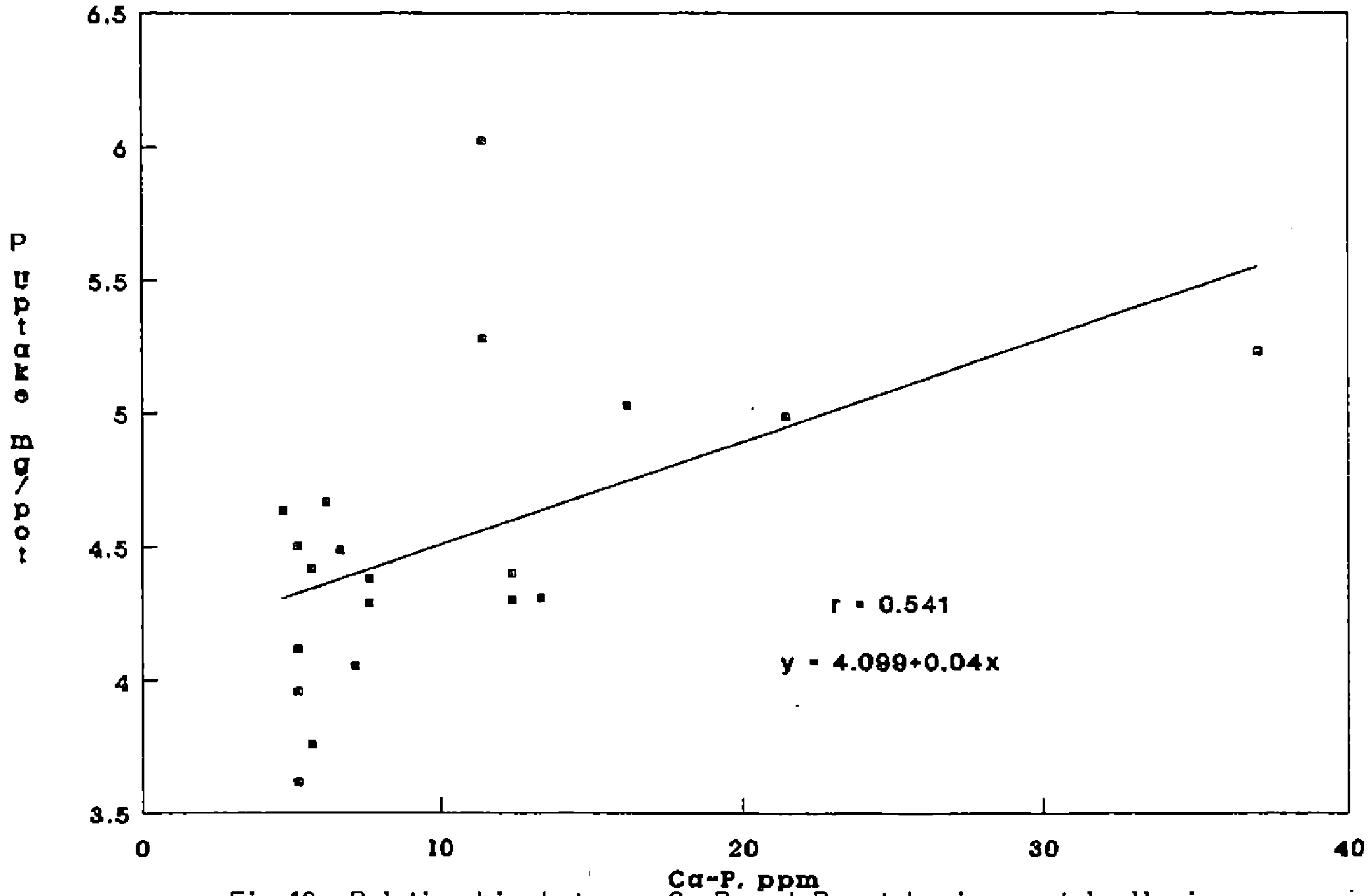

Fig.10. Relationship between Ca-P and P uptake in coastal alluvium

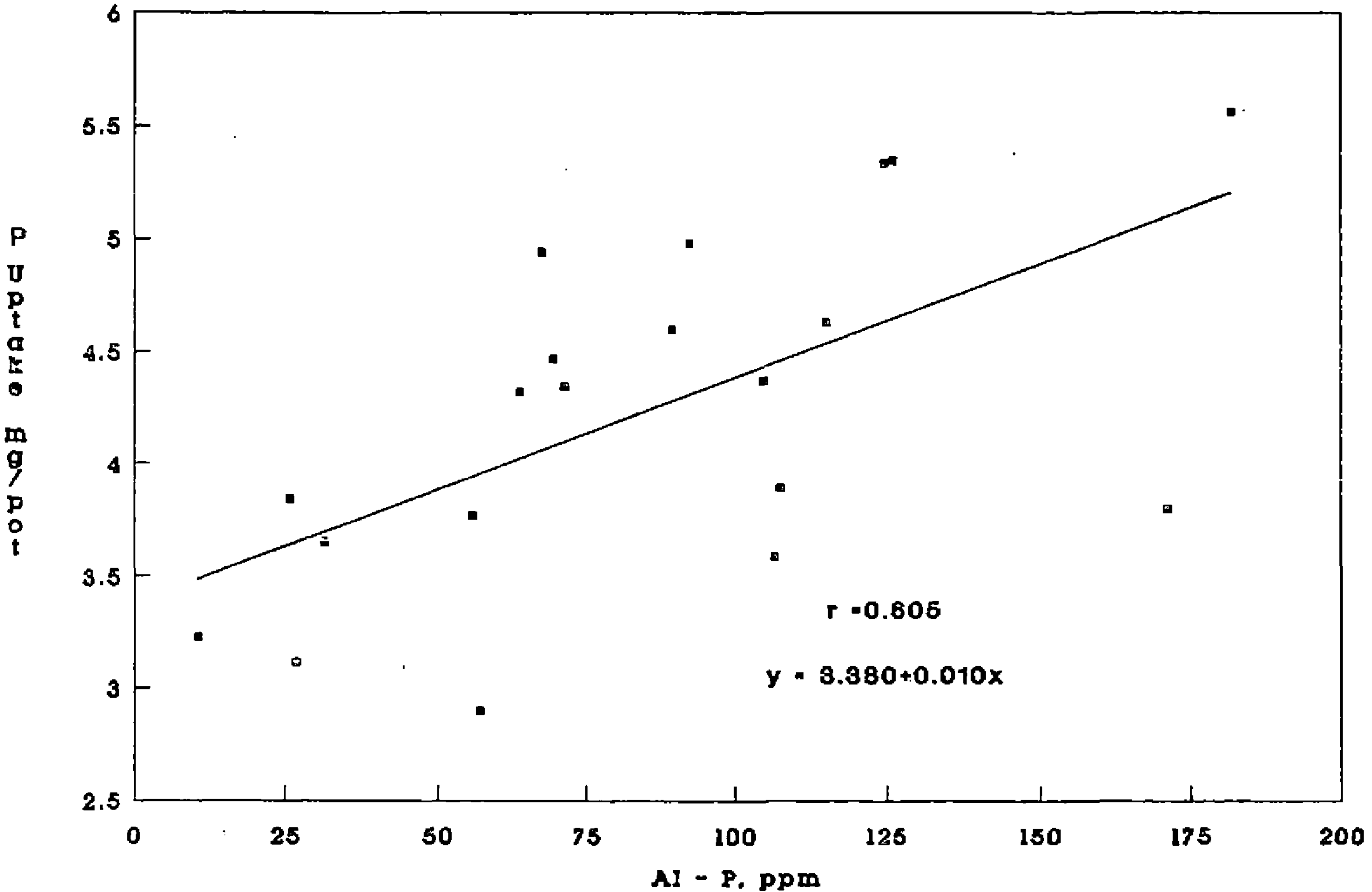

Fig.11. Relationship between Al-P and P uptake in Kuttanad alluvium

hydromorphic soil (r = -0.508), but failed to correlate significantly in laterite and black soil. Illustrations in this respect to the significant relationships are given in Fig.19, 20 and 21.

Sengupta (1966) opined that phosphate potential to be a better method for available phosphate measurement than the conventional methods in the case of soils not grouped on the basis of their clays. Polyzopoulos _et al_. (1982) correlated phosphate potential with P uptake by ryegrass in Alfisols.

14.4. EPP vs. P uptake

A simple regression analysis showed that EPP is correlated negatively to P-uptake only in coastal alluvium (r = -0.542*) as shown by Fig.22. In all other soil types it failed to correlate significantly with P-uptake.

Sengupta (1975) got better correlation with in oat for EPP than Schofield's phosphate potential.

14.5. DPBC vs. P uptake

Results of the analysis showed that DPBC is not a suitable method for predicting available P in the selected soil types studied. In all the five soil types viz., laterite, coastal alluvium, brown hydromorphic, Kuttanad alluvium and black soil, DPBC failed to correlate significantly with uptake of phosphorus.

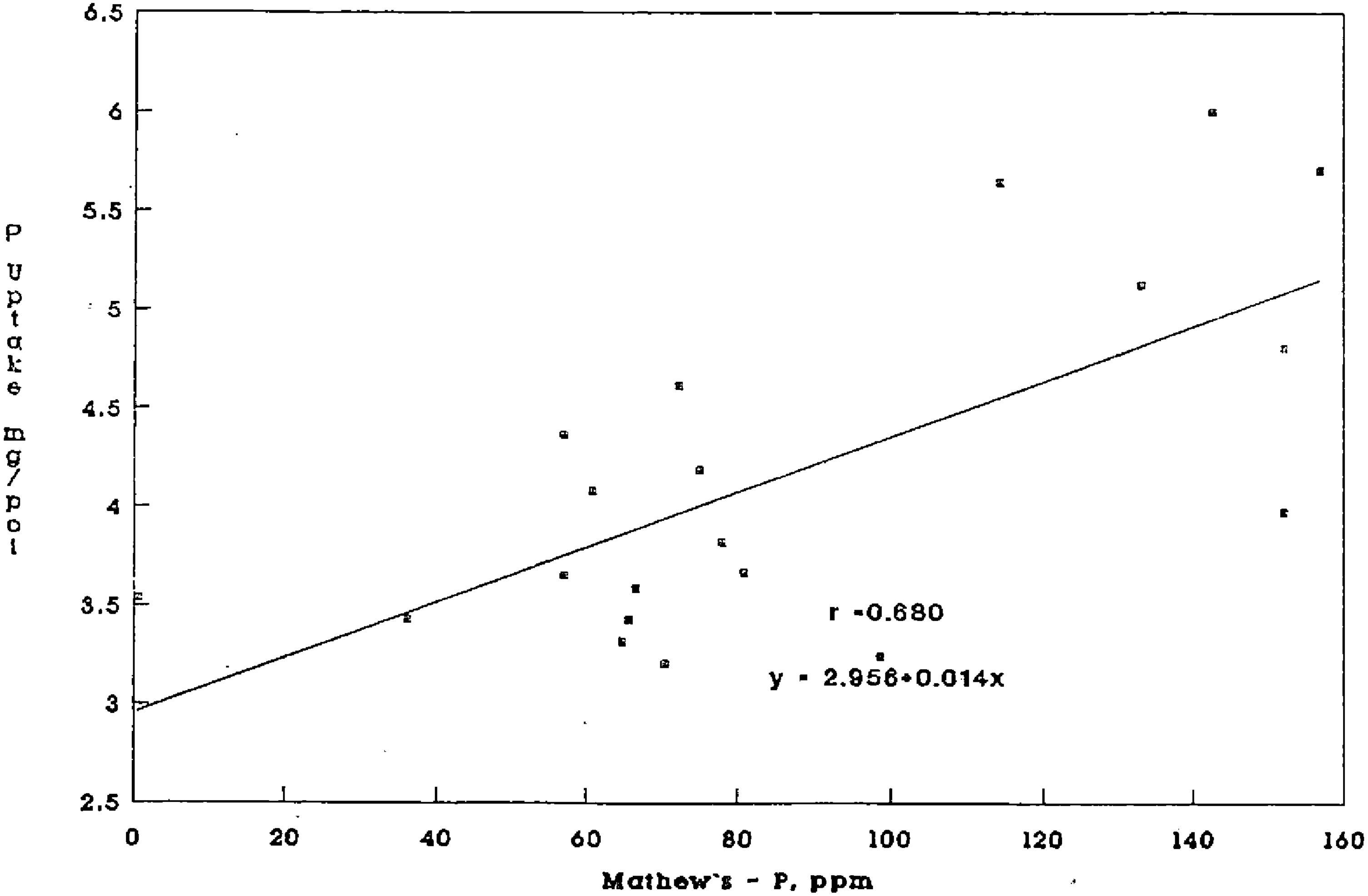

Fig.12. Relationship between Mathew's P and P uptake in laterite soil

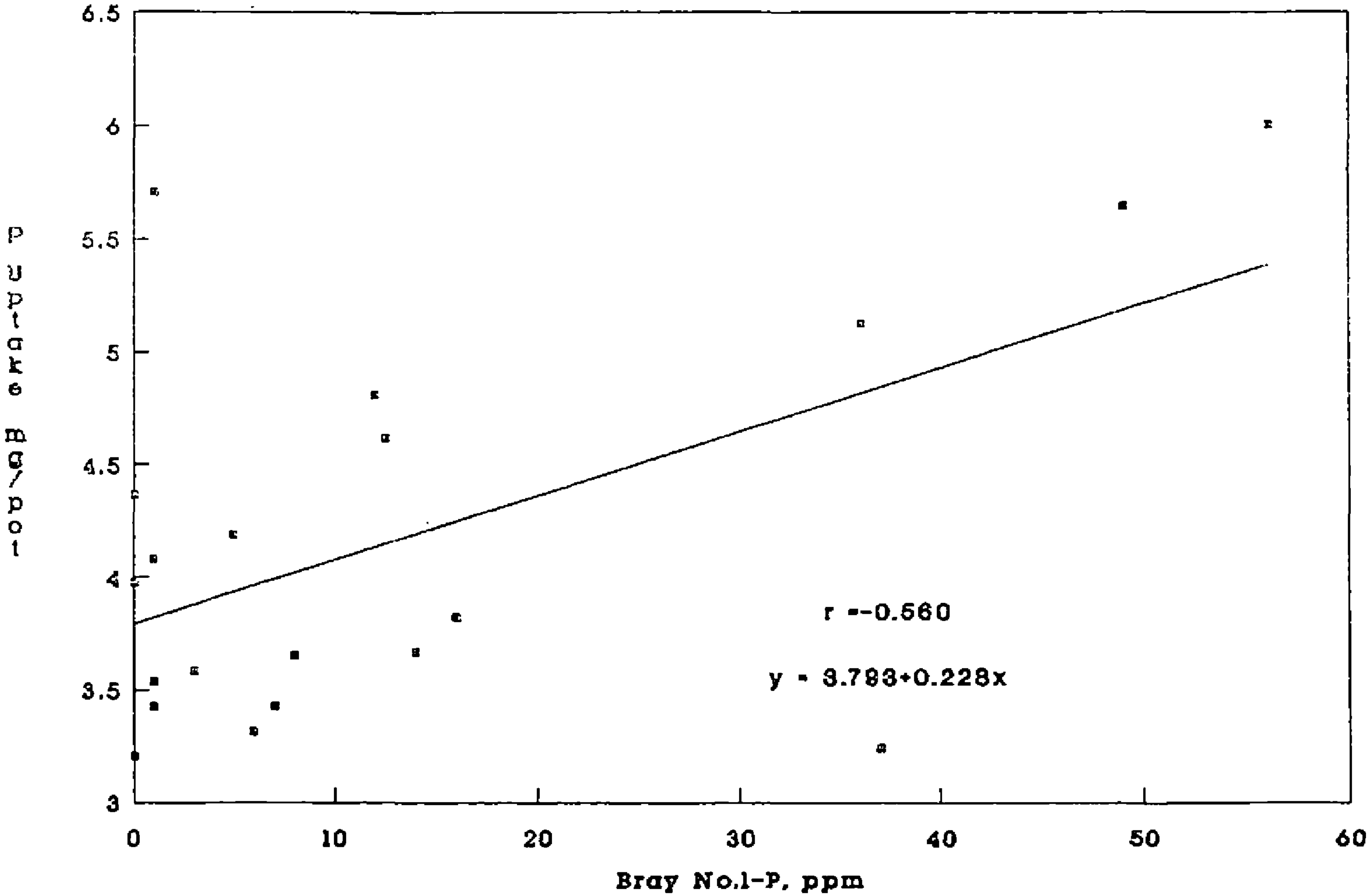

Fig.13. Relationship between Bray No.1-P and P uptake in laterite soil

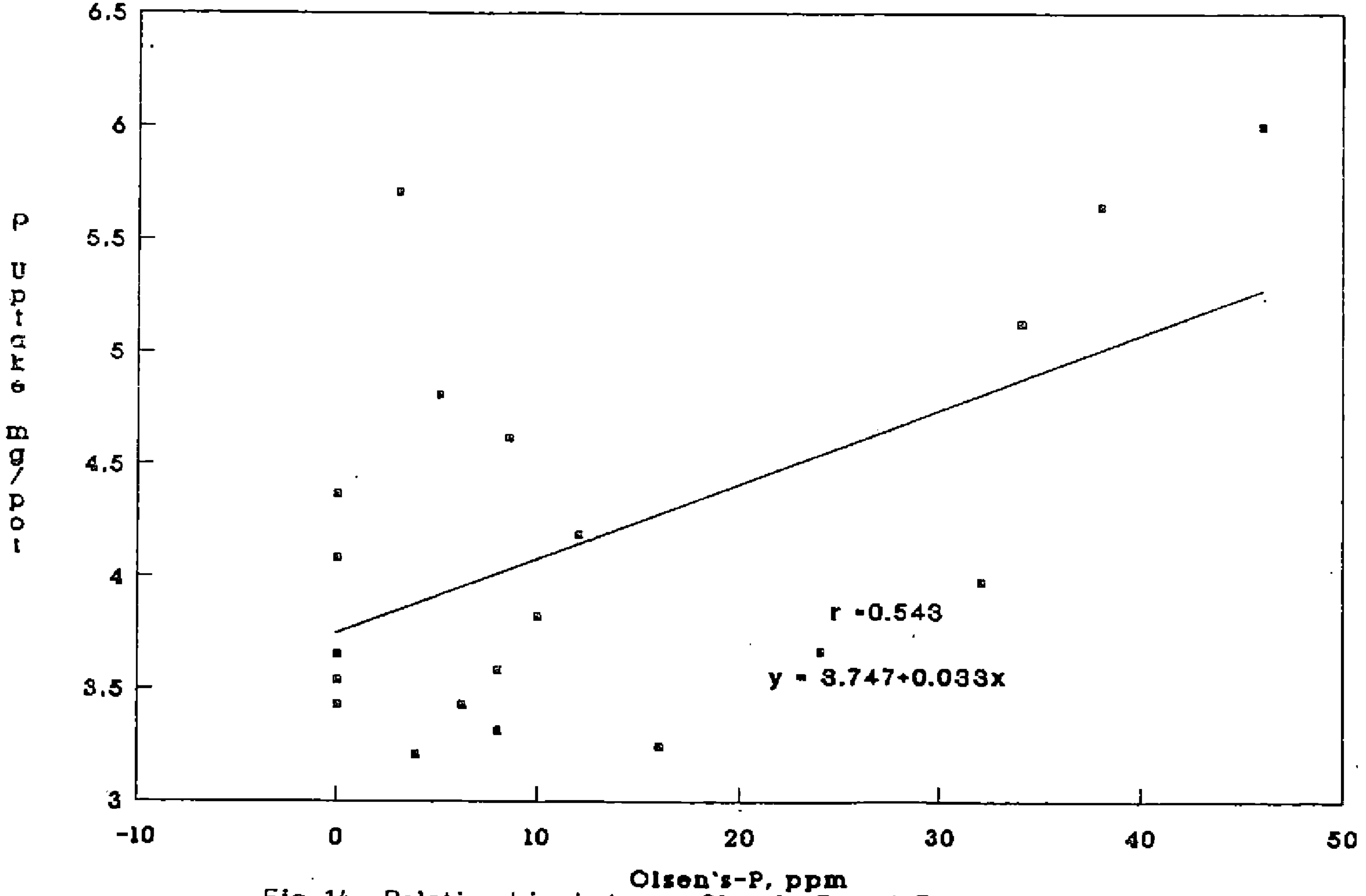

Fig. 14. Relationship between Olsen's-P and P uptake in laterite soil

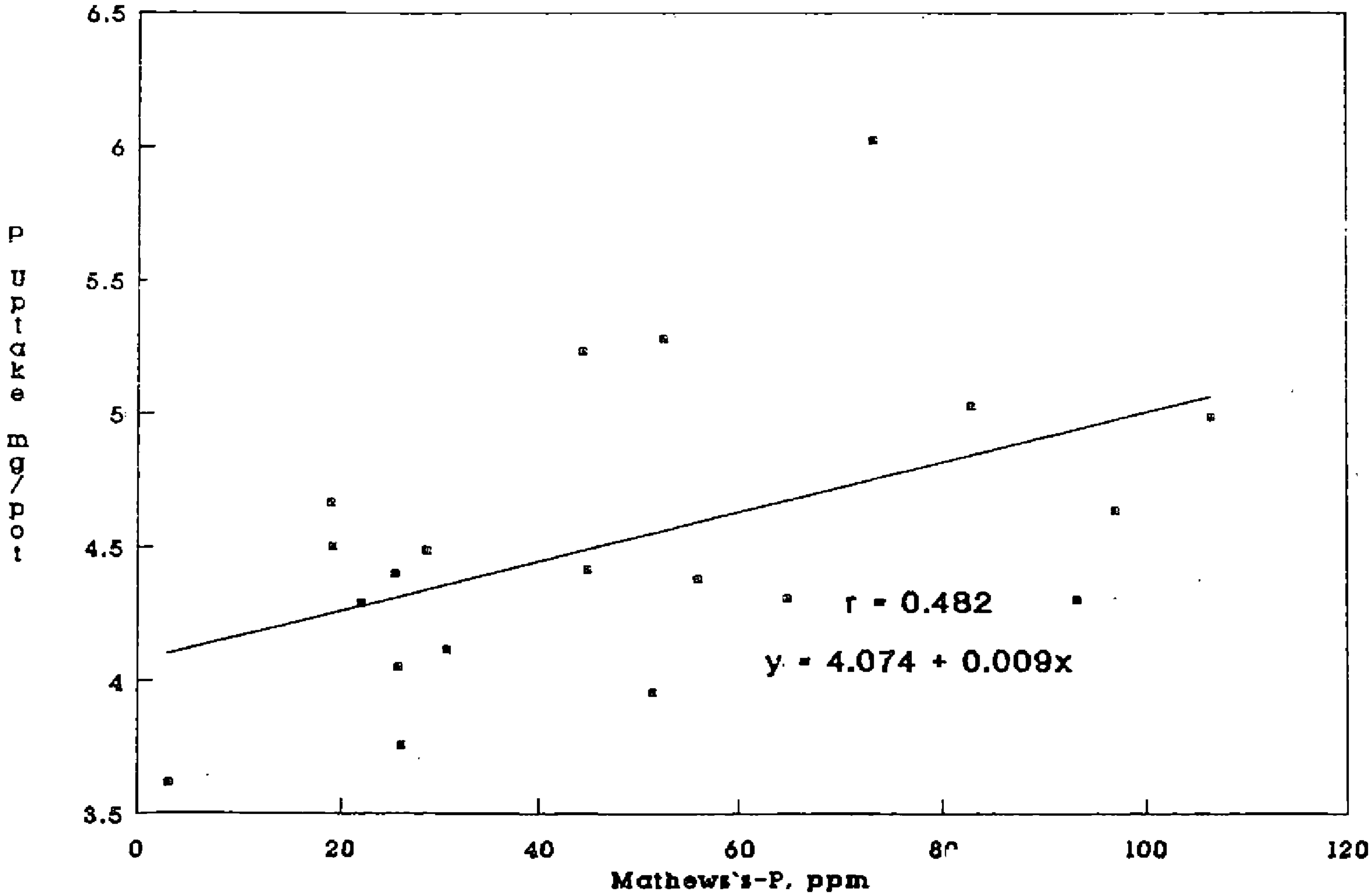

Fig.15. Relationship between Mathew's-P and P uptake in coastal alluvium

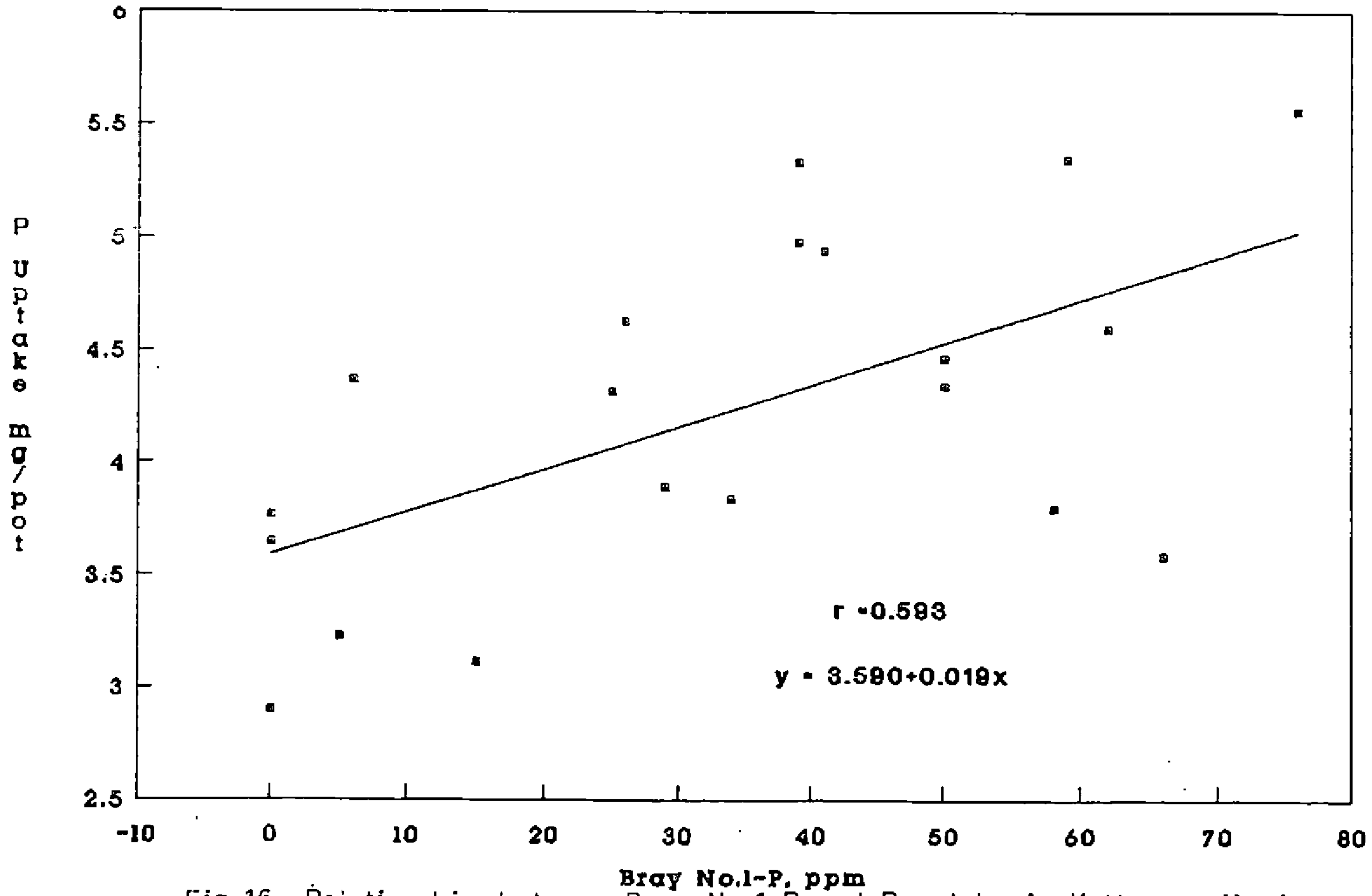

Fig.16. Relationship between Bray No.1-P and P uptake in Kuttanad alluvium

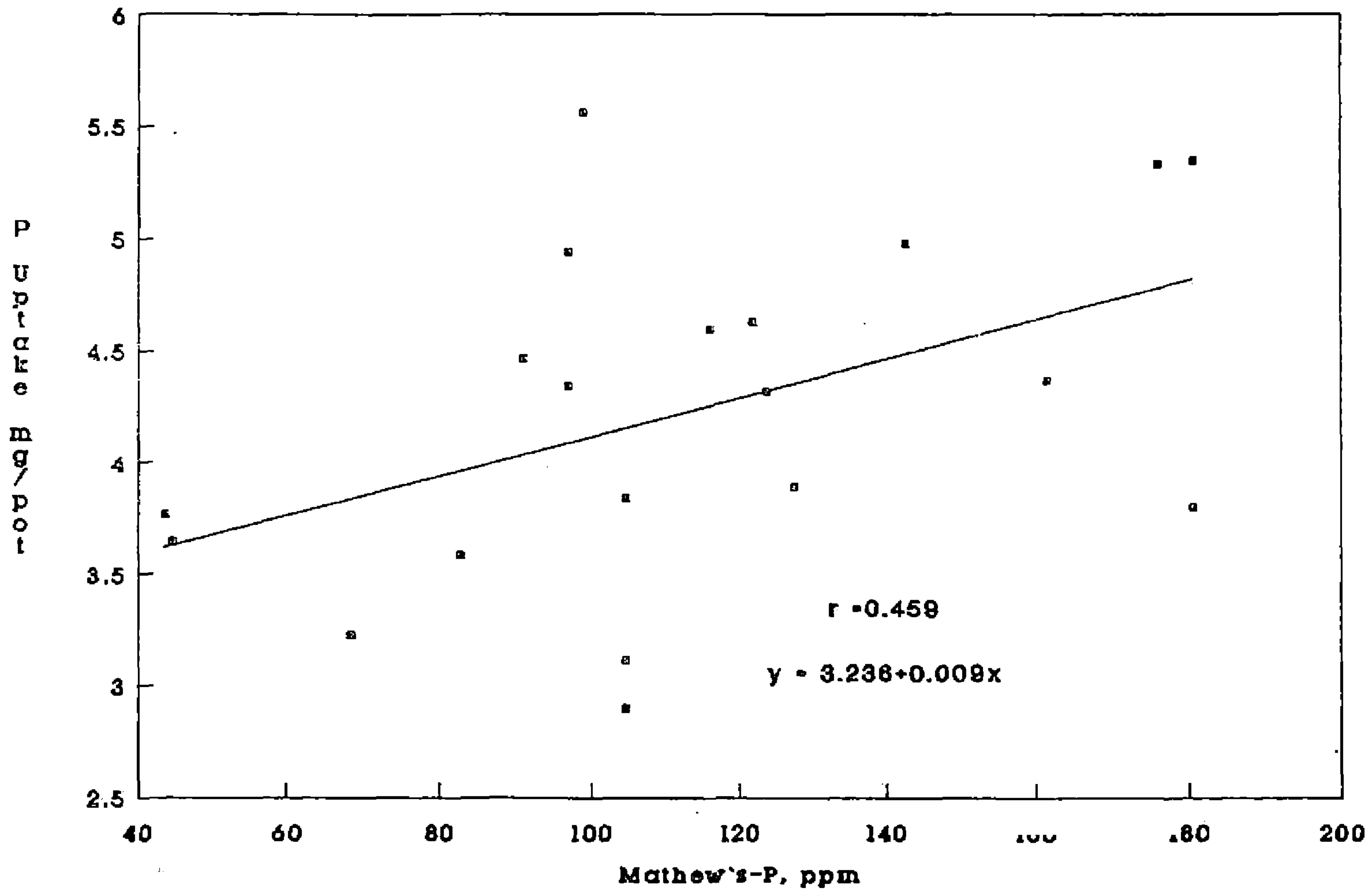

Fig.17. Relationship between Mathew's-P and P uptake in Kuttanad alluvium

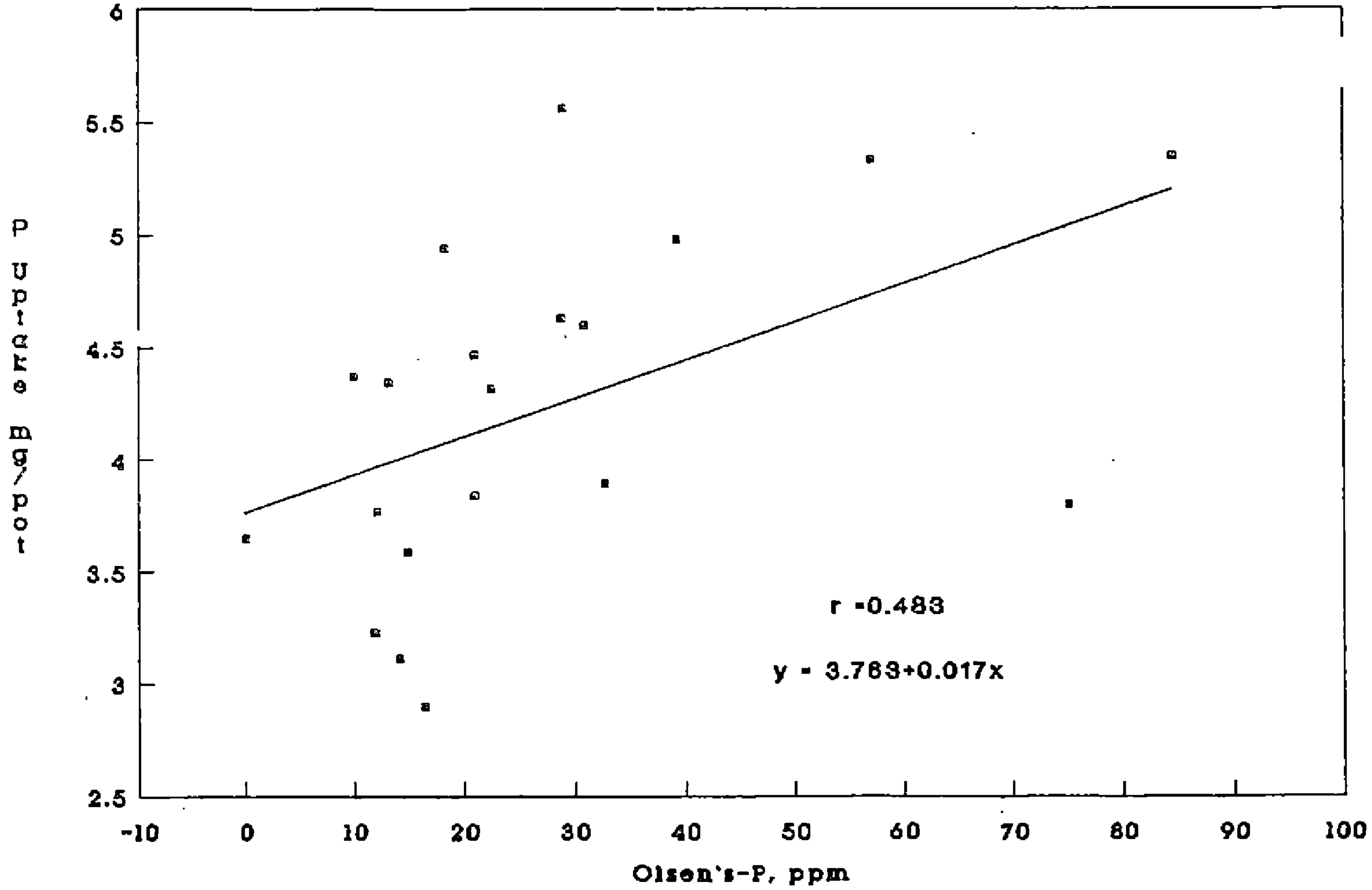

Fig.18. Relationship between Olsen's-P and P uptake in Kuttanad alluvium

14.6. Desorbed-P vs. P uptake

Desorbed P correlated positively and significantly to uptake in laterite soils only ($r = 0.813^{**}$) Fig.23. In all other soil types, viz., coastal alluvium, brown hydromorphic soil, Kuttanad alluvium and black soil, desorbed P failed to correlate significantly with P uptake.

14.7. Adsorption maximum vs. P uptake

From the present study it is found that adsorption maximum cannot be taken as an index of P availability to plants. In these soil types no significant relationship was established between P uptake and adsorption maximum. The case was the same for the constant related to bonding energy 'K'.

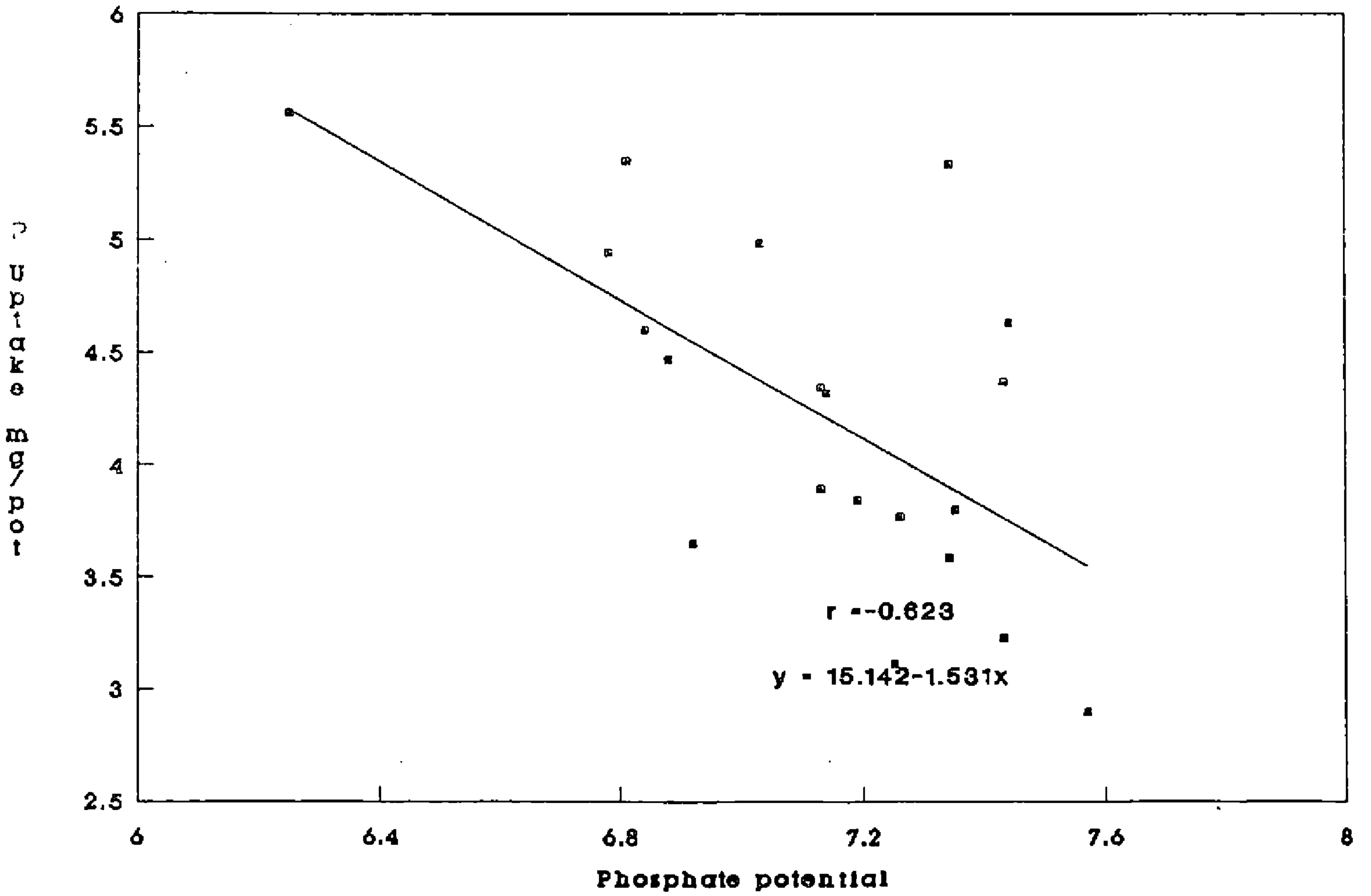

Fig. 19. Relationship between phosphate potential and P uptake in Kuttanad alluvium

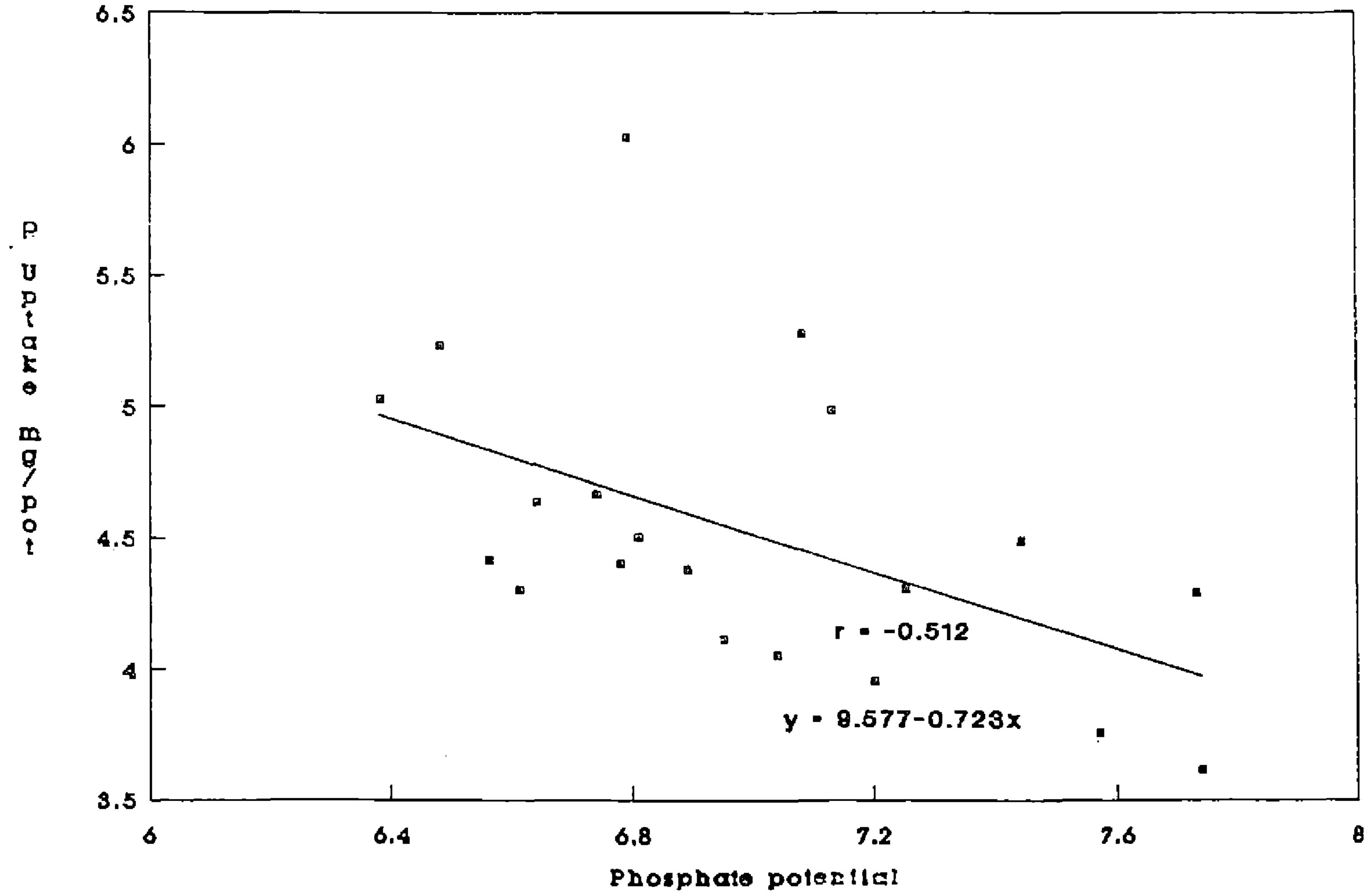

Fig.20. Relationship between Phosphate potential and P uptake in coastal alluvium

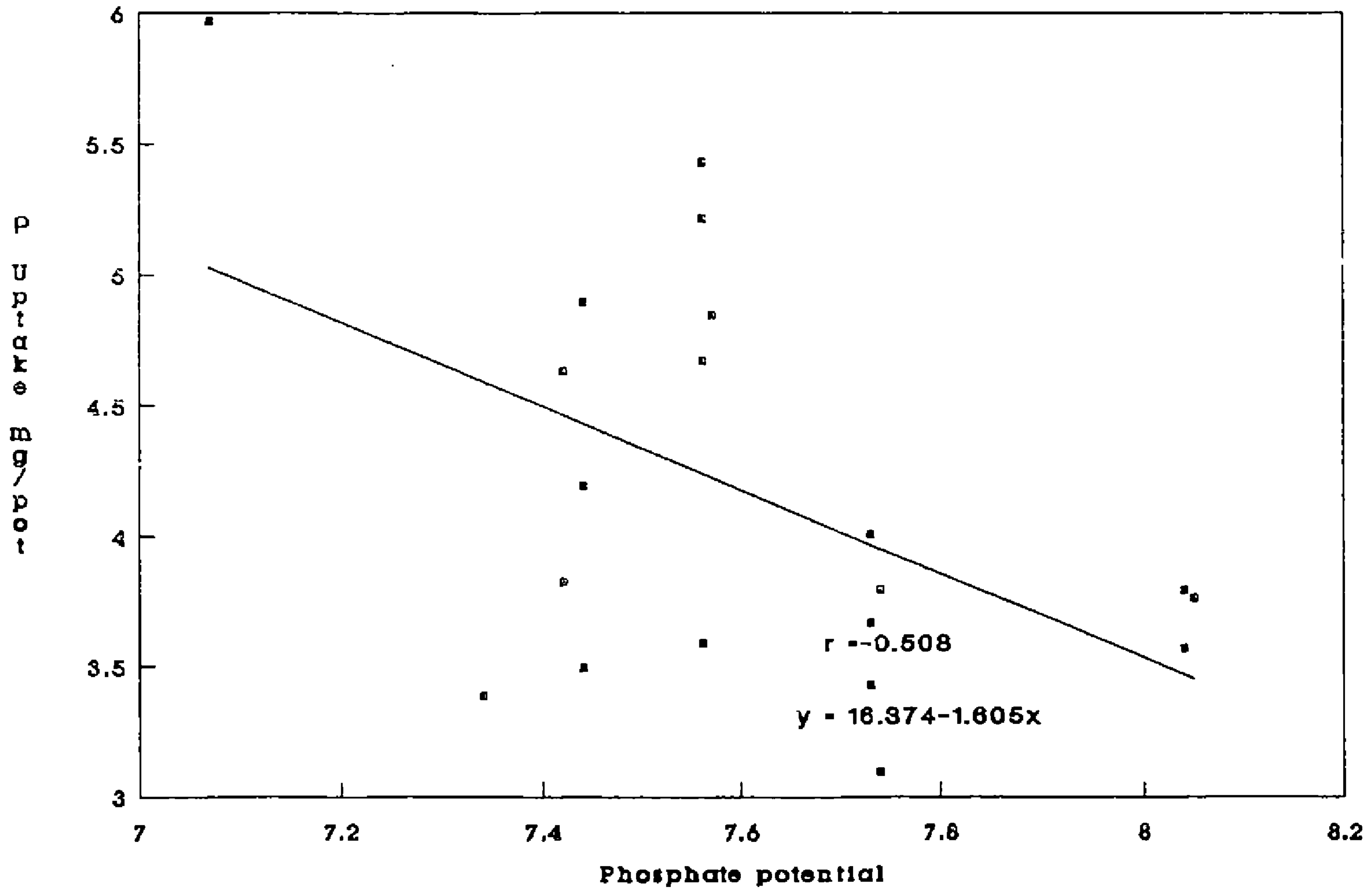

Fig.21. Relationship between phosphate potential and P uptake in brown hydromorphic soil

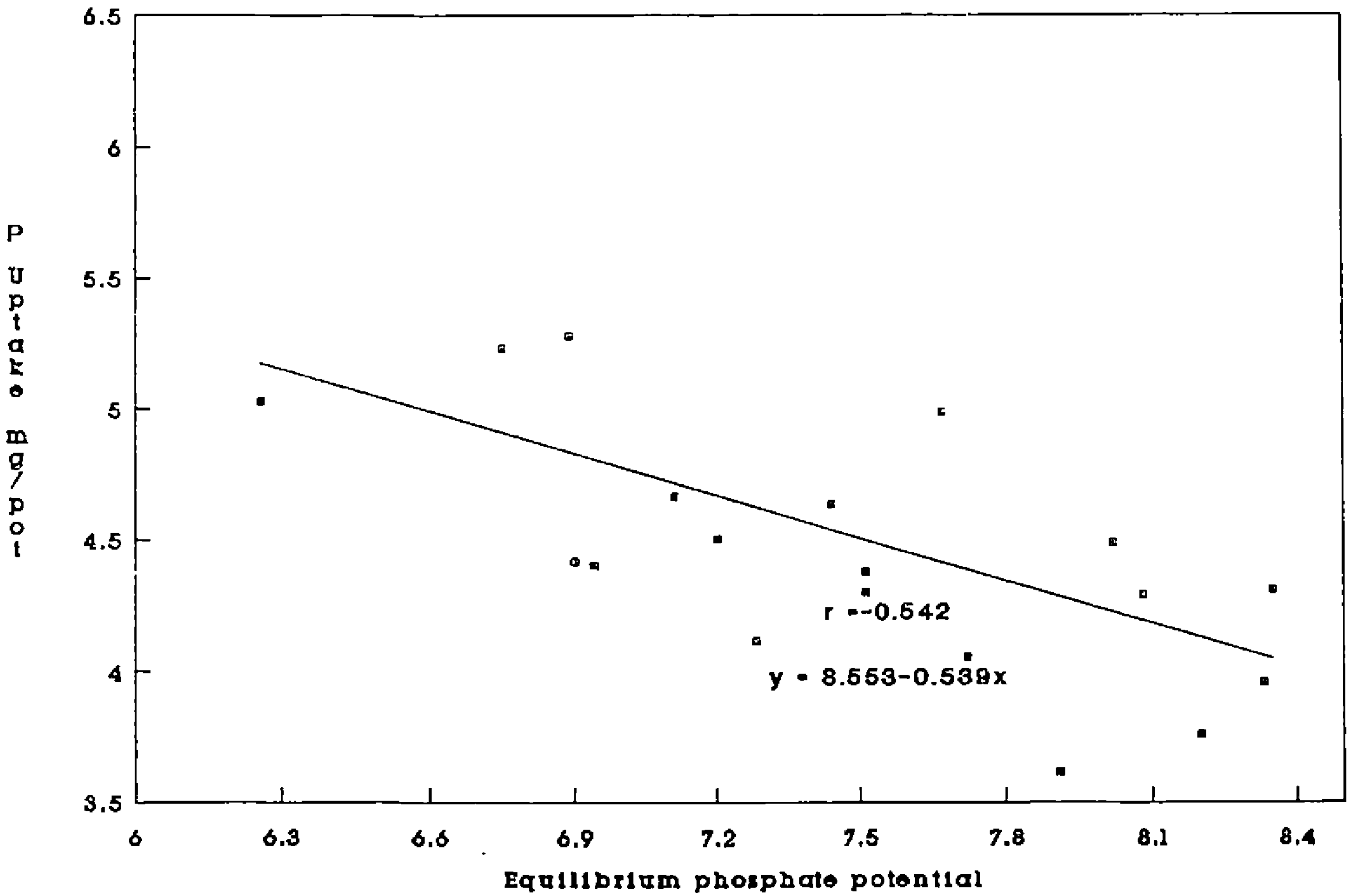

Fig.22. Relationship between equilibrium phosphate potential and P uptake in coastal alluvium

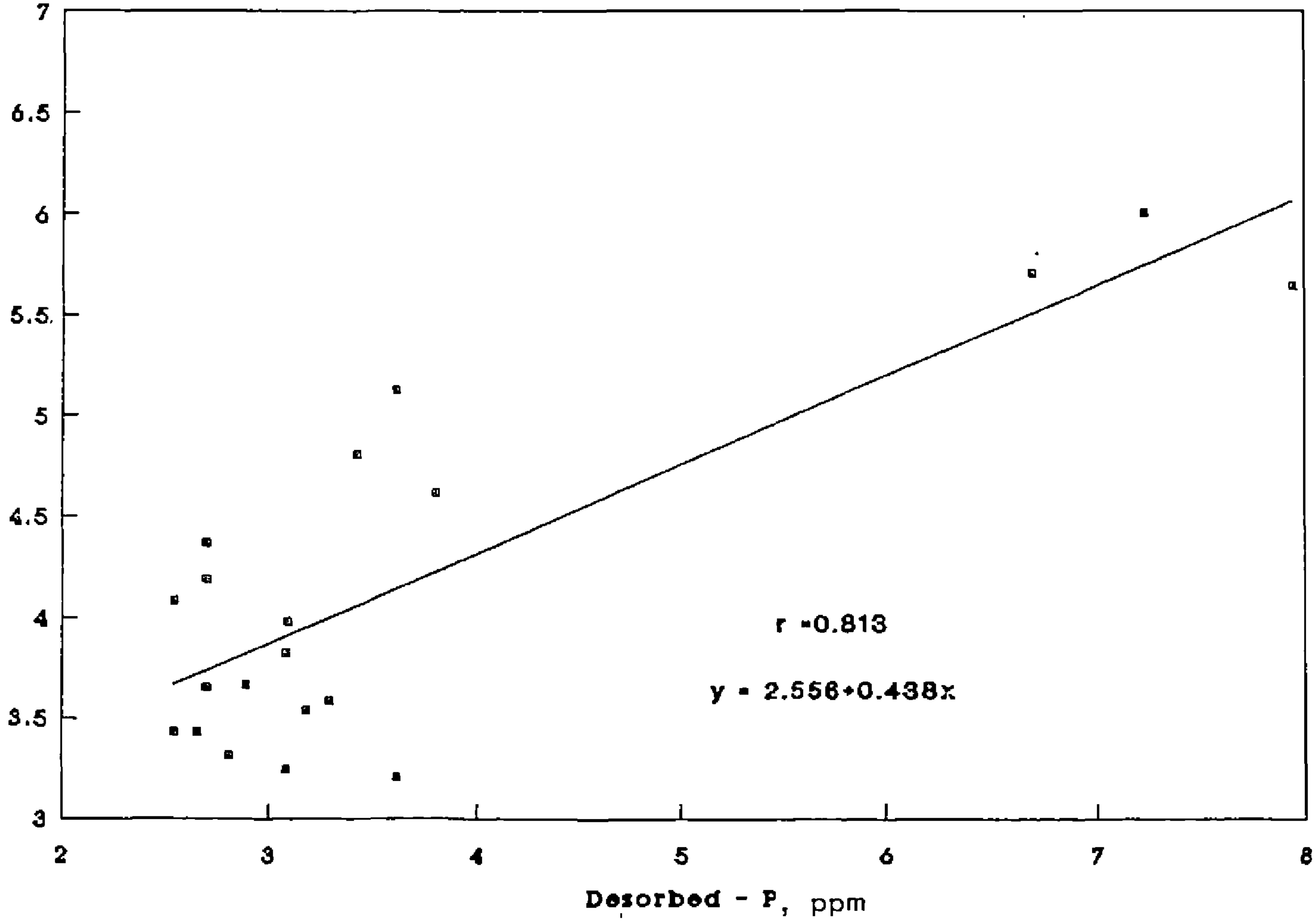

Fig.23. Relationship between desorbed-P and P uptake in laterite soil

Summary

SUMMARY

Surface samples belonging to five soil types viz., laterite, coastal alluvium, brown hydromorphic, Kuttanad alluvium and black soil selected from various places of the state were anslysed. The results of the study are summarised as follows:

1. Major inorganic fraction in coastal alluvium is Fe-P followed by Al-P, Ca-P and saloid-P.

2. In case of brown hydromorphic soil Fe-P is the major fraction followed by Ca-P, Al-P and saloid-P.

3. In Kuttanad soil the content of fractions followed the decending order Fe-P, Al-P, Ca-P and saloid-P. Among the five soil types studied the maximum amount of Al-P(mean 84.80 ppm) was recorded for Kuttanad soils.

4. In the case of black soil the major fraction is Ca-P followed by Al-P, Fe-P and saloid-P.

5. pH influences inorganic P fractions in coastal alluvium and Kuttanad alluvium.

6. Free carbonate showed positive correlation with total P in black soil.

7. Among the three extractants tried Mathew's triacid extracted more P than Bray No.1 and Olsen's P extractant.

8. Among the various soils studied Al-P correlated significantly to Bray No.1 P in Kuttanad soils.

9. Olsen's correlated to Al-P, Ca-P and Fe-P in brown hydromorphic soil, with Al-P in Kuttanad alluvium and with saloid-P in black soil.

10. Mathew's triacid P showed positive correlation with Ca-P and Fe-P in laterite, with Fe-P, Ca-P and Al-P in coastal alluvium, with Fe-P and Al-P in Kuttanad alluvium and with Al-P in black soil.

11. Laterite soil recorded the maximum DPBC values and coastal alluvium the minimum.

12. Desorbed P established positive relationship with saloid-P, Al-P and Ca-P in coastal alluvium and with Al-P and Ca-P in Kuttanad alluvium.

13. The mean adsorption was maximum in brown hydromorphic soil 727.56 µg/g followed by Kuttanad alluvium, laterite, black soil and coastal alluvium.

14. Uptake of phosphorus correlated to saloid-P, Ca-P, Al-P and Fe-P in case of coastal alluvium and with Al-P in Kuttanad alluvium.

16. Mathew's triacid proved as a better extractant for available P in laterite and coastal alluvium. In case of Kuttanad alluvium Bray No.1 is better. Mathew's P correlated significantly to uptake in laterite, coastal alluvium and Kuttanad alluvium. Bray No.1 P significantly correlated to uptake in laterite and Kuttanad alluvium. Olsen's P correlated to uptake in laterite and Kuttanad soils.

17. Phosphate potential negatively correlated to uptake in Kuttanad alluvium, coastal alluvium and brown hydromorphic soil.

18. Equilibrium phosphate potential negatively correlated to uptake in coastal alluvium.

19. Differential phosphate buffering capacity values are not recorded as a suitable method for the estimation of available P.

20. Desorbed P correlated significantly and positively to P uptake in laterite soil alone.

21. Adsorption maximum was not found as a better index of P availability for the soils selected for the study.

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* Orginals not seen

BEHAVIOUR OF PHOSPHORUS IN SELECTED SOIL TYPES OF KERALA

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ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
requirement for the degree

Master of Science in Agriculture

Faculty of Agriculture
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1993

ABSTRACT

In order to study the distribution of inorganic P-fractions finding suitable chemical extractant for phosphorus, to study Q/I relationship as a method of estimating available P and for studying adsorption-desorption characteristics of the soil types of Kerala, 100 surface soil samples were collected. These soil types were selected from different parts of the state belonging to five soil types viz., laterite, coastal alluvium, brown hydromorphic, Kuttanad alluvium and black soil.

It is observed that all the soil types except black soil were acidic, clay content was comparable in case of black soil, Kuttanad alluvium, brown hydromorphic and lateritic but it was very low in coastal alluvium. Maximum content of sesquioxide and total phosphorus recorded in laterite soils and minimum in coastal alluvium.

Dominant inorganic fraction in laterite and black soil was Ca-P while in coastal alluvium, brown hydromorphic, and Kuttanad alluvium dominant fraction was Fe-P. Coastal alluvium recorded maximum content of saloid-P, Al-P and Fe-P content were maximum in Kuttanad alluvium. Maximum content of Ca-P was recorded in black soil. Studies in black soil showed that total P is correlated to free carbonates significantly and positively.

The different extractants studied in different soils showed that extractants should be selected according to soil types. Mathew's triacid proved as a better extractant for available P in laterite and coastal alluvium. In case of Kuttanad alluvium soil Bray No.1 is better. Mathew's P correlated significantly to uptake in laterite, coastal alluvium and Kuttanad alluvium. Olsen's P correlated to uptake in laterite and Kuttanad soils.

Phosphate potential negatively correlated to uptake in Kuttanad alluvium, coastal alluvium and brown hydromorphic soil. Where as equilibrium phosphate potential negatively correlated to uptake in coastal alluvium alone.

DPBC values are not found as a suitable method for the estimation of available P.

The P desorption adsorption studies showed that adsorption studies was not correlated to P uptake, While the desorbed P correlated significantly and positively to P uptake in laterite soil alone.