STUDIES ON
THE FRACTIONATION OF SOIL PHOSPHORUS
AND
THE ADSORPTION AND RETENTION OF AMMONIUM NITROGEN
IN
KERALA SOILS

BY
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CERTIFICATE

This is to certify that the thesis herewith submitted contains the results of bonafide research work carried out by Shri P.K. Narayanan Nambiar under my supervision. No part of the work embodied in this thesis has been submitted earlier for the award of any degree.

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PART I

THE FRACTIONATION OF SOIL PHOSPHORUS

INTRODUCTION

Phosphorus is one of the major nutrient elements essential for plant growth. The concentration of phosphorus in plants is considerably lower than that of nitrogen, potassium and calcium. As a limiting factor, however, phosphorus is more critical than calcium and, probably, second in importance only to nitrogen.

Extensive fertility surveys carried out in Kerala during the past several years have shown that most of our soils are deficient in phosphorus, both total and available. It is well known that phosphorus exists in the soil in various forms, such as, iron and aluminium phosphates, calcium phosphates and organic forms of phosphorus. These various forms differ in their availability to plants, as well as in their stability in the soil. A knowledge of the distribution of soil phosphorus in these different forms is, therefore, extremely important in a study of its availability to crops.

'Available' phosphorus in soils has been determined by various methods. In many of these methods attempts have been made to simulate conditions similar to those existing in the roots or the surfaces between the roots and the soil particles. Thus different chemical extractants of various levels of acidity and other characteristics have been suggested for estimating available phosphorus. These methods have been applied to different soils with different degrees of success, but no universal method applicable to all soils and under all conditions, has so far been evolved. In fact, the conventional methods for available phosphorus extract a portion of all chemical forms of soil phosphorus, and so it has been recognised that a study of the distribution of soil phosphorus in these different forms will give a better insight into the problem of phosphorus availability in soils. This work was, therefore, undertaken with the following objectives:

i. To study the distribution pattern of the various forms of phosphorus in typical Kerala soils, before and after the addition of a phosphatic fertiliser.

ii. To compare the amounts of available phosphorus determined by different methods and to correlate these amounts with the various forms of soil phosphorus.

REVIEW OF LITERATURE

A. Fractionation of soil phosphorus

1. Chemical nature and distribution of phosphorus in soils:

Phosphorus exists in the soil in various forms, both organic and inorganic, which vary widely in the chemical composition and availability to crops. Dyer (1894) was probably the first to effect a fractionation of soil phosphorus by extracting available phosphorus with one percent citric acid. Russel (1932) has indicated that soil phosphorus compounds can be classified into three broad groups as follows:

i. Inorganic phosphorus in neutral and alkaline soils probably a calcium phosphate : hydroxyapatite.
ii. Inorganic phosphorus in acid soils likely to be in combination with iron and aluminium oxides.
iii. Organic phosphorus compounds.

According to Hibbard (1931) the phosphorus forms in alkaline soils consisted of hydroxy- fluor- and chlor- apatites, wavellite and organic compounds. McGeorge and Breazeale (1931) concluded that calcium phosphate existed in calcareous soils mainly in the carbonato apatite form. In a fractionation study of 34 different soils Dean (1937) found that in acid soils phosphorus existed mostly in the alkali soluble forms whereas in alkali soils the acid soluble form predominated.

Ghani and Aleem (1943) studied the different fractions of soil phosphorus in some Indian soils and found that the acetic acid soluble fraction was considerably low in acid soils over a pH range of 4.2 to 5.8. This fraction occurred in the highest proportion in the neutral and alkaline soils. Iron and aluminium phosphates were high in acid soils and tended to decrease with increase in pH. Acid soils contained the largest proportion of organic phosphorus which decreased with increasing pH and reached a minimum value at neutrality and again tended to increase as the pH shifted to the alkaline side. The insoluble form which was not correlated with either the pH or the sesquioxide content was found to constitute about 25 percent of the total phosphorus.

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

Chai Moo Cho and Cladwell (1959) observed that the iron and aluminium phosphate predominated in acid soils while calcium phosphates dominated the calcareous soils. In their study of the phosphorus forms in Punjab soils Kanwar and Grewal (1959) noticed that in soils of high pH the EDTA-borate buffer soluble phosphate was about twice as much as that in soils of low pH. About three fourth of the total phosphorus content of the Punjab soils was in the apatite or other resistant forms and this fraction tended to increase with increase in alkalinity. Goel and Agarwal (1959) found that the surface soils of Kanpur contained more of iron and aluminium phosphate than calcium phosphate. Patel and Mehta (1961) fractionated soil phosphorus in 25 soils into the following components:

- (a) calcium phosphate,
- (b) absorbed phosphate,
- (c) phosphates of iron and aluminium,
- (d) organic phosphorus, and
- (e) phosphorus insoluble in reagests dissolving a,b,c.

They found that none of these fractions formed a fixed proportion of the total.

2. <u>The different forms of soil phosphorus in relation to soil genesis</u>:

Fractionation studies of soil phosphorus have proved helpful in obtaining valuable information regarding the process of soil formation. Chang and Jackson (1959) were able to establish a relationship between the various forms of soil phosphorus and the degree of chemical weathering undergone by the soil. Their studies revealed that in the initial stages of weathering calcium and aluminium ions being relatively more active, the phosphates of these metals were more likely to be formed as compared to the phosphate of iron. In course of time calcium and aluminium phosphates gradually changed into the less soluble iron phosphate. The activity of ferric irons in soils increased with decrease in pH and increase in the amount of ironoxide. In latosols the iron phosphate and part of the aluminium phosphate were occluded by an iron oxide coating which was formed in the course of chemical weathering. The formation of occluded phosphate required considerably long periods and as time advanced this resistant form of phosphorus tended to accumulate in soils.

Goel and Agarwal (1959) fractionated the phosphorus in genetically related soils of the gangetic alluviam representing different stages of maturity and found that the total phosphorus and the organic phosphorus fraction decreased with soil maturity. In the more mature soils the concentration of phosphorus decreased with depth, while in the younger soils it tended to increase with depth. The inorganic phosphorus fraction amounting to 80-90 percent of the total was generally present in combination with iron and aluminium in the mature soils and in the form of calcium phosphate in the less mature soils.

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

3. Soil phosphorus fractions in relation to fertility

Ghani and Aleem (1943) fractionated soil phosphorus and estimated its availability in a large number of Indian soils. Their study revealed that phosphorus availability was mainly a function of the soil reaction. In acid soils phosphorus became unavailable due to the formation of iron and aluminium phosphates and the accumulation of organic compounds. The unavailability of phosphorus in alkali soils could be attributed to the formation of insoluble apatite forms and the low rate of organic matter decomposition. Under neutral conditions the availability of phosphorus was high due to the rapid mineralisation of organic phosphorus and the absence of fixation as compounds of iron, aluminium or calcium.

Williams (1950) fractionated soil phosphorus before and after the growth of plants and observed that crops utilised phosphorus mainly in the acetic acid soluble form even though the soil contained large quantities of the alkali soluble fraction. Significant correlations were obtained between the phosphorus content of plants and the alkali soluble and the acetic acid soluble inorganic phosphorus fractions of soils. There was very little relationship between the total or organic phosphorus content and the phosphorus absorbed by plants. He concluded that in the case of neutral to slightly acid soils either the acetic acid, or alkali soluble fraction or the sum total of these two forms could be used as an index of phosphorus fertility. For alkaline soils, however, the alkali soluble inorganic fraction might constitute the most suitable index.

Chang and Jackson (1958) investigated the occurrence of the various forms of soil phosphorus in relation to fertilizer practices and showed that the phosphorus added to the soil was converted into calcium, aluminium and iron phosphates. This transformation was observed in acid as well as in neutral soils. As calcium phosphate was more soluble than the other forms of phosphate it was more readily absorbed by crops or rapidly converted into less soluble forms. Raising the pH of the soil by the application of lime would help to increase the calcium activity and induce the formation of calcium phosphate and the consequent release of phosphorus in an available form.

According to Kanwar and Grewal (1959) the low content of phosphorus soluble in EDTA-borate buffer solution would account for the ready response of crops to phosphatic fertilizers in the acid soils of the Punjab. Goel and Agarwal (1959) found that the mature soils which contained more of iron and aluminium phosphates responded to phosphatic fertilization whereas the less mature soils which were rich in calcium phosphate did not respond to applications of phosphate. Using labelled monobasic potassium phosphate and adopting the fractionation procedure followed by Chang and Jackson (1957), Yuvan et al (1960) traced the changes undergone by soluble phosphates applied to soils. More than 80 percent of the added phosphorus was retained by the soil as aluminium and iron phosphates and only less than 10 percent remained in the water soluble form. It was further noticed that the ratio of aluminium phosphate to iron phosphate increased with the rate of phosphorus applied.

The fractionation of soil inorganic phosphorus carried out by Wright and Peech (1960) revealed that the native phosphorus in the soils investigated was present chiefly in the form of iron phosphate. In the soils collected from long time fertilizer experiments it was observed that phosphate fertilization had resulted primarily in an increase in the iron phosphate fraction, except in two soils, in which the applied phosphorus was converted almost entirely into the phosphate of aluminium.

4. Methods of fractionation of soil phosphorus

Numerous methods have been followed by different workers for the fractionation of soil phosphorus. McGeorge (1932) and Holman (1936) investigated the chemical nature of soil phosphorus qualitatively by studying the solubility curves at different pH values. Gardner and Kelly (1940) determined the phosphorus content of soils soluble in solutions adjusted to varying pH values with sulphuric acid or potassium carbonate solution. In a study of 13 Colarado soils they found that the solubility of soil phosphorus was a minimum near the neutral point and that the solubility in the pH range corresponding to that of the soil was closely related to the available phosphorus content. Stelly and Pierre (1943) compared the phosphate solubility of some Iowa soils at various pH values ranging from 2 to 10 with that of apatite and other known minerals. The solubility curves for alkaline soils were similar to that of apatite whereas the curves for acid soils resembled those of iron and aluminium phosphates. Thus, they found that the pH-phosphate solubility curves could be used for identifying the different forms of inorganic phosphorus in the soil.

Fisher and Thomas (1935) used acetic acid buffered to pH 5 with sodium acetate and dilute sulphuric acid adjusted to pH 3 for extracting soil phosphorus. On the basis of the pH and the period of extraction they classified soil phosphorus into three groups. With acetic acid buffered to pH 5 and by shaking for 45 minutes phosphates of calcium, magnesium, manganese and about one eleventh of the phosphates of iron and aluminium were dissolved. Using the same reagent for a period of 135 minutes about six elevenths of the iron and aluminium phosphates together with the calcium, magnesium and manganese phosphates could be extracted. Dilute sulphuric acid at pH 3 dissolved the phosphates of calcium, magnesium, manganese and iron and aluminium together with apatites when shaken for a period of three hours.

Williams (1937) separated soil phosphorus into alkali soluble and alkali insoluble fractions using sodium hydroxide as the extractant. The alkali soluble fraction consisted of the organic and exchangeable phosphorus together with the more soluble of the inorganic forms such as the dicalcium and sesquioxide phosphates. Apatites, titanium phosphate and crystal lattice phosphorus constituted the alkali insoluble forms.

Dean (1938) suggested a procedure for separating soil phosphorus into alkali soluble and acid soluble fractions. The soil was first treated with sodium acetate to remove exchangeable calcium and then digested overnight with sodium hydroxide solution at 90°C. The solution was filtered and a portion of the filtrate evaporated to dryness, ignited, extracted with sulphuric acid and the phosphorus estimated. The remaining portion of the filtrate was neutralised, filtered and the phosphorus determined in the clear solution. The former fraction included organic, iron and aluminium phosphates while the latter contained iron and aluminium phosphates only. The soil after extraction with sodium hydroxide was neutralised, washed with sodium chloride and treated with 0.5 N sulphuric acid and shaken for one hour. The phosphorus estimated in the extract was shown as calcium phosphate. Ghani (1942) examined Dean's method and suggested the use of 0.5 N acetic acid in place of sodium acetate. Acetic acid extraction helped to remove the exchangeable cations as well as to separate the readily available forms of mono- di- and tri- calcium phosphates. Subsequent extraction of the soil with 0.25 N sodium hydroxide solution gave organic, iron and aluminium phosphates while 2 N sulphuric acid extracted the apatite forms. The fraction which was not dissolved by any of these reagents was designated as insoluble phosphorus. One disadvantage in this method was that a part of the phosphorus brought into the solution by acetic acid was readsorbed by the soil and was included in the sodium hydroxide extract. In a later work the same author (1942) has, therefore, suggested the use of 8-hydroxy quinoline as a blockade against the readsorption of phosphorus by iron and aluminium. Koshi (1952) studied the distribution of various fractions of soil phosphorus in typical profiles of Travancore State adopting Ghani's (1942) method.

According to Dean (1937) the phosphorus fraction extracted by sodium hydroxide included the adsorbed form as well as the phosphates of iron and aluminium. Dickman and Bray (1941) observed that the fluoride ion could be used satisfactorily to replace adsorbed phosphorus. Bray and Dickman (1941) fractionated soil inorganic phosphorus into five forms using ammonium chloride, ammonium fluoride and sulphuric acid. Replaceable phosphorus was obtained in the first fraction by extraction with ammonium chloride. Adsorbed phosphorus was obtained in the next two fractions by extracting with neutral ammonium fluoride. The fourth fraction obtained by using acid ammonium fluoride represented acid soluble fractions such as calcium, magnesium, iron and aluminium phosphates. Sodium hydroxide was used for the final extraction. The authors classified the 1st, 2nd and 3rd fractions together as adsorbed phosphate and treated it as the readily available form. Later Bray and Kurtz (1945) utilised ammonium fluoride of varying strengths for the extraction of available, total and organic phosphorus in soils.

The investigations of Turner and Rice (1952) have clearly shown that neutral ammonium fluoride reacts with aluminium hydroxide to form $(NH_4)3\ AlF_6$ thereby releasing the phosphate adsorbed by the aluminium gel. No such reaction was found to take place with ferric hydroxide gel and, therefore, the extraction with ammonium fluoride as suggested by Bray and Kurtz (1945) would help to dissolve mainly the aluminium phosphate.

✓ Kanwar and Grewal (1959) used EDTA-borate buffer solution at pH 8.5 and decinormal sodium hydroxide as the extractant for fractionating soil phosphorus. The phosphate extracted with EDTA-borate buffer contained mono- and di- calcium phosphate, magnesium phosphate and small amounts of tricalcium, iron and aluminium phosphates. The alkaline extract contained mostly the organic and in a part inorganic phosphorus. The phosphate not dissolved by either of these reagents but extracted by constant boiling hydrochloric acid was considered as the apatite, lattice bound and other resistant forms.

In their study of Kanpur soils Goel and Agarwal (1959) determined organic phosphorus by estimating the total phosphorus in acid extracts before and after ignition of the soil and noting the difference. Calcium phosphate was determined by extraction with 0.2 N sulphuric acid. Total inorganic phosphorus was found out as the difference between total and organic phosphorus. The difference between total inorganic and calcium phosphates gave iron and aluminium phosphate.

A more satisfactory method of fractionation of soil inorganic phosphorus into phosphates of iron, aluminium and calcium and occluded forms of iron and aluminium phosphates has been developed by Chang and Jackson (1957) based on the selective solubility of phosphorus in various extractants. Their method consisted in pretreating the soil with normal ammonium chloride solution followed by extraction with neutral ammonium fluoride. This treatment dissolved all the aluminium phosphate and negligible quantities of apatite and iron phosphates. Subsequent extraction with alkali removed the iron phosphate completely and extraction with dilute sulphuric acid dissolved the apatite form. Chelation treatment with sodium citrate and sodium dithionite extracted the occluded iron phosphate and the final treatment with ammonium fluoride removed the occluded aluminium phosphate. This method of fractionation was followed by Chai Moo Cho and Caldwell (1959) with satisfactory results.

Fife (1959) reported that in the extraction of aluminium phosphate with ammonium fluoride in Chang and Jackson's method there was a possibility of the extracted phosphate being readsorbed by iron.

He, therefore, suggested the use of alkaline ammonium fluoride in place of neutral ammonium fluoride for soils of pH less than 8.5.

Yuvan <u>et al</u> (1960) adopted the procedure of Chang and Jackson to trace the path of applied phosphorus tagged with P^{32}.

Janardhanan Nair (1961) fractionated the inorganic phosphorus of 4 south Indian soils using the procedure adopted by Chang and Jackson.

5. Available phosphorus in relation to other soil phosphorus fractions.

Chai Moo Cho and Caldwell (1959) studied the distribution of inorganic and available phosphorus in several soils and worked out the correlation between these different forms with a view to determining the actual form of phosphorus measured by the various extractants used in quick soil tests. Their findings could be summarised as follows:

a) The major portion of the available phosphorus was released from the inorganic forms present in the soil,

b) There was a high degree of correlation between available phosphorus and the inorganic phosphorus content,

c) A high correlation existed between the aluminium phosphate fraction and the phosphorus extracted by Bray's reagents,

d) Sodium bicarbonate extractable phosphorus was highly correlated to the content of iron and aluminium phosphates. This fraction was not, however, negatively correlated with the calcium phosphate content,

e) Available phosphorus determined by Morgan's method was well correlated with the calcium phosphate fraction,

f) Water-soluble phosphate was similar to the phosphorus extracted by Morgan's reagent but had a lower correlation value. This suggested that water soluble phosphate did not consist entirely of calcium phosphate although this constituted the major fraction dissolved by water.

Patel and Mehta (1961) fractionated the phosphorus in 21 soil samples and found that none of the fractions determined, viz., calcium phosphate, adsorbed phosphate, iron and aluminium phosphate, organic phosphorus and the insoluble phosphorus, formed a constant proportion of the total. The amount of adsorbed phosphorus gave the highest correlation with phosphorus uptake by sorghum and it was also highly correlated with available phosphate determined using 0.5 M sodium bicarbonate. The amount of phosphorus absorbed by plants was correlated to the calcium phosphate to a lesser degree but there was no correlation what-so-ever between phosphorus uptake by plants and the other forms of soil phosphorus.

Laverty and McLean (1961) applied Chang and Jackson's fractionation procedure to soils fixing 28-72 percent of applied soluble phosphorus and found that soils of low fixing capacities tied up 2½ times as much phosphorus in the aluminium phosphate fraction as in the iron phosphate fraction. The reverse was found to be true of soils with high fixing capacities. This suggested that aluminium phosphate was considerably more available to plants than iron phosphate. In soils treated with different forms of phosphatic fertilizers phosphorus availability to oats was highly correlated to the iron and aluminium phosphate contents as well as the ammonium chloride extractable fraction.

B. 'Available' soil phosphorus.

Liebig in 1840 and Way in 1850 demonstrated that phosphorus might be retained in the soil in an unavailable form. Since then and even earlier soil chemists have attempted to estimate the amount of available phosphorus in soils by various methods. These methods include the use of different chemical reagents for extracting the soluble phosphorus as well as studying the growth of plants and micro organisms in the soil. As chemical methods are practically more convenient most of the procedures for determining available phosphorus involves the use of chemical extractants. Such reagents have been developed on the basis of different concepts regarding the absorption of phosphorus by plants. No single procedure so far suggested has been approved as a suitable method for determining available phosphorus in soils. The literature bearing on this subject is rather voluminous and so only such works as are pertinent to the present study will be reviewed here.

1. Use of dilute acids as extractants:

Various organic acids have been used by different workers as extracting reagents for available phosphorus. One of the earliest methods which is still in use is that of Dyer (1894) who used one percent citric acid for this purpose. Egner (1941) and Riehm (1942) suggested the use of active lactate buffer while Hibbard (1931) employed acetic acid and Brown (1940) used acetate buffer as extractants for determining phosphate availability. Dilute mineral acids have been used by several workers for the extraction of available soil phosphorus. Vonsigmond (1929) used 0.1 N nitric acid whereas 0.2 N nitric acid was used earlier by Fraps (1909). Baver and Burner (1939) and Olsen (1946) extracted available phosphorus with 0.3 N hydrochloric acid and 0.7 N hydrochloric acid mixed with ammonium molybdate respectively. Truog (1930) used 0.002 N sulphuric acid buffered at pH 3 with ammonium sulphate in a soil solvent ratio of 1:200 whereas the same reagent in the ratio of 1:100 was used for extracting available phosphorus by Peech _et al_ (1947). Morgan (1935) used acetic acid buffered to pH 4.8 with sodium acetate for estimation of available phosphorus. Beater (1949) used N/21 sulphuric acid buffered with sodium borate at pH 1.5 for this purpose. Ghani (1943) employed 8-hydroxay quinoline in the acetic acid as an extractant and recommended its use for acid soils containing higher proportions of active sesquioxides.

2. _Use of alkalies as extractants._

Darks and Sheffer (1928) used calcium bicarbonate and Das (1930) used 1 percent potassium carbonate for dissolving available soil phosphorus. Lasstsch (1941) employed potassium bicarbonate solution with advantage to replace exchangeable phosphorus. Olsen (1954) proposed the use of 0.5 N sodium bicarbonate adjusted to pH 8.5 as an extractant for both calcareous and noncalcareous soils. Jones (1949) recommended 0.5 N sodium hydroxide solution for tropical soils while Williams (1950) suggested 0.1 N sodium hydroxide for both acid and alkaline soils. Rubins (1953) found extraction with 0.5 N sodium hydroxide suitable for determining available phosphorus in acid soils. Saunders (1956) developed a method using hot 0.1 N sodium hydroxide and obtained satisfactory results for different types of tropical soils.

3. Use of ammonium fluoride as extractant.

Bray and Kurtz (1945) have developed a method for the extraction of available phosphorus using dilute acid solutions of ammonium fluoride. The two reagents recommended by these workers are 0.03 N ammonium fluoride in 0.025 N hydrochloric acid and 0.03 N ammonium fluoride in 0.1 N hydrochloric acid. The weaker reagent extracts only the adsorbed fraction while the stronger solution also dissolves a part of the acid soluble phosphorus.

4. Comparison between the different methods used for extracting available phosphorus.

In calcareous soils Das (1926) found that extraction with potassium carbonate yielded more satisfactory results for available phosphate than extraction with dilute acids. Hocken Smith (1933) compared different soil testing methods in calcareous soils and found that the phosphorus extracted with potassium carbonate was highly correlated to crop yields. A number of soil testing methods were compared on a group of soils neutral to acid in reaction by Anderson and Noble (1937) and they found that the amounts of phosphates extracted by acids were generally better correlated to crop yields. Basu et al (1942) made a study of the different methods for estimating available phosphorus in relation to the different soil types belonging to the black cotton soil group and found that the limits of response differed considerably. Mukerjee (1941) compared Truog's method with the citric and acetic acid methods in noncalcareous red soils and obtained fair correlation between them. Frap and Fudge (1945) studied the phosphorus availability of 34 soils and several phosphatic minerals using 0.2 N nitric acid, 0.75 N hydrochloric acid, 0.002 N sulphuric acid, and 0.5 N acetic acid and observed that none of them gave a quantitative measure of the amount of phosphorus available to plants.

Rubins and Dean (1946) compared several methods for determining available phosphorus and found that the amount of phosphorus extracted by acetic acid, Truog's and Morgan's reagents and by the lactate method were all correlated to one another. Among the several methods suggested for determining available phosphorus Raychaudhuri _et al_ (1954) obtained the highest correlation between phosphorus extracted from Bihar soils by Truog's reagent and the yield of paddy. The next highest correlation for these soils was obtained with Bray's reagent. Caronell and Valencia (1957) in a comparative study of the different methods for available phosphorus showed that Truog's method was the best suited for soils with a pH range of 5.7 - 7.2. Datta and Kamath (1959) compared nine different methods and evaluated them using percentage yield response and "A" values. They found that the performance of the sodium bicarbonate method was the best and the most satisfactory as in almost all cases highly significant correlations were obtained. Tseng and Wang (1959) compared a number of methods on paddy soils and found that Olsen's reagent extracted very little available phosphorus. They observed that more phosphorus was extracted from most soils by Bray's method than by Truog's procedure.

Bray's method yielded reproduceable results only when the temperature and shaking time were strictly controlled. Bouyer (1959) compared different methods for the determination of available phosphorus. He obtained high correlation between the amounts of available phosphoric acid determined by the methods proposed by Bray and Kurtz (1945) Olsen (1954) and Saunder (1956) and the total phosphoric acd content. The lowest value for available phosphoric acid was obtained by Olsen's method while Saunder's reagent extracted nearly half of the total phosphoric acid. Miller (1960) found that extraction with sulphuric acid - ammonium fluoride reagent (both 0.03 N) gave the most satisfactory values for available phosphorus as determined by crop response though in many instances there was very little difference in the amounts determined by various other methods. He also observed that soil type determined to a large extent the correlation between yield and phosphorus extracted by the different methods. There was considerable difference in the amounts of super phosphate to be applied to different soils in order to maintain identical levels of available phosphorus.

Swaminathan (1960) compared the amounts of phosphorus extracted from 14 potato soils by nine rapid chemical test methods and found that the reagents suggested by Truog, Spurway and Bray as well as 2.5 N acetic acid and 1% citric acid had similar relative capacities for extracting available phosphorus. Though the phosphorus index obtained from each test was positively, but not significantly, correlated with the average percentage yield values in each case, Olsen's method (extraction with M/2 sodium bicarbonate) gave the maximum degree of correlation with crop response in these soils. Sokolov, Koritskaya and Mallina (1961) in a comparative study found that 0.002 N H_2SO_4 (Truog's agent) and 0.5 N acetic acid (Chirikov's reagent) gave similar values for soluble phosphorus. Kirsanov's method (extraction with 0.2 N hydrochloric acid) gave somewhat higher values than Chirikov's and Truog's methods but much smaller values than Egner Richm's method (extraction with calcium lactate).

MATERIALS AND METHODS

Eight typical soil samples representing the major soil groups of Kerala were used in this study. These soils were sampled at plough layer depth, air-dried and screened through a 2-mm. sieve. The general characteristics of the soils are given in table I.

TABLE I

GENERAL CHARACTERISTICS OF SOILS

Sl. No.	Locality	Soil Group	Texture
1.	Keerikkadu (Alleppey)	Coastal sand	Sandy loam
2.	Vellayani (Trivandrum)	Red	Clay
3.	Vellayani (Trivandrum)	Laterite	Sandy clay
4.	Valparai (Kottayam)	Forest	Sandy clay loam
5.	Chengannur (Alleppey)	Alluvial	Sandy clay loam
6.	Pilicode (Cannanore)	Laterite	Sandy clay loam
7.	Nileshwar II (Cannanore)	Red	Sandy loam
8.	Nileshwar III (Cannanore)	Coastal sand	Sand

The study consisted of the following three parts:

i. An investigation of the chemical and mechanical composition of the soils with a view to finding out any correlation between the soil properties and the various phosphorus fractions.

ii. Fractionation of soil phosphorus before and after treatment with a phosphatic fertilizer so as to study the distribution pattern of the various phosphorus forms, and further, to find out to which fraction the added phosphorus is ultimately reverted.

iii. A comparison of the different methods commonly followed for the determination of 'available' phosphorus with respect to these soils.

A. Chemical and Mechanical composition of soils.

Standard analytical procedures were followed for determining the chemical and mechanical composition of the soils. The methods adopted are briefly indicated below:

1. Chemical analysis.

(a) Moisture: 5 g. of the soil was dried in an electric oven at 100-105°C for 8 hours and the loss in weight was expressed as percent of the oven dry weight of the soil.

(b) Loss on ignition: 20 g. of the soil sample was ignited under a rose-head flame at 700°C for 8 hours to get constant weight and the loss on ignition was calculated as percent of the soil on moisture free basis.

(c) Acid insolubles: 20 g. of the air dry soil was placed in a 500 ml. flask and treated with 200 ml. of constant boiling hydrochloric acid and digested on a sand bath for 2-3 hours. The extract was filtered into a 500 ml. volumetric flask and the volume made up.

The residue was washed free of chloride with distilled water, dried in an air oven and ignited until constant weight was obtained. This was calculated as percent of the soil on moisture free basis and reported as acid insolubles.

(d) Acid soluble silica: The acid soluble fraction obtained in the above determination was evaporated to dryness on a water bath and the residue moistened with concentrated nitric acid and again brought to dryness. The process was repeated 3 to 4 times till the dried residue showed a granulated appearence. The residue was then digested with dilute hydrochloric acid on a water bath, filtered, and washed with boiling water until free from chloride. The filtrate collected constituted the hydrochloric acid extract which was used for the subsequent estimations. The residue which represented the acid soluble silica was dried, ignited to get constant weight and reported as percent of the soil on moisture free basis.

(d) Total sesquioxides: The sesquioxides were precipitated as the hydroxides in an aliquot of the hydrochloric acid extract by the addition of ammonium hydroxide. The precipitate was filtered, ignited to constant weight and reported as percent of the moisture free weight of the soil.

(f) Iron: An aliquot of the hydrochloric acid extract was evaporated to dryness, taken up with dilute sulphuric acid, and the iron reduced to the ferrous state by nascent hydrogen. It was then estimated by titration with standard potassium permanganate.

(g) Calcium: Calcium was precipitated in the filtrate obtained after the separation of the sesquioxides as calcium oxalate and estimated volumetrically by titration against standard potassium permanganate.

(h) Magnesium: Magnesium was precipitated in the filtrate from calcium separation as magnesium ammonium phosphate, filtered, washed free of chloride, dried, ignited and weighed as magnesium pyrophosphate.

(i) Phosphoric acid: Phosphorus was precipitated in a suitable aliquot of the hydrochloric acid extract as ammonium phosphomolybdate in nitric acid medium. The precipitate was filtered, washed free of acid and dissolved in a known excess of standard alkali and the excess determined by titration with standard acid. From the volume of alkali consumed the P_2O_5 content was calculated.

(j) Potassium: Potassium was precipitated as potassium sodium cobaltinitrite in glacial acetic acid medium. The precipitate was filtered through asbestos in a gooch crucible and oxidised in an excess of standard potassium permanganate. The permanganate consumed was determined volumetrically and hence the percentage of potassium in the soil was calculated.

(k) Nitrogen: Nitrogen was estimated by the Kjeldahl method using sulphuric-salycilic acid mixture.

(l) Organic carbon: The wet digestion method of Walkley and Black was followed for the estimation of organic carbon. 0.5 - 1.0 g. of the soil was digested with a known volume of normal potassium dichromate and sulphuric acid making use of the heat of dilution of sulphuric acid. The excess chromic acid was determined by titration with standard ferrous sulphate solution using diphenylamine as internal indicator. From the volume of potassium dichromate consumed the organic carbon was estimated.

(m) pH: The pH was determined in a 1:2.5 soil-water suspension using a Photovoltmeter (Model 115).

(n) Cation exchange capacity: 10 g. of the soil was leached with neutral ammonium acetate solution to displace the cations. The adsorbed ammonium was determined by steam distillation with magnesium oxide and absorption in excess of standard acid followed by titration with standard alkali. The number of milliequivalents of ammonium ions adsorbed per 100 g. of the soil gave its cation exchange capacity.

2. Mechanical analysis.

The mechanical composition of the soils was determined by the International Pipette method after oxidation of the organic matter with hydrogenperoxide.

B. Fractionation of soil phosphorus

The method suggested by Chang and Jackson (1957) was followed for the separation of the inorganic soil phosphorus into the following five fractions:

i. Aluminium phosphate - extracted with 0.5 N neutral ammonium fluoride.
ii. Iron phosphate - extracted with 0.1 N sodium hydroxide.
iii. Calcium phosphate - extracted with 0.5 N sulphuric acid.
iv. Occluded iron phosphate - dissolved by dithionate-citrate extraction.
v. Occluded aluminium phosphate - extracted with 0.5 N neutral ammonium fluoride.

The difference between the total phosphorus and the sum of these various fractions was reported as organic phosphorus.

In the method followed 1.0 g. of the soil was first treated with 50 ml. of N ammonium chloride to remove the negligible amounts of water soluble and loosely bound phosphorus which might be present. After this treatment the soil was extracted with the various reagents and the different phosphorus fractions separated and estimated as follows:

(a) Aluminium phosphate: This fraction was extracted by shaking the soil with 50 ml. of 0.5 N ammonium fluoride for one hour. The solution was filtered and the extracted phosphorus estimated and reported as aluminium phosphate.

(b) Iron phosphate: The soil after treatment with ammonium fluoride was washed with saturated sodium chloride solution and then shaken with 0.1 N sodium hydroxide for 17 hours. The phosphorus extracted was estimated and reported as iron phosphate.

(c) Calcium phosphate: After sodium hydroxide extraction the soil was again washed with saturated sodium chloride and calcium phosphate was extracted by shaking with 50 ml. of 0.5 N sulphuric acid for one hour and then estimated.

(d) Occluded iron phosphate: This fraction was determined by chelation with sodium citrate and sodium dithionite. For this the soil after the previous treatment was washed with saturated sodium chloride and then suspended in 50 ml. of 0.3 M sodium citrate containing 5 ml. of sodium bicarbonate. The suspension was heated in a water bath at 80°C and treated with 1 g. of sodium dithionite with rapid stirring. After 15 minutes, it was centrifuged and the solution collected in a 100 ml. volumetric flask. The soil was washed twice with 25 ml. portions of saturated sodium chloride and the washings added to the extract in the volumetric flask and the volume made up. An aliquot of the made up solution was transferred into 150 ml. Erlenmeyer flask and heated cautiously with phosphorus free hydrogenperoxide adding a drop of 0.5 M ferric chloride to moderate the oxidation. After completion of the oxidation the solution was dried on a steam plate and then digested with 2 N sodium hydroxide for 5 minutes. It was then filtered to remove the iron oxide precipitate and the solution made up to 100 ml. Occluded iron phosphate was estimated in this solution.

(e) Occluded aluminium phosphate: The residue left after the dithionate citrate extraction was again extracted with 50 ml. neutral ammonium fluoride and the aluminium phosphate estimated as before and reported as the occluded aluminium phosphate.

The phosphorus extracted by the different reagents as described above was estimated colorimetrically using a Klett Summerson photo electric colorimeter. For the aluminium phosphate and occluded aluminium phosphate fractions "molybdenum blue" colour was developed in the sulphuric acid system as suggested by Jackson (1957). For the other fractions the colour was developed in the hydrochloric acid system.

The soil phosphorus in the different soils was fractionated before and after treatment with a phosphatic fertilizer. Fractionation before treatment enabled the study of the distribution pattern of native soil phosphorus in the various forms. Fractionation after treatment with fertilizer helped to find out the specific chemical form to which the phosphorus applied was reverted in the soil. Treatment was effected by adding 100 mg. superphosphate (17.0 percent P_2O_5) to 100 g. soil which was kept moist for two days to enable equilibrium to be reached and then air-dried. This corresponded to a rate of application of 74 ug. P per g. of soil.

C. 'Available' phosphorus by different methods

Available phosphorus in the soils was determined using the following chemical extractants before and after treatment with superphosphate.

(a) Bray and Kurtz, (No. 1) solution (0.03 N ammonium fluoride in 0.025 N hydrochloric acid).

(b) Bray and Kurtz, (No. 2) solution (0.03 N ammonium fluoride in 0.1 N hydrochloric acid).

(c) Truog's reagent (0.002 N sulphuric acid buffered to pH 3 with ammonium sulphate).

(d) Olsen's solution (0.5 N sodium bicarbonate adjusted to pH 8.5 with sodium hydroxide).

Phosphorus availability was also determined biologically in the treated and untreated soils using the Neubauer method. Rice seedlings were used instead of rye and the method was modified as follows:

100 g. soil was mixed with 50 g. quartz sand and placed in a dish 11 cm. in diameter. 100 sprouted rice seeds were grown on these cultures for 17 days and then harvested and the phosphorus estimated. A control was also run by growing the seedlings in the quartz sand

and then determining the phosphorus in the plant material. The difference between these two values gave the amount of phosphorus actually absorbed to rice.

RESULTS

1. Chemical and mechanical composition of soils

The eight soils used in this study represent five of the major soil groups of Kerala, viz., the sandy, alluvial, forest, red and laterite soil groups. From the data presented in tables II and III it may be seen that these soils vary widely in their chemical and mechanical composition. They are all acid in reaction, the pH ranging from 5.1 for the sandy soil from Keerikkadu and the laterite from Pilicode to 5.9 for the laterite from Vellayani. The generally acid nature of these soils is coexistent with a correspondingly low level of the bases. Thus the level of the calcium in all the soils is extremely low ranging from 0.04 percent CaO in the sandy soil from Nileshwar to 0.21 percent CaO in the alluvial soil from Chengannur. Similarly the magnesium content varies from 0.10 percent MgO in the laterite from Vellayani to 0.42 percent MgO in the Chengannur soil. The level of potassium, again, is extremely low and varies from 0.03 percent K_2O in the Pilicode soil to 0.23 percent K_2O in the alluvial soil from Chengannur.

The higher fertility of the alluvial soil is further reflected in its nitrogen and phosphorus contents. Thus, this soil contains 0.08 percent P_2O_5 whereas the sandy soil from Nileshwar and red soil from Vellayani contain only 0.02 percent of this nutrient. The highest level of 0.13 percent nitrogen is found in the forest soil from Kottayam while the lowest level of this element is found in the sandy soil from Nileshwar (0.04 percent). If a P_2O_5 content of more than 0.10 percent in a soil may be rated as 'high', 0.06-0.10 as 'medium',

TABLE II

CHEMICAL ANALYSIS OF SOILS

(Expressed as percent, on oven dry basis)

Sl. No.	Components	Locality							
		Keerikkadu	Vellayani	Vellayani	Kottayam	Chengannur	Pilicode	Nileshwar II	Nileshwar III
1.	Moisture	1.18	4.87	1.82	6.11	4.23	2.84	1.07	0.47
2.	Loss on ignition	3.71	4.27	4.94	10.76	9.88	5.31	3.53	1.32
3.	Insolubles	91.11	78.02	84.96	63.56	66.50	77.85	90.26	95.38
4.	Soluble Silica	0.10	0.15	0.10	0.28	0.33	0.33	0.08	0.08
5.	Sesquioxides	4.13	13.42	8.74	19.21	18.50	14.03	5.20	3.34
6.	Iron (Fe_2O_3)	1.42	4.92	3.30	4.86	4.55	4.12	1.54	0.89
7.	Calcium (CaO)	0.13	0.10	0.09	0.10	0.21	0.06	0.08	0.04
8.	Magnesium (MgO)	0.14	0.10	0.10	0.14	0.42	0.17	0.12	0.15
9.	Potassium (K_2O)	0.18	0.08	0.07	0.11	0.21	0.09	0.07	0.03
10.	Phosphoric acid (P_2O_5)	0.04	0.02	0.03	0.06	0.08	0.05	0.04	0.02
11.	Nitrogen	0.10	0.06	0.04	0.13	0.10	0.09	0.06	0.04
12.	pH	5.1	5.4	5.9	5.4	5.8	5.1	5.3	5.8
13.	Cation Exchange Capacity (m.e/100 g. of soil)	4.3	4.6	4.4	10.2	9.1	5.9	3.7	1.9

TABLE III

MECHANICAL ANALYSIS OF SOILS

Percentage on oven dry basis

Locality	Textural separate				Textural class
	Coarse Sand	Fine Sand	Silt	Clay	
1. Keerikkadu (Alleppey)	59.32	22.28	2.34	14.58	Sandy loam
2. Vellayani (Trivandrum)	20.86	21.45	0.80	51.90	Clay
3. Vellayani (Trivandrum)	34.69	24.69	3.71	31.95	Sandy clay
4. Valparai (Kottayam)	32.68	31.10	1.50	28.58	Sandy clay loam
5. Chengannur (Alleppey)	9.23	53.79	4.52	23.57	Sandy clay loam
6. Pilicode (Cannanore)	40.94	27.27	3.45	23.57	Sandy clay loam
7. Nileshwar II (Cannanore)	53.65	23.43	2.40	16.22	Sandy loam
8. Nileshwar III (Cannanore)	79.77	11.91	1.31	6.18	Sand

0.03-0.06 as 'low', and less than 0.03 percent as 'very low', then all except the alluvial soil from Chengannur should be considered as either 'low' or 'very low' in phosphoric acid. On the basis of similar standards for nitrogen the sandy soil from Keerikadu, forest soil from Kottayam and the alluvial soil from Chengannur may be rated as high in this nutrient, and the soils from Vellayani, Pilicode, and Nileshwar II may be treated as medium, whereas the other two soils may be considered as low. Fixing 0.25 percent as the upper limit of a soil to be rated as low with respect to CaO and K_2O all the eight soils examined should be treated as low in these two nutrients. On the basis of a similar standard for organic carbon all the soils except the forest and alluvial soils should be considered as low in organic matter.

These soils vary considerably in their sesquioxide content also. The highest proportion of the sesquioxides is found in the forest soil from Kottayam and in the alluvial soil from Chengannur. These soils contain respectively 19.21 and 18.50 percent of the sesquioxides. As might be expected, the lowest level of the sesquioxides is found in the sandy soil from Nileshwar. The variation in the Fe_2O_3 content is more or less similar to that of the sesquioxides. The highest level of the Fe_2O_3 (4.93 percent) is in the red soil from Vellayani while the lowest proportion of this constituent (0.89 percent) is found in Nileshwar soil.

The data relating to the mechanical composition of the soils presented in table III reveal that three of them, (Kottayam, Chengannur and Pilicode) are sandy clay loams in texture. The soils from Keerikkad and Nileshwar II are sandy loams whereas the red and laterite soils from

Vellayani should be classed as clay and sandy clay respectively. The clay content in these soils varies from 6.2 in the sandy soil from Nileshwar to as much as 51.9 percent in the red soil from Vellayani. Similarly, the silt content varies from 0.8 percent in the Vellayani soil to 4.5 percent in the alluvial soil from Chengannur. The variation in the fine sand fraction is from 11.9 percent in sandy soil from Nileshwar to as much as 53.8 percent in the alluvial soil from Chengannur. The Changannur soil, however, contains a much lower proportion of coarse sand (9.2 percent) whereas the Nileshwar soil contains a rather high level (79.8 percent) of this constituent.

2. Fractionation of soil Phosphorus

The results of fractionation of native soil phosphorus are presented in tables IV and V. The data reveal that there is considerable variation in the nature of distribution of the various fractions from soil to soil and that none of these fractions constitutes a fixed proportion of the total. It is, however, noteworthy that among the different forms of inorganic soil phosphorus, iron phosphate constitutes the most predominant fraction in almost all the soils investigated. The next largest fraction is that of aluminium phosphate followed by calcium phosphate and the occluded forms of phosphorus, in order.

The aluminium phosphate fraction varies from 10.0 µg.P/g. of soil in Vellayani to as much as 54.5 µg.P/g. of soil in Chengannur. When expressed as percent of total phosphorus the highest proportion of this fraction is found in the soil from Nileshwar (28.71 percent) and the lowest in the red loam from Vellayani (10.42 percent). It is

TABLE IV

RESULTS OF FRACTIONATION OF NATIVE SOIL PHOSPHORUS

(Expressed as µg. P per g. of soil)

Locality	Active inorganic phosphates			Occluded		Organic P	Total P
	Al-P	Fe-P	Ca-P	Al-P	Fe-P		
1. Keerikkadu (Alleppey)	45.0	42.5	19.5	13.8	13.5	40.2	174.5
2. Vellayani (Trivandrum)	10.0	30.7	8.1	16.1	16.8	14.3	96.0
3. Vellayani (Trivandrum)	18.0	53.7	13.0	16.1	16.8	22.4	140.0
4. Valparai (Kottayam)	26.5	72.7	23.9	23.0	25.2	81.8	253.1
5. Chengannur (Alleppey)	54.5	88.0	50.3	25.3	33.7	97.3	349.1
6. Pilicode (Cannanore)	22.4	73.2	13.7	23.0	28.0	57.9	218.2
7. Nileshwar II (Cannanore)	38.7	67.0	15.3	23.0	11.2	23.7	178.9
8. Nileshwar III (Cannanore)	28.8	26.1	12.2	13.8	9.0	10.4	100.3

TABLE V

RESULTS OF FRACTIONATION OF NATIVE SOIL PHOSPHORUS

(Expressed as percent of total phosphorus)

Locality	Active inorganic phosphates			Occluded		Organic P	Total
	Al-P	Fe-P	Ca-P	Al-P	Fe-P		
1. Keerikkadu (Alleppey)	25.79	24.36	11.18	7.91	7.73	23.03	100
2. Vellayani (Trivandrum)	10.42	31.98	8.44	16.77	17.50	14.89	100
3. Vellayani (Trivandrum)	12.86	38.36	9.28	11.50	12.00	16.00	100
4. Valparai (Kottayam)	10.47	28.72	9.44	9.09	9.96	32.32	100
5. Chengannur (Alleppey)	15.62	25.22	14.41	7.24	9.65	27.86	100
6. Pilicode (Cannanore)	10.27	33.55	6.28	10.54	18.70	20.66	100
7. Nileshwar II (Cannanore)	21.63	37.46	8.56	12.85	6.26	13.24	100
8. Nileshwar III (Cannanore)	28.71	26.01	12.18	13.76	8.97	10.37	100

interesting to note that the sandy soils generally contained a higher proportion of this fraction (21.63 - 28.71 percent) when compared to the rest of the soils (10.42 - 15.62 percent).

The highest level of iron phosphate (88 µg. P/g. of soil) was found in the alluvial soil from Chengannur while the lowest amount (26.1 µg. P/g. of soil) of this fraction was obtained in the sandy soil from Nileshwar. Expressed as percent of total phosphorus the variation in this fraction was from 24.4 percent in Keerikkadu soil to 33.4 percent in the laterite from Vellayani.

As regards the variation in the calcium phosphate fraction it was observed that the highest amount of this fraction (50.3 µg.P/g. of soil) was in Chengannur soil and the lowest amount (8.1 µg.P/g. of soil) in the red soil from Vellayani. When expressed as percent of total phosphorus the highest proportion (14.4 percent) was, again, in the Chengannur soil, whereas the lowest level (6.3 percent) was in the soil from Pilicode.

The alluvial soil from Chengannur contained the highest amounts of occluded aluminium, occluded iron and organic forms of phosphorus as well (25.3, 33.7 and 97.3 µg. P/g. of soil respectively). The lowest amounts of these different forms of phosphorus were found in the sandy soil from Nileshwar (13.8, 9.0 and 10.4 µg. P/g. of soil). When considered as percent of total phosphorus the variation in occluded aluminium phosphate was from 7.24 percent in the Chengannur soil to 16.8 percent in the red soil from Vellayani. Occluded iron phosphate varied from 6.3 percent in Pilicode soil to 18.7 percent in the soil from Nileshwar. As might be expected, the forest soil from Kottayam contained the highest level of organic phosphorus (32.3 percent) and the sandy soil from Nileshwar the lowest proportion (10.4 percent) of this fraction.

The results of fractionation after the application of super phosphate at the rate of 74 µg. P/g. of soil to these soils are given in tables VI - IX. The data reveal that about 38-77 percent of the added phosphorus was recovered as calcium phosphate in these soils. The maximum recovery as calcium phosphate (76.7 percent) took place in the sandy soil from Nileshwar and the minimum recovery in this form was from the alluvial soil from Chengannur. Reversion of added phosphate to the iron phosphate form varied from 15.3 percent in the laterite soil from Vellayani to 30.7 percent in the sandy soil from Keerikkadu. Fixation in the form of aluminium phosphate was also quite considerable and ranged from 9.2 percent in the red soil from Nileshwar to 30.5 percent in the alluvial soil from Chengannur. Only a very small proportion of the added phosphorus was generally retained in the occluded forms of soil phosphorus while it appeared that a small part of the organic phosphorus got mineralised to inorganic forms consequent on the treatment with superphosphate.

The inter relationships between organic carbon, nitrogen and organic phosphorus are presented in table X. It may be noted that the C/N ratio varies from 11.91 for the soil from Keerikkadu to 27.00 for the alluvial soil from Chengannur, the average for all the soils being 18.43. The variation in the C/P ratio is from 227.6 for the Pilicode soil to as high as 780.0 for the sandy soil from Nileshwar with an average of 426.7. The N/P ratio ranges from 10.4 for Chengannur soil

TABLE VI

RESULTS OF FRACTIONATION OF SOIL PHOSPHORUS AFTER TREATMENT WITH SUPERPHOSPHATE

(Expressed as µg. P per g. of soil)

Locality	Active inorganic phosphates			Occluded		Organic P	Total
	Al-P	Fe-P	Ca-P	Al-P	Fe-P		
1. Keerikkadu (Alleppey)	62.5	65.2	47.3	14.0	21.3	38.2	248.5
2. Vellayani (Trivandrum)	21.0	49.0	42.5	20.0	23.5	14.0	170.0
3. Vellayani (Trivandrum)	29.9	65.0	54.1	21.5	22.5	21.0	214.0
4. Valparai (Kottayam)	42.2	88.6	68.5	20.0	25.8	82.0	327.1
5. Chengannur (Alleppey)	77.1	110.0	78.4	25.1	36.0	96.5	423.1
6. Pilicode (Cannanore)	32.1	90.1	66.7	20.6	28.7	54.0	292.2
7. Nileshwar II (Cannanore)	45.5	78.5	72.1	20.0	16.8	20.0	252.9
8. Nileshwar III (Cannanore)	39.5	40.5	53.3	18.3	12.7	10.0	174.3

TABLE VII

RESULTS OF FRACTIONATION OF SOIL PHOSPHORUS AFTER TREATMENT WITH SUPERPHOSPHATE
(Expressed as percent of total phosphorus)

Locality	Active inorganic phosphates			Occluded		Organic P	Total P
	Al-P	Fe-P	Ca-P	Al-P	Fe-P		
1. Keerikkadu (Alleppey)	25.15	26.23	19.03	5.63	8.58	15.38	100
2. Vellayani (Trivandrum)	12.35	28.82	25.60	11.77	13.82	8.24	100
3. Vellayani (Trivandrum)	13.97	30.38	25.28	10.05	10.52	9.80	100
4. Valparai (Kottayam)	12.90	27.09	20.94	6.11	7.89	25.07	100
5. Chengannur (Alleppey)	18.23	26.00	18.53	5.93	8.50	22.81	100
6. Pilicode (Cannanore)	10.99	30.84	22.82	7.05	9.82	18.48	100
7. Nileshwar II (Cannanore)	17.99	31.04	28.51	7.91	6.64	7.91	100
8. Nileshwar III (Cannanore)	22.67	23.25	30.56	10.51	7.28	5.73	100

TABLE VIII

INCREASE OF PHOSPHORUS IN DIFFERENT FRACTIONS DUE TO TREATMENT

(Expressed in μg. P per g. of soil)

Locality	Active inorganic phosphates			Occluded		Organic P	Total added
	Al-P	Fe-P	Ca-P	Al-P	Fe-P		
1. Keerikkadu (Alleppey)	17.5	22.7	27.8	0.2	7.8	-2.0	74.0
2. Vellayani (Trivandrum)	11.0	18.3	34.4	3.9	6.7	-0.3	74.0
3. Vellayani (Trivandrum)	11.9	11.3	41.1	5.4	5.7	-1.4	74.0
4. Valparai (Kottayam)	15.7	15.9	44.6	-3.0	0.6	0.2	74.0
5. Chengannur (Alleppey)	22.6	22.0	28.1	-0.2	2.3	-0.8	74.0
6. Pilicode (Cannanore)	9.7	16.9	53.0	-2.4	0.7	-3.9	74.0
7. Nileshwar II (Cannanore)	6.8	11.5	56.8	-3.0	5.6	-3.7	74.0
8. Nileshwar III (Cannanore)	10.7	14.4	41.1	4.5	3.7	-0.4	74.0

TABLE IX

INCREASE OF PHOSPHORUS IN DIFFERENT FRACTIONS DUE TO TREATMENT

(Expressed as percent oftotal phosphorus)

Locality	Active inorganic phosphates			Occluded		Organic P	Total P added
	Al-P	Fe-P	Ca-P	Al-P	Fe-P		
1. Keerikkadu (Alleppey)	23.6	30.7	37.6	0.3	10.5	-2.7	100
2. Vellayani (Trivandrum)	14.9	24.7	46.4	5.3	9.1	-0.4	100
3. Vellayani (Trivandrum)	16.1	15.3	55.5	7.3	7.7	-1.9	100
4. Valparai (Kottayam)	21.2	21.5	60.2	-4.0	0.8	0.3	100
5. Chengannur (Alleppey)	30.5	29.7	38.0	-0.3	3.1	-1.0	100
6. Pilicode (Cannanore)	13.1	22.8	71.6	-3.2	0.9	-5.4	100
7. Nileshwar II (Cannanore)	9.2	15.5	76.7	-4.0	7.6	-5.0	100
8. Nileshwar III (Cannanore)	14.5	19.5	55.5	6.0	5.0	-0.5	100

TABLE X

INTER RELATIONSHIPS BETWEEN ORGANIC CARBON, NITROGEN, AND ORGANIC PHOSPHORUS IN SOILS

Locality	Organic Carbon Percent	Nitrogen Percent	Organic Phosphorus Percent	C/N ratio	C/P ratio	N/P ratio
1. Keerikkadu (Alleppey)	1.20	0.1008	0.0040	11.91	300.0	25.2
2. Vellayani (Trivandrum)	0.90	0.0616	0.0014	14.61	642.8	44.0
3. Vellayani (Trivandrum)	1.02	0.0448	0.0022	22.25	463.7	20.4
4. Valparai (Kottayam)	2.82	0.1288	0.0082	21.89	343.9	15.7
5. Chengannur (Alleppey)	2.72	0.1008	0.0097	27.00	280.4	10.4
6. Pilicode (Cannanore)	1.32	0.0932	0.0058	14.66	227.6	16.1
7. Nileshwar II (Cannanore)	0.90	0.0560	0.0024	16.07	375.0	23.3
8. Nileshwar III (Cannanore)	0.78	0.0392	0.0010	19.09	780.0	39.2
		Mean		18.43	426.7	24.3

to 44.0 for the soil from Keerikkadu, the average for the soils studied being 24.3.

3. Available Phosphorus by different methods

Data relating to the available phosphorus status of these soils as determined by extraction with different reagents are presented in tables XI - XVI. It may be noted from these tables that Bray's reagent generally extracted more phosphorus from the sandy soils than from the other soils. Truog's reagent, on the other hand, extracted less phosphorus from the sandy soils and more from the others. Available phosphorus as determined by Olsen's method was generally very low when compared to that estimated by the other methods. In spite of the differences in the actual amount of phosphorus dissolved by these different extractants, the trends in the solubility of soil phosphorus in these reagents were similar. The amounts of phosphorus removed by rice seedlings in the Neubauer technique were highly correlated to the available phosphorus determined by the chemical methods.

The correlation studies with regard to different variable characters are taken up and the correlation coefficients and the corresponding regression equations which are found to be statistically significant are tabulated in table XVII.

TABLE XI

DETERMINATION OF 'AVAILABLE' PHOSPHORUS BY VARIOUS METHODS

(Untreated Samples)

(Expressed in µg P/ g. soil)

Locality	Total P	Bray's No.1	Bray's No.2	Trugg's method	Olsen's method
1. Keerikkadu (Alleppey)	174.5	18.72	23.68	29.90	6.44
2. Vellayani (Trivandrum)	96.0	1.48	2.56	12.65	2.53
3. Vellayani (Trivandrum)	140.0	5.44	7.36	21.85	3.45
4. Valparai (Kottayam)	253.1	4.16	5.12	20.13	3.22
5. Chengannur (Alleppey)	349.1	9.30	10.48	18.40	4.60
6. Pilicode (Cannanore)	218.2	3.92	4.48	16.68	2.30
7. Nileshwar II (Cannanore)	178.9	17.60	20.80	8.63	5.29
9. Nileshwar III (Cannanore)	100.3	16.00	16.48	8.05	3.91

TABLE XII

DETERMINATION OF 'AVAILABLE' PHOSPHORUS BY VARIOUS METHODS

(Untreated Samples)

(Expressed as percent of total phosphate)

Locality	Bray's No.1	Bray's No.2	Truog's method	Olsen's method
1. Keerikkadu (Alleppey)	10.51	13.57	17.14	3.69
2. Vellayani (Trivandrum)	1.58	2.67	13.17	2.64
3. Vellayani (Trivandrum)	3.89	5.26	15.61	2.46
4. Valparai (Kottayam)	1.64	2.02	7.95	1.27
5. Chengannur (Alleppey)	2.66	3.00	5.27	1.31
6. Pilicode (Cannanore)	1.79	2.05	7.64	1.05
7. Nileshwar II (Cannanore)	9.83	11.62	4.82	2.96
8. Nileshwar III (Cannanore)	15.95	16.44	8.02	3.89

TABLE XIII

DETERMINATION OF 'AVAILABLE' PHOSPHORUS BY VARIOUS METHODS

(Treated with Superphosphate)

(Expressed in μg P/g. soil)

Locality	Total P	Bray's No. 1	Bray's No. 2	Truog's method	Olsen's method
1. Keerikkadu (Alleppey)	248.5	56.00	62.10	48.88	34.04
2. Vellayani (Trivandrum)	170.0	13.92	18.24	20.13	11.50
3. Vellayani (Trivandrum)	214.0	38.72	41.72	25.88	18.17
4. Valparai (Kottayam)	327.1	25.76	40.36	26.45	14.03
5. Chengannur (Alleppey)	423.1	23.36	48.41	27.60	16.10
6. Pilicode (Cannanore)	292.2	31.52	33.62	18.40	12.88
7. Nileshwar II (Cannanore)	252.9	58.00	61.04	37.95	25.07
8. Nileshwar III (Cannanore)	174.3	48.00	50.60	37.38	23.23

TABLE XIV

DETERMINATION OF 'AVAILABLE' PHOSPHORUS BY VARIOUS METHODS

(Treated with Superphosphate)

(Expressed as percent of total phosphorus)

Locality	Bray's No. 1	Bray's No. 2	Truog's method	Olsen's method
1. Keerikkadu (Alleppey)	22.53	24.98	19.66	13.70
2. Vellayani (Trivandrum)	8.19	10.73	11.84	6.77
3. Vellayani (Trivandrum)	18.09	19.49	12.10	8.49
4. Valparai (Kottayam)	7.88	12.33	8.09	4.29
5. Chengannur (Alleppey)	5.52	11.44	6.52	3.81
6. Pilicode (Cannanore)	10.78	11.50	6.30	4.41
7. Nileshwar II (Cannanore)	22.93	24.13	15.01	9.91
8. Nileshwar III (Cannanore)	27.53	29.03	21.45	13.33

TABLE XV

'AVAILABLE' PHOSPHORUS AS PER NEUBAUER TECHNIQUE

	Locality	Untreated			
		Total yield of P from plant	Available P from soil	Average P from soil	Total P in soil
		(µg. P/100 g. of soil)		(µg. P/g. of soil)	
1.	Keerikkadu (Alleppey)	6060	962	9.62	174.5
2.	Vellayani (Trivandrum)	5146	48	0.48	96.0
3.	Vellayani (Trivandrum)	5576	478	4.78	140.0
4.	Valparai (Kottayam)	5627	529	5.29	253.1
5.	Chengannur (Alleppey)	5670	572	5.72	349.1
6.	Pilicode (Cannanore)	5540	442	4.42	218.2
7.	Nileshwar II (Cannanore)	5970	872	8.72	178.9
8.	Nileshwar III (Cannanore)	5845	747	7.47	100.3

Note: Phosphorus from plants grown in Quartz sand 5098 µg. P/100 g. of Quartz Sand.

TABLE XVI

AVAILABLE PHOSPHORUS AS PER NEUBAUER TECHNIQUE

Locality	Treated with superphosphate			
	Total Yield of P from plant	Available P from soil	Average P from soil	Total P in soil
	(µg.P/100 g. soil)		(µg. P/ g. of soil)	
1. Keerikkadu (Alleppey)	7547	2449	24.49	248.5
2. Vellayani (Trivandrum)	5886	788	7.88	170.0
3. Vellayani (Trivandrum)	6825	1727	17.27	214.0
4. Valparai (Kottayam)	6871	1773	17.73	327.1
5. Chengannur (Alleppey)	6622	1524	15.24	423.1
6. Pilicode (Cannanore)	6448	1350	13.50	292.2
7. Nileshwar II (Cannanore)	7186	2088	20.88	252.9
8. Nileshwar III (Cannanore)	7206	2106	21.08	174.3

Note: Phosphorus from plants grown in Quartz sand

5098 µg. P/100 g. of Quartz sand.

TABLE XVII

CORRELATION COEFFICIENTS AND REGRESSION EQUATIONS

Sl. No.	Variables		Correlation Coefficient	Regression equation
	x	y	r	
1.	Fine sand	Iron phosphate	0.6648^{+}	$y = 1.6x + 13.5$
2.	Fine sand	calcium phosphate	0.8958^{++}	$y = 1.03x - 8.31$
3.	Fine sand	Occluded iron phosphate	0.9428^{++}	$y = 0.78x - 2.91$
4.	Total sesquioxides	Iron phosphate	0.6233^{+}	$y = 1.92x + 35.1$
5.	Aluminium phosphate	Bray & Kurtz No. 1 available phosphorus	0.6421^{++}	$y = 0.71x - 1.31$
6.	Aluminium phosphate	Bray & Kurtz No.2 available phosphorus	0.6606^{++}	$y = 0.77x - 0.63$
7.	Bray & Kurtz No. 1 av.P	Neubauer av.P	0.9770^{+++}	$y = 0.36x + 2.49$
8.	Bray & Kurtz No. 2 av.P	Neubauer av.P	0.9770^{+++}	$y = 0.32x + 2.32$
9.	Truog's av.P	Neubauer av.P	0.8231^{+++}	$y = 0.52x - 0.77$
10.	Olsen's av.P	Neubauer av.P	0.9378^{+++}	$y = 0.7x + 3.37$

Note: The asterick mark indicates statistical significance as shown below:

+	Significant at 0.1 level
++	Significant at 0.01 level
+++	Significant at 0.001 level

DISCUSSION OF RESULTS

From the data obtained in the present study it is seen that the total P_2O_5 content of the alluvial soil is higher than that of the other soils, viz., the sandy, forest, laterite and red soils. The high level of phosphorus could arise as a result of manuring or from the parent material which might have been rich in phosphatic minerals. Since virgin soils were used in this study the possibility of a higher fertility status due to manuring has to be rejected. Though this soil contains appreciable amounts of iron and alumina it also contains a comparatively high percentage of the bases, suggesting thereby, that the soil has not undergone a very high degree of weathering. According to Goel and Agarwal (1959) the total P_2O_5 content decreases with increase in the maturity of a soil. It is also noted in the present study that the alluvial soil contains the highest amount of calcium phosphate. This is in accordance with the findings of Chang and Jackson (1958) who report that in the initial stages of weathering calcium and aluminium phosphates predominate in the soil and as that time advance these forms are converted into iron phosphate. Therefore the high amoun of calcium phosphate in the alluvial soil from Chengannur indicates that it is less weathered than the other soils investigated. The rest of the soils, viz., the sandy, forest, red and laterite soils contain about 50 percent of the total P_2O_5 in the form of iron phosphates and in all these cases the iron and aluminium phosphates together constitute about 60-80 percent of the total. The level of aluminium and calcium phosphates is found to be slightly higher in the sandy soils, which suggests that these soils are relatively less weathered. Among the forest, red and laterite soils, the red and laterite soils contain the highest amounts of iron and aluminium phosphates. Chang and Jackson (1958) point out that in latosols the iron phosphate and a part of the aluminium phosphate would be coated with iron oxides formed during the course of weathering to form the occluded forms of phosphorus. These forms of phosphorus tend to accumulate in the soil with time. The red and laterite soils which contain high percentages of the most resistant forms of occluded iron and aluminium phosphates can, therefore, be considered as the most weathered and mature soils.

It is found that the iron and alumina content of these soils significantly correlated to the iron phosphate fraction (fig. 1). There was positive correlation between the sesquioxide and the aluminium phosphate contents but it was not significant. Significant correlations were, further, obtained between the fine sand fraction of the soils and the contents of iron and calcium phosphates and the occluded iron phosphates (fig. 2 - 4).

It is found that the phosphorus applied as fertilizer in the form of superphosphate was recovered in all inorganic forms of soil phosphorus, viz., calcium, aluminium and ironphosphates. The addition of fertilizer phosphorus resulted in considerable increase in the calcium phosphate fraction in all the soils. Reversion occurred to the iron and aluminium phosphate forms but only to a small extent. The increase in the content of occluded iron and aluminium phosphates as a result of phosphate application was negligible. The increase in the calcium phosphate fraction may be attributed to the slow conversion of the

SESQUI OXIDE Vs IRON PHOSPHATE

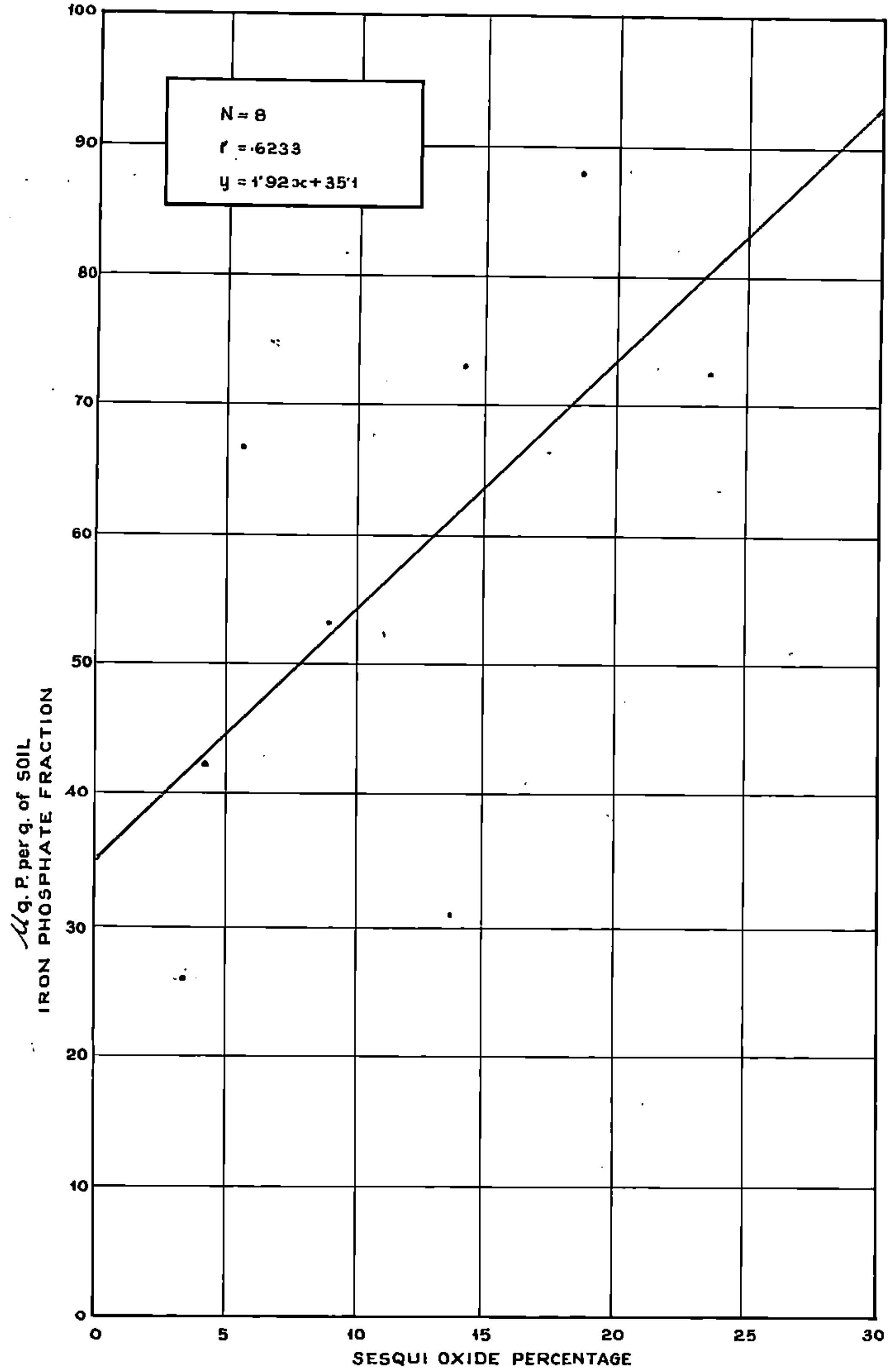

FIG. 1

FINE SAND Vs IRON PHOSPHATE

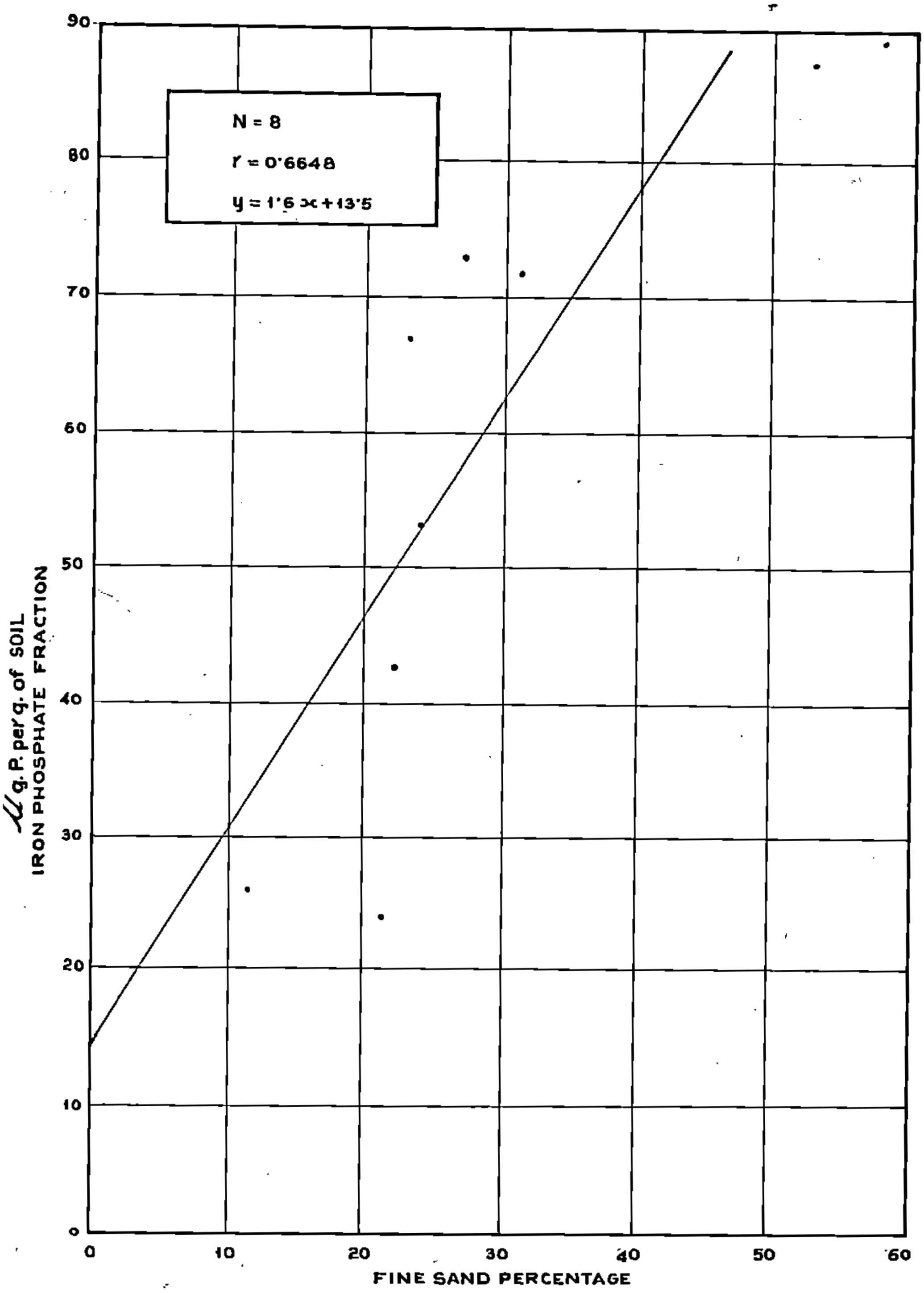

FIG. 2

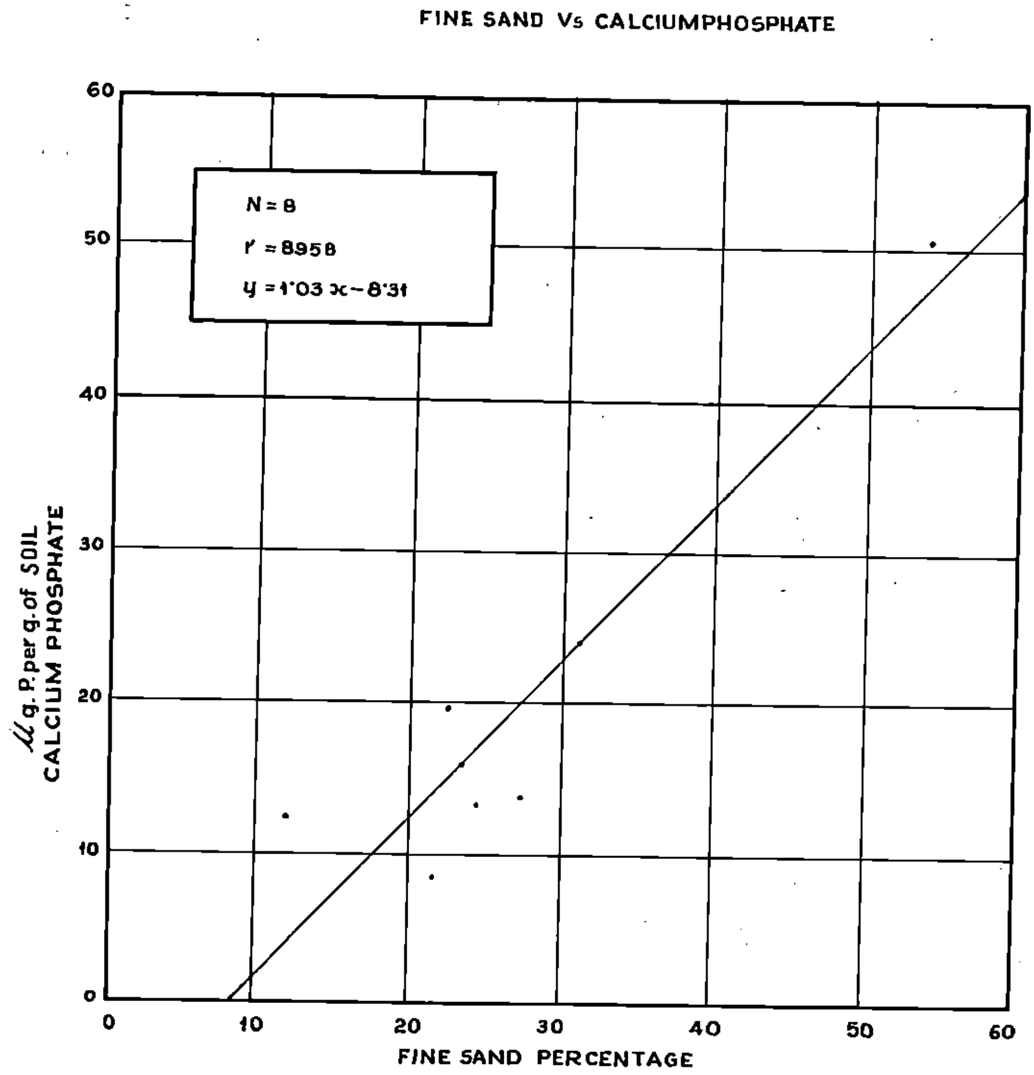
FINE SAND Vs CALCIUMPHOSPHATE
N = 8
r = 8958
y = 1·03 x – 8·31
μg. P. per g. of SOIL
CALCIUM PHOSPHATE
0
10
20
30
40
50
60
FINE SAND PERCENTAGE

FIG. 3

applied superphosphate into the more resistant iron and aluminium phosphates. The general trend in the conversion shows that the phosphate applied will ultimately be converted to the more the resistant phosphates of iron ahd aluminium. In a study on the fixation and availability of phosphorus in Kerala soils, Koshy and Brito mutunayagam (1961) observed that the available phosphorus decreased progressively with time of contact of the soil and the fertilizer and that equilibrium was reached after about 8 to 12 weeks. It should, therefore, be inferred that the accumulation of calcium phosphate as observed in the present study might be due to the insufficiency of time between the addition of superphosphate and the fractionation of the soil phosphorus.

There is considerable variation in the available phosphorus extracted by different reagents. It is found that Bray's reagents extract more phosphorus from these soils especially from the sandy soils. In the soil fractionation study it is found that sandy soils contain a considerably higher proportion of aluminium phosphates. The correlation study also shows that the amounts of phosphorus extracted by Bray's reagents are highly correlated with aluminium phosphate fraction (fig. 5 - 6). This is possible because as Turner and Rice (1952) has pointed out ammonium fluoride in Bray's reagents dissolve aluminium phosphate and a part of the iron phosphate. Chai Moo Cho and Caldwell (1959) and Janardhanan Nair (1961) have reported similar results. Between the two reagents suggested by Bray the more acidic extractant gave higher values for available phosphorus, as these reagent extracted more of the acid soluble fraction. It is

ALUMINIUM PHOSPHATE
Vs
BRAY & KURTZ (No 1) AVAILABLE PHOSPHORUS

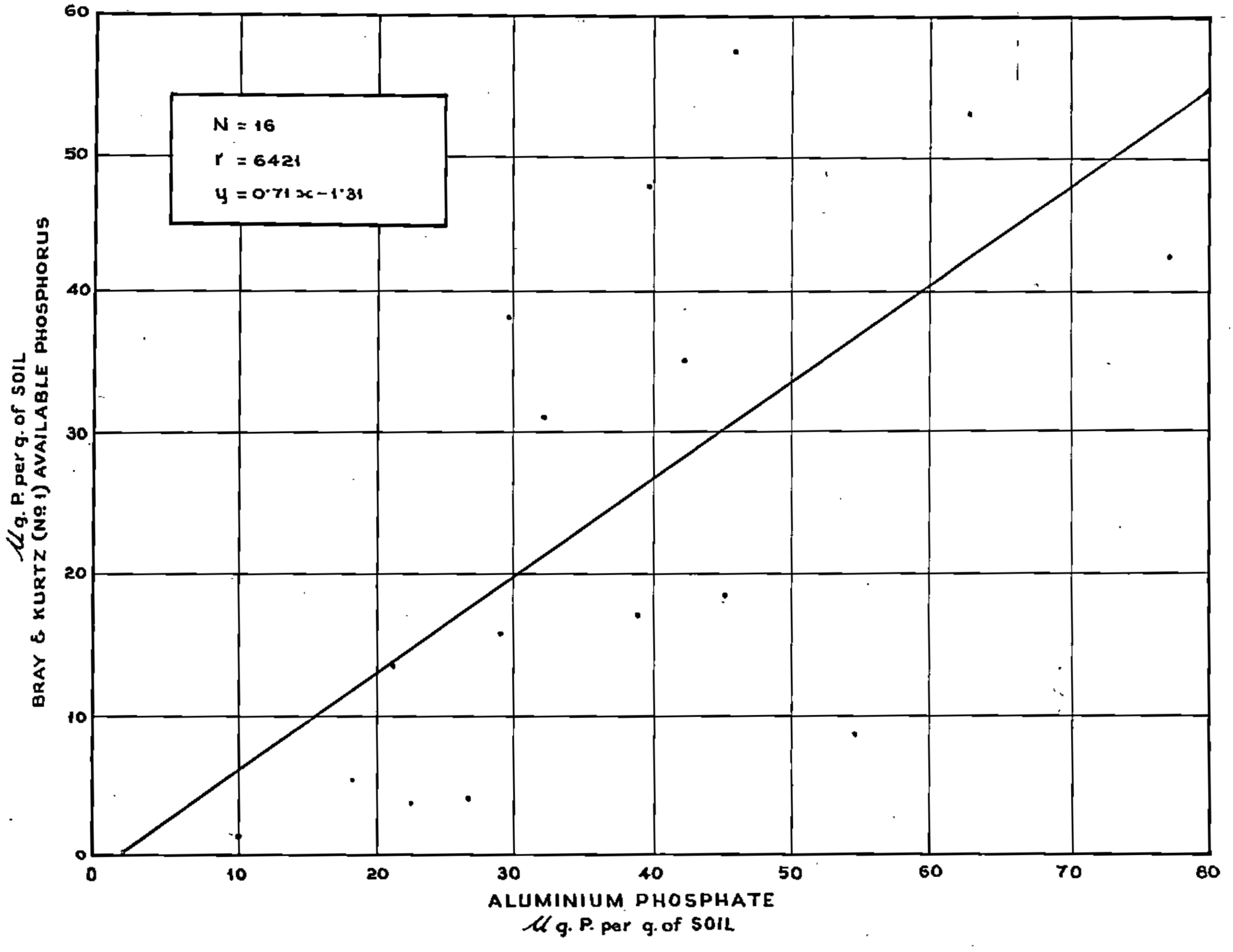

FIG. 5

ALUMINIUM PHOSPHATE
Vs
BRAY & KURTZ (No. 2) AVAILABLE PHOSPHORUS

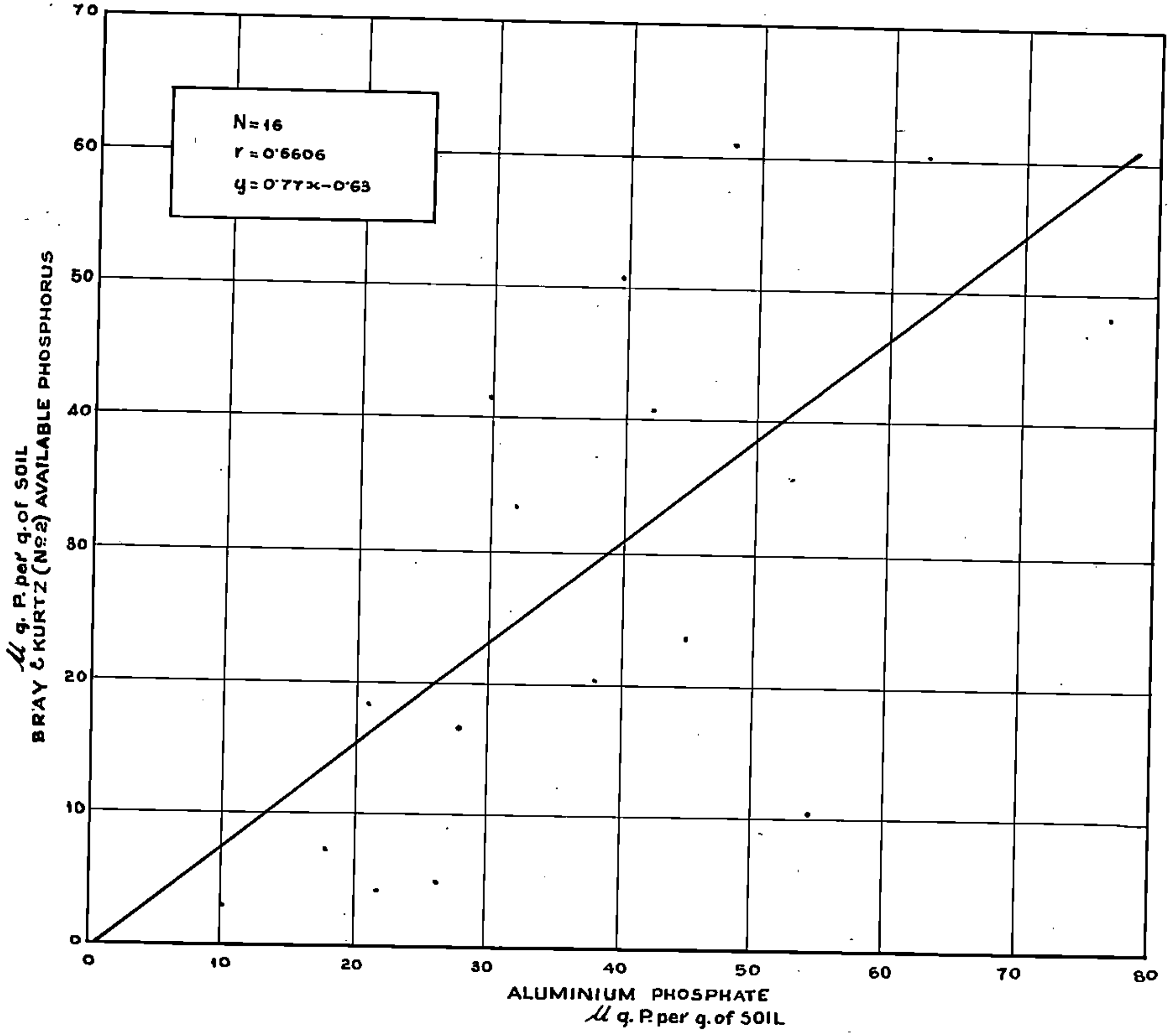

FIG. 6

found that there is significant correlation between the phosphorus extracted by these two reagents. The lowest figures for available phosphorus were obtained by Olsen's method. Available phosphorus as determined by all these methods compared fairly with the amounts of phosphorus removed by rice seedlings in the Neubauer method. When the available phosphorus values obtained by the Neubauer technique are taken as independent measures of available phosphorus in soils all the four chemical methods gave good estimates of available phosphorus. Thus when the correlation to the Neubauer method is observed Bray's reagents are found to give the highest correlation coefficient of 0.9770 and Truog's reagent the lowest value of 0.8231 (fig. 7 - 10). It is also found that there is very close relationship between the total and the available phosphorus estimated by different methods. All the reagents used, extract available phosphorus which is positively correlated to the total phosphorus content of the soil. Using the several extractants Rayachaudhari <u>et al</u> (1954) reported that best correlation significant at 1 percent level could be obtained with Truog's method for paddy crop in the red and laterite soils of Bihar and the next best correlation significant at 5 percent level for the same soils with Bray's method. Datta and Kammath (1958) reported that for soils ranging in pH from 5.0 to 8.8 Olsen's method gives the highest correlations. In conclusion it may be stated that any one of these methods may be used to get an approximate idea of the available phosphorus in Kerala soils, provided, the extent of correlation to the actual availability as determined by Neubauer's or a similar method is taken into account.

FINE SAND Vs. OCCLUDED IRON PHOSPHATE

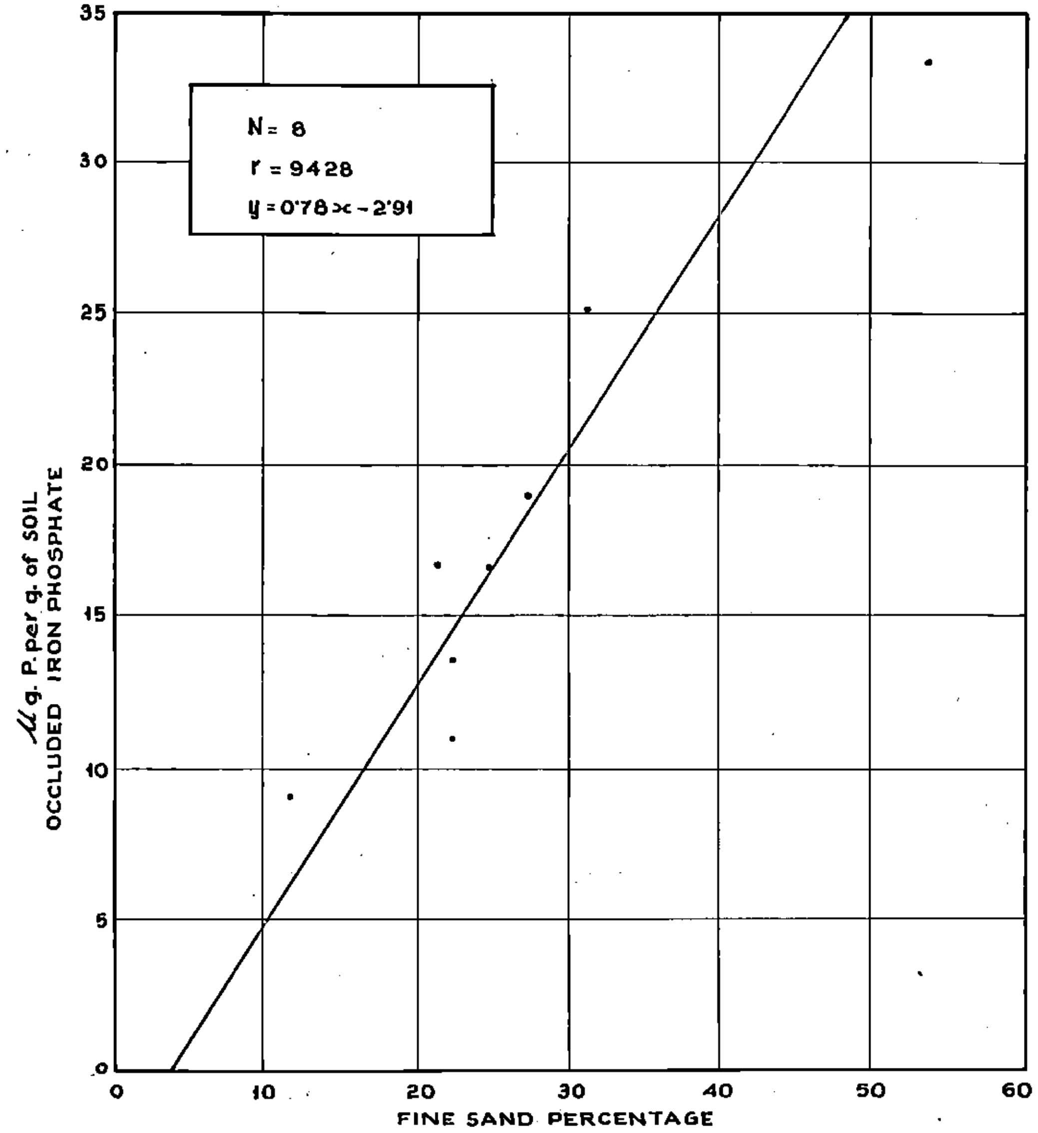

FIG. 4

AVAILABLE PHOSPHORUS

BRAY & KURTZ (No 1) Vs. NEUBAUER

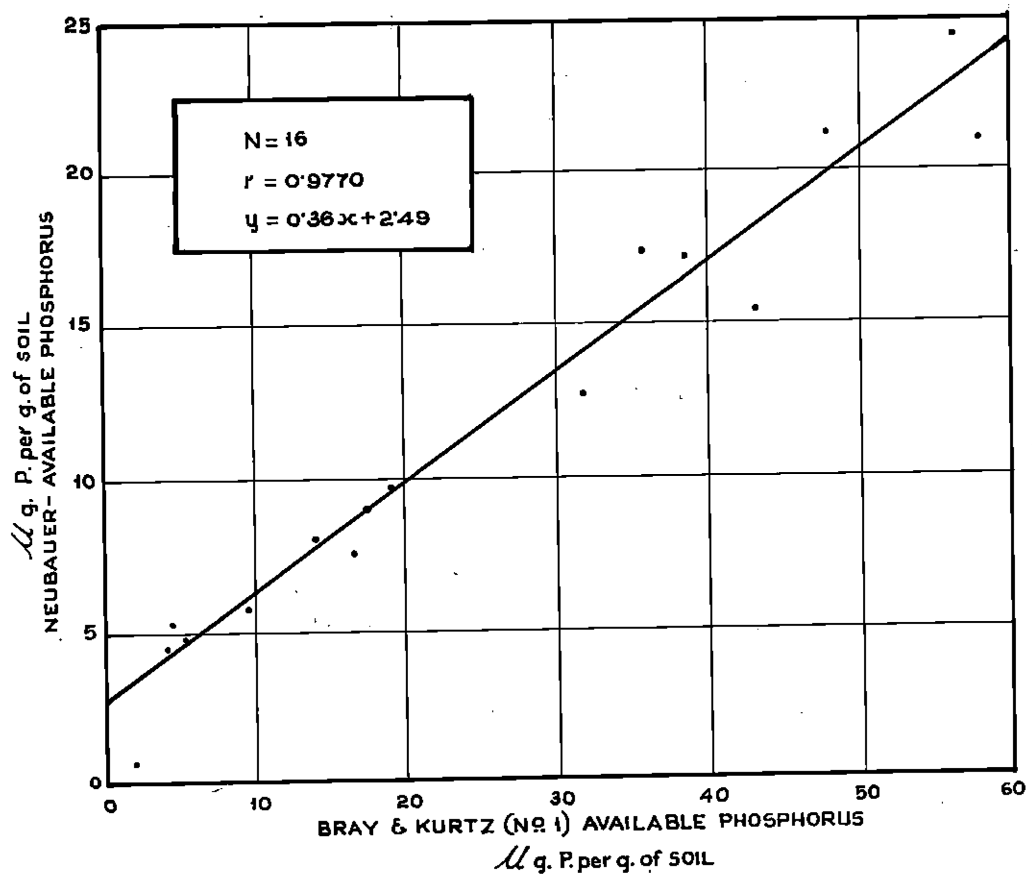

FIG. 7

AVAILABLE PHOSPHORUS
BRAY & KURTZ (No. 2) Vs. NEUBAUER

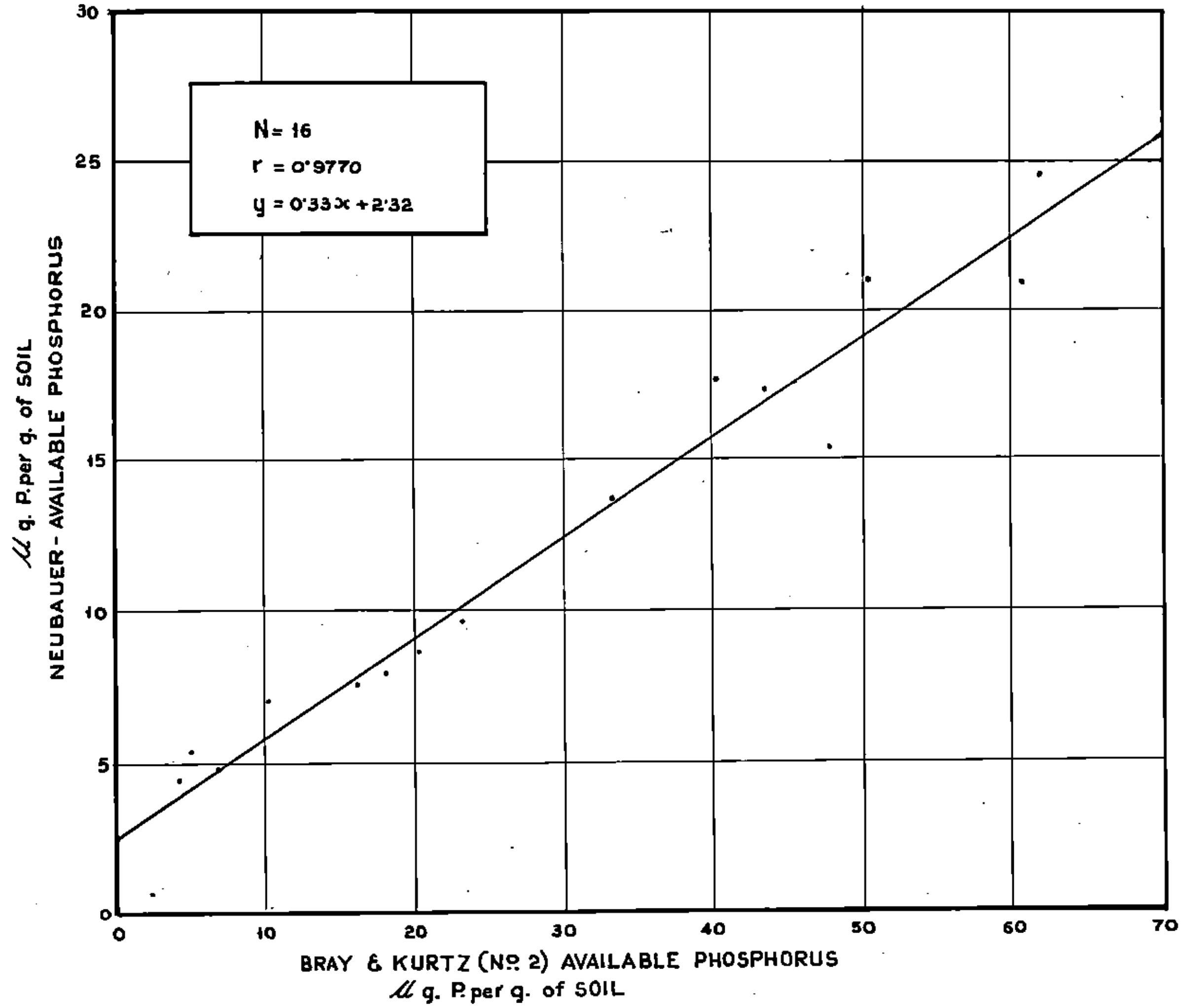

FIG. 8

AVAILABLE PHOSPHORUS
TRUOG'S Vs. NEUBAUER

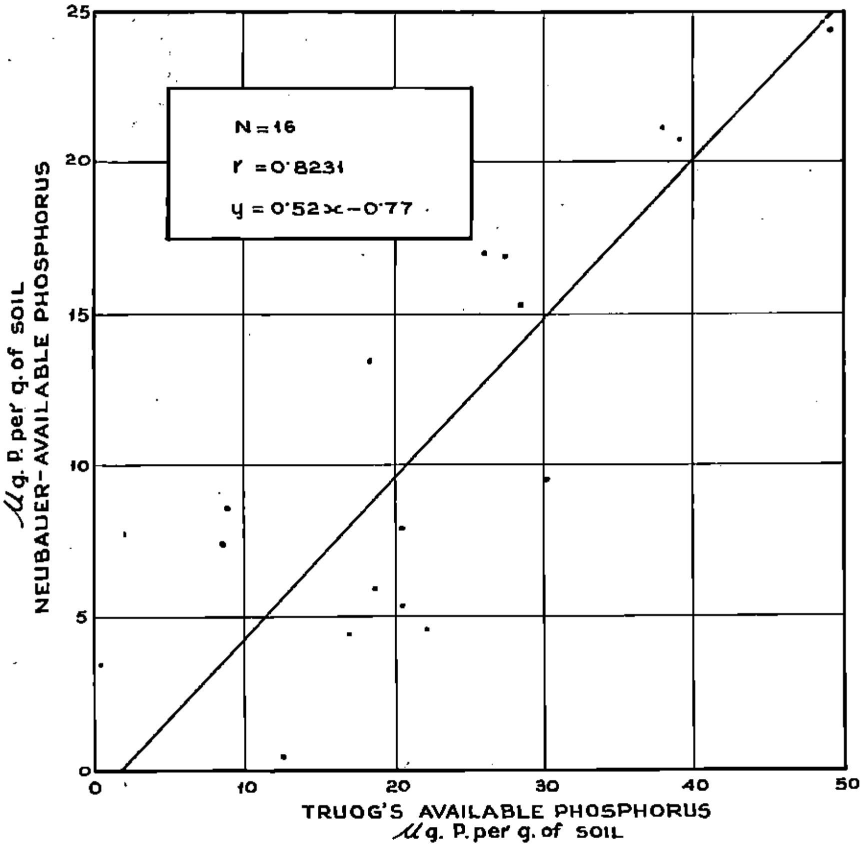

FIG. 9

AVAILABLE PHOSPHORUS
OLSEN'S Vs NEUBAUER

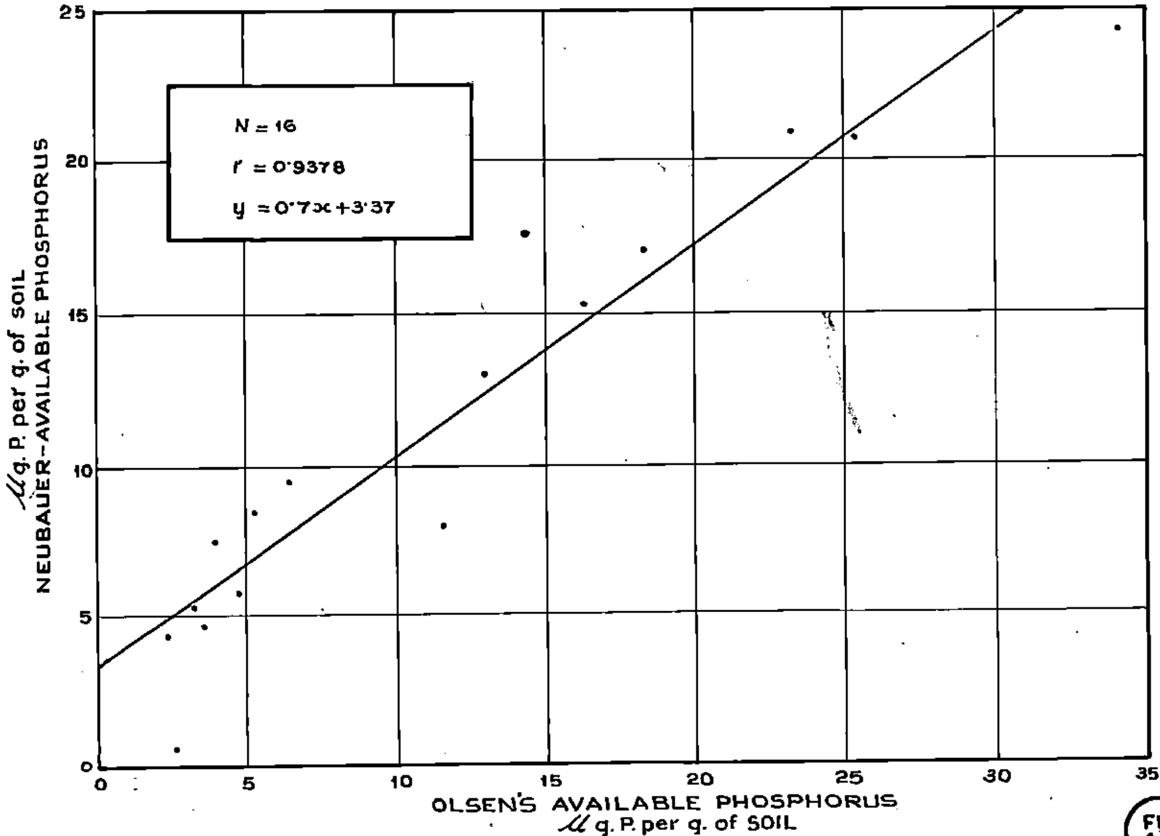

FIG. 10

SUMMARY AND CONCLUSIONS

A study was made to determine the various phosphorus fractions present in eight typical soil samples representing the major soil groups of Kerala. The chemical and mechanical composition of the soils and their relation to the various forms of phosphorus were also studied. The fractionation of soil phosphorus before and after treatment with superphosphate helped to understand the distribution and reversion pattern of applied phosphorus in these soils. 'Available' phosphorus in these soils was determined by various methods. The amounts of phosphorus removed by rice seedlings in the Neubauer method were used for evaluating these different procedures. The relationship between the various forms of soil phosphorus and the available phosphorus obtained by extraction methods was also studied.

The soils investigated varied widely in their chemical and mechanical composition. They also varied in the nature of the distribution of the various phosphorus fractions. Phosphorus was present in these soils mainly in the form of iron phosphates. The next largest fraction was that of aluminium phosphate followed by calcium phosphate and the occluded forms of phosphorus in order. None of these fractions constituted a fixed proportion of the total. The sandy soils contained the highest proportion of aluminium phosphate. The alluvial soil contained the highest amount of total and calcium phosphates. The largest proportion of organic phosphorus was found in the forest soil.

Taking the relative proportions between the various forms of phosphorus as an index of weathering these soils could be arranged in the order of increasing maturity as alluvial, sandy, forest, red and laterite soils.

The iron phosphate fraction was significantly correlated to the total sesquioxide content. There was significant linear correlation between the fine sand fraction of the soils and the contents of iron phosphate, calcium phosphate and occluded aluminium phosphate.

Phosphorus dissolved by Bray's reagents was highly correlated to the aluminium phosphate content.

Available phosphorus determined by different chemical methods was highly correlated to the phosphorus removed by the rice seedlings in the Neubauer technique.

PART II

THE ADSORPTION AND RETENTION OF AMMONIUM NITROGEN

INTRODUCTION

Artificial fertilizers are as a rule water soluble. This poses certain problems to farmers and agricultural scientists, because of the possibility of the soluble materials being lost in drainage in regions of heavy and uncertain rainfall. In Kerala, particularly, the rice fields occur at different contours and there is always a tendency for a nature of flow of water from one field to another. Hence the question is often asked what the time interval between the application of a fertilizer and the drainage of the field should be. Similarly it is necessary to know the extent of fertilizer loss when its application is followed by rains. As ammonium sulphate is used as a fertilizer for rice on a large scale in this State, it was considered desireable to carry out a study to find out how much of ammonium nitrogen is retained by different soils after definite intervals of time and how far its efficiency is influenced by different soil characteristics.

Some work on these lines have been reported by Brito-Mutunayagam and Abraham (1946). Their studies were confined to the soils of the erstwhile Travancore State and no other work on this aspect has been reported in literature thereafter.

Kerala soils exhibit extreme textural variations. It has been generally recognised that among other factors, the texture of the soil determines, to a certain extent, the amount of soluble nitrogen retained in the soil and, as such, a more comprehensive study covering the major soil groups of Kerala and representing all the textural groupings met with, was considered to be useful and hence the present study.

It is expected that the present investigation which is of both fundamental and economic importance may give sufficient indication which can be taken as a basis for the recommendation of soluble fertilizers to cultivators.

REVIEW OF LITERATURE

The modern study of the subject dates back from the work of Thompson and Way in the middle of the nineteenth century. The stimulus to their work was provided by the fear that the newly introduced soluble fertilizers might be washed out of soil in drainage.

Thompson 1850 analysed the leachates obtained by percolating water equivalent to 3" rain through short columns of sandy loam to which 0.64 g. of ammonium sulphate or ammonium carbonate had been added and found that only about one fourth of the added ammonium sulphate or one eighth of the ammonia added as ammonium carbonate had been recovered in the leachate. Chaminade <u>et</u> <u>al</u> 1936 observed that when soil was ground in a ballmill, the exchangeable ammonium increased greatly. They further noted that non-exchangeable ammonium also increased considerably by ammonium fertilization. Brito-Mutunayagam and Abraham (1946) studied the absorption power of Travancore rice soils for soluble fertilizers and found that the absorption power of different types of soil varied with variation in clay and organic matter content. They also observed that the total amount of fertilizer absorbed did not increase appreciably with time of contact and even 90 percent of absorption taken place during the first two hours of contact. Stanford and Pierre (1947) and Allison, Kefauver and Roller (1953) studied the fixation of ammonia by soil in detail. Black (1957) pointed out that lignin might also be taken part in the reaction with ammonia besides the mineral components.

Baker (1959) studied the fate of ammonia applied as anhydrous ammonia to soils and found that losses of ammonia from soils at optimum moisture content were negligible. In many soils a quarter of the retained ammonia was fixed in a form which was not extractable with 10% sodium chloride. Acid soils containing large quantities of organic matter retained large amounts of ammonia. It was concluded that ammonia retention capacity was determined primarily by the amount of exchangeable hydrogen and aluminium ions and not by the exchange capacities of the soils determined by the conventional ammonium acetate method.

Jenny, Ayers and Hosking (1945) found that adsorption of ammonia from ammonium hydroxide was largely depend upon soil texture. The fine textured soils adsorbed more nitrogen than coarse, textured soils. They found that acid soils tended to adsorb more nitrogen from ammonium hydroxide than from ammonium sulphate while the reverse was true on alkaline soils.

Abichandani and Patnaik (1958) while studying on the nitrogen changes and fertilizer losses in low land water logged soils found that under anaerobic conditions ammonification was active and nitrate decreased until only traces remained. With 80% of moisture 25% more of ammonia occured after six days than with 40% moisture.

Dobrzanski and Myszka 1948 found that the sandy soils has less sorptive capacity and base saturation was less than that of silty soils. They pointed out that neither soil should be treated with acidic mineral fertilizer but with one containing lime. Wahhab Randhawa and Alam (1956) observed that twice as much ammonia volatalised from a sandy than from a sandy loam soil. They further noted that the loss of NH_4 - N increased with increase in NH_4 - N concentration but decreased with decrease in soil pH until at pH 5.4, there was no loss. The loss of NH_4 - N increased with the increase in temperature. Abhiswarsen et al (1957) in a study on ammonia content of some Indian soils in relation to their reaction and hygroscopic moisture found that the ammonia nitrogen is increased with the moisture of the soil and it decreased with increase in soil reaction.

Schachtschabel (1961) observed that fixed NH_4 - N amounted 8-21 mg./100 g. of soil in loess soils and 15-85 mg./100 g. of soil in marsh soils; it decreased with increasing particle size and was 28.3 - 41.9 mg./100 g. of soil in the $< 2\ \mu$ fraction and 3.5-4.4 mg. in the $< 20\ \mu$ fraction of loess and marsh soils respectively. He obtained highly significant correlation between fixed ammonia and clay content and also noted that most of the ammonia was fixed by illite and by the coarser fractions of potash feldspars and micas in the soil.

MATERIALS AND METHODS

The 8 soil samples described previously, were used for this investigation. 100 g. soil was taken in a 250 ml. beaker and 100 ml. of the ammonium sulphate solution of the required strength added and mixed with a glass rod. After the expiry of the specified period, the contents in the beaker were transferred into a Buchner funnel and filtered. The ammoniacal nitrogen in the filtrate was estimated by adopting the direct method of estimation. The soil left on the Buchner funnel was leached with 100 ml. distilled water and the nitrogen in the leachate estimated as before. The treatments consisted of using ammonium sulphate solution in three different concentrations, so as to supply 5250, 10500 and 21000 µg.N/ 100 g. of soil and estimating the ammoniacal nitrogen in the leachate of soil after one day interval and in a duplicate sample after a period of one week time. The amounts of nitrogen estimated in the supernatent liquid and in the leachate after leaching with 100 ml. water were taken as amounts of nitrogen unadsorbed and leached respectively. The difference between the total nitrogen added and the unadsorbed portion estimated was taken as the actually adsorbed portion. Similarly the actually retained nitrogen was calculated by subtracting the sum of unadsorbed and leached nitrogen from total nitrogen added to the soil.

RESULTS

The data relating to the retention of nitrogen when 5250, 10500, and 21000 µg.N/100 g. of soil in the form of ammonium sulphate solution were added kept in contact for a day and leached with water are presented in table XVIII:

From the table it is seen that the various types of soils treated with 5250 µg.N/100 g. of soil retained ammonium nitrogen in the order of Chengannur alluvial soil $\rangle$ Vellayani red soil $\rangle$ Kottayam forest soil $\rangle$ Pilicode laterite soil $\rangle$ Vellayani laterite soil $\rangle$ Keerikkadu sandy soil $\rangle$ Nileshwar II red soil $\rangle$ Nileshwar III sandy soil. In the last 3 soils coarse fractions predominate, while in others, fine fractions are the major components. Soils containing high percent of clay retain more ammonium nitrogen.

When treated at concentrations of 10500 µg.N/100 g. of soil and 21000 µg.N/100 g. of soil also the soils behave very similarly. Though the quantity of ammonium nitrogen retained by the soil increases slightly with concentration, it is not proportionate. Maximum percent of retention is at the low concentration and minimum at the highest. It is worthy to note that soil containing more fine fractions can retain more than 11000 µg.N/100 g. of soil, while soil containing more coarse fraction can retain only about 500 µg.N/100 g. of soil.

At 5250 µg.N/100 g. of soil level loss in leachate is highest in Nileshwar II sandy loam and the least in Chengannur and Pilicode soils. Onattukara soils and Nileshwar III soils come next. Here also it can be noted that loss in leachate is more where coarse sand

TABLE XVIII

RETENTION OF AMMONIUM NITROGEN IN KERALA SOILS

Nitrogen applied as ammonium sulphate and leached with water

(Contact for a day)

Sl. No.	Particulars of soil	Nitrogen added	Unadsorbed Nitrogen	Sorbed Nitrogen	%	Received in the leachate	Retained in the soil	%
		(µg.N/100 g. of soil)				(µg.N/100 g.of soil)		
1.	Keerikkadu	5250	2975	2275	43.3	1050	1225	23.3
	(Alleppey)	10500	5950	4550	43.3	2800	1750	16.6
	Sandy loam	21000	12950	8050	38.8	5250	2800	13.3
2.	Vellayani	5250	1400	3850	73.3	350	3500	66.6
	(Trivandrum)	10500	2800	7700	73.3	1400	6300	60.0
	Clay	21000	6650	14350	68.3	3850	10500	50.0
3.	Vellayani	5250	2100	3150	60.0	350	2800	53.3
	(Trivandrum)	10500	5600	4900	46.6	700	4200	40.0
	Sandy clay	21000	11900	9100	43.3	4200	4900	23.3
4.	Valparai Estate	5250	1575	3675	70.0	350	3325	63.3
	(Kottayam)	10500	4200	6300	60.0	525	5775	55.0
	Sandy clay loam	21000	9800	11200	53.3	1050	10150	48.3
5.	Chengannur	5250	1400	3850	73.3	175	3675	70.0
	(Alleppey)	10500	3500	7000	66.6	525	6475	61.6
	Sandy clay loam	21000	8400	12600	60.0	875	11725	55.8
6.	Pilicode	5250	2100	3150	60.0	175	2975	56.6
	(Cannanore)	10500	4900	5600	53.3	875	4725	45.0
	Sandy clay loam	21000	11200	9800	46.7	1050	8750	41.7
7.	Nileshwar II	5250	2450	2800	53.3	1925	875	16.6
	(Cannanore)	10500	6475	4025	38.3	2975	1050	10.0
	Sandy loam	21000	14350	6650	31.6	5250	1400	6.6
8.	Nileshwar III	5250	4200	1050	20.0	700	350	6.6
	(Cannanore)	10500	9275	1225	11.6	875	350	3.3
	Sandy soil	21000	18375	2625	12.5	2100	525	2.5

fraction predominated.

At 10500 µg.N/100 g. of soil level and 21000 µg.N/100 g. of soil level also the soil behave very similarly. The loss in leachate is increased when the concentration of ammonium nitrogen in the solution increased. Thus the loss is highest at 21000 µg.N/100 g. of soil concentration.

At 5250 µg.N/100 g. of soil level adsorbed ammonium nitrogen is highest in Chengannur alluvium and Vellayani red loam and least in sandy loam of NileshwarIII. Here it is worthy to note that the soils behave very similar as in the case of retention of ammonium nitrogen.

At higher concentration also the soils behave as in 5250 µg.N/100 g. of soil level. Thus it is seen that Vellayani red loam adsorbed maximum ammonium nitrogen whereas NileshwarIII soil the minimum.

The data of unadsorbed nitrogen obtained is seen to behave similar to loss in leachate. When 5250 µg.N/100 g. of soil level ammonium nitrogen is applied, the unadsorbed ammonium nitrogen is highest in NileshwarIII soil and lowest in Vellayani red loam. At higher doses also the soils behave similarly.

It is noted from table XIX that in all cases ammonium nitrogen retained on keeping the fertilizers in contact with the soil for a week is almost the same as compared to one day contact. When 5250 µg.N/100 g. of soil level ammonium nitrogen is applied the maximum retention is in Vellayani red loam followed by Chengannur alluvium and least in NileshwarIII soil.

TABLE XIX

RETENTION OF AMMONIUM NITROGEN IN KERALA SOILS

Nitrogen applied as ammonium sulphate and leached with water

(Contact for a week)

Sl. No.	Particulars of soil	Nitrogen added	Unadsorbed Nitrogen	Sorbed Nitrogen.	%	Received in the leachate	Retained in the soil	%
		(µg.N/100 g. of soil)				(µg.N/100 g. of soil)		
1.	Keerikkadu	5250	2625	2625	50.0	1050	1575	30.0
	(Alleppey)	10500	5600	4900	46.7	2450	2450	23.3
	Sandy loam	21000	12600	8400	40.0	4550	3850	18.3
2.	Vellayani	5250	875	4375	82.9	350	4025	76.6
	(Trivandrum)	10500	2100	8400	80.0	1225	7175	68.3
	Clay	21000	6125	14875	70.8	3675	11200	53.8
3.	Vellayani	5250	1575	3675	70.0	350	3325	63.3
	(Trivandrum)	10500	5075	5425	51.7	525	4900	46.6
	Sandy clay	21000	11550	9450	45.0	4200	5250	25.0
4.	Valparai Estate	5250	1400	3850	73.3	175	3675	70.0
	(Kottayam)	10500	3500	7000	66.6	350	6650	63.3
	Sandy clay loam	21000	8400	12600	60.0	1400	11200	53.3
5.	Chengannur	5250	1400	3850	73.3	175	3685	70.7
	(Alleppey)	10500	3150	7350	70.0	350	7000	66.6
	Sandy clay loam	21000	7700	13300	63.3	525	12775	60.8
6.	Pilicode	5250	1400	3850	73.3	350	3500	66.6
	(Cannanore)	10500	4200	6300	60.0	525	5775	55.0
	Sandy clay loam	21000	10500	10500	50.0	1050	9450	45.0
7.	Nileshwar II	5250	2450	2800	53.4	1925	875	16.6
	(Cannanore)	10500	6475	4025	38.3	2800	1225	11.6
	Sandy loam	21000	14000	7000	33.3	5075	1935	9.2
8.	Nileshwar III	5250	4200	1050	20.0	700	350	6.6
	(Cannanore)	10500	9100	1400	13.3	1050	350	3.3
	Sand	21000	18200	2800	13.3	2100	700	3.3

Loss in leachate is not affected appreciably by keeping the soil in contact for a week. It behaved in the same manner as in the case of one day contact.

In most cases adsorbed ammonium nitrogen increased only slightly by one week contact. Adsorbed ammonium nitrogen also behaved very similarly as in the previous experiment being highest in Vellayani red loam and lowest in NileshwarIII soils.

DISCUSSION

From the results presented in tables XVIII and XIX, it is evident that there is considerable variations in the retention capacity of soils for nitrogen. The variation is brought about by the texture of the soil. In all the soils where the total contents of finer fractions (fine sand + silt + clay) are increased, the retention capacity in those soils are also found to be increased. The sum of the percents of fine sand, silt and clay is positively correlated with the percent of nitrogen retained. This striking relationship indicates the influence of texture on the retention capacity of soils for soluble fertilisers like ammonium sulphate.

The high percentage of finer fractions like clay and silt in a soil indicates large surface area for such soils. Since retention of ammonium nitrogen is an adsorption reaction which is a surface phenomenon those soils which contain a greater percentage of finer fractions will naturally be able to retain more nitrogen and the results of the present investigation go to confirm this contention.

Chaminade (1936) has reported that retention of ammonia is increased by powdering the soil. Jenny Ayres and Hosking (1945) have observed that adsorption of ammonia is largely dependent on soil texture and fine textured soils adsorb more ammonia. These observations are in corroboration with the findings of the present investigation.

The results presented also show that when the content of finer fractions in the soil is 50% and above it exhibits a good degree of sorption of added soluble fertilizers like ammonium sulphate. This is suggestive of one important fact that better retention of added nitrogen in soils, poor in finer fractions (clay and silt) like the sandy soils of Keerikkadu and Nileshwar, can be brought about by adding tank silt or clay or organic matter.

Within 24 hours of contact it is seen that major percentage of nitrogen applied gets sorbed by the soil, and subsequent contact of one week has no appreciable effect in increasing the sorption of added soluble fertilisers like ammonium sulphate. Brito-Mutunayagam et al (1946) have reported that the amount of fertilisers sorbed by the soil does not increase appreciably with time of contact. The present study is in agreement with their observation.

The results of leaching the soil treated with ammonium sulphate show that subsequent washings does not bring about any serious loss of sorbed nitrogen except in the case of soils where the coarse fractions predominate. The leaching loss is more when the dose of soluble fertilisers added to the soil is increased and this is more so in the case of sandy soils. Wahhab et al (1956) have reported that the loss of ammonium nitrogen is increased with increase in ammonium nitrogen. In the present investigation, it is seen that when the soil is treated @ 5250 µg.N/100 g. of soil and leached after contact of one day, 46% of the sorbed nitrogen is lost and this percentage increased to 61.5 and 65.2 when the dose of nitrogen added is increased to 10500, 21000 µg.N/100 g. of soil. This again shows that in sandy soils application of nitrogen in high doses is uneconomical and wasteful and results in the loss of valuable nutrients. The present study indicates that in such areas application of fertilizers in splitswill prove more efficient and advantageous.

SUMMARY AND CONCLUSIONS

A study was undertaken with the object of finding out the retention of ammonium nitrogen in different soils of Kerala when applied in the form of ammonium sulphate and leached after one day or one week contact.

Eight soils differing in texture were taken and treated with ammonium sulphate solution of three different concentrations, viz., 5250, 10500 and 21000 µg.N/100 g. of soil under the laboratory conditions. The unadsorbed nitrogen was found out by estimating nitrogen in the supernatent liquid. The ammonium nitrogen retained by the soil was estimated after leaching the soil with known volume of water. The statistical evaluation of the relation between the textural separates and the ammonium nitrogen retained was also made. The following conclusions were drawn:

i) The retention of ammonium nitrogen by the soil is directly related to the content of fine fractions (fine sand, silt and clay) in soils. The loss in leachate is increased when coarse sand fraction increased.

ii) The major percentage of applied ammonium nitrogen gets adsorbed with one day contact. Increasing the time of contact for a week has no appreciable effect on the adsorption of ammonium nitrogen.

iii) Loss of ammonium nitrogen by leaching increased when increased dose of fertiliser applied.

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[+] Originals not seen.

CORRELATION BETWEEN COARSE SAND & UNADSORBED NITROGEN

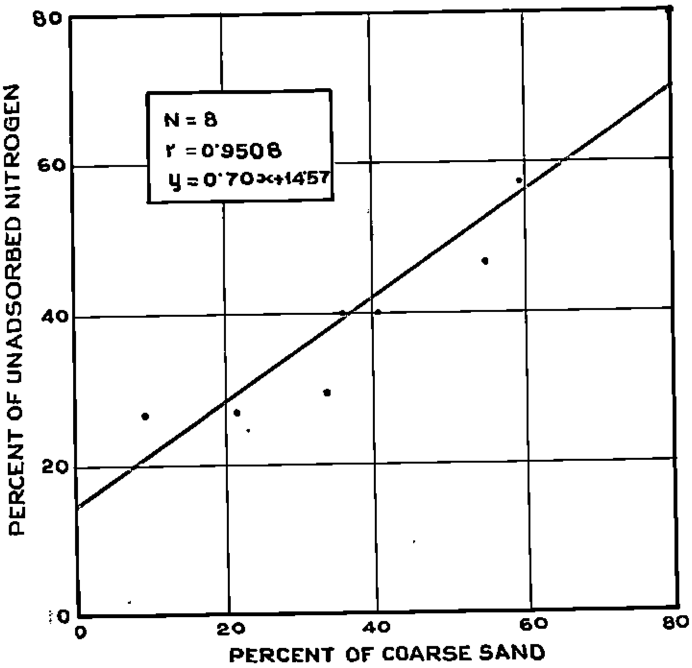

FIG. 11

CORRELATION BETWEEN SUM OF FINE SAND, SILT AND CLAY & NITROGEN

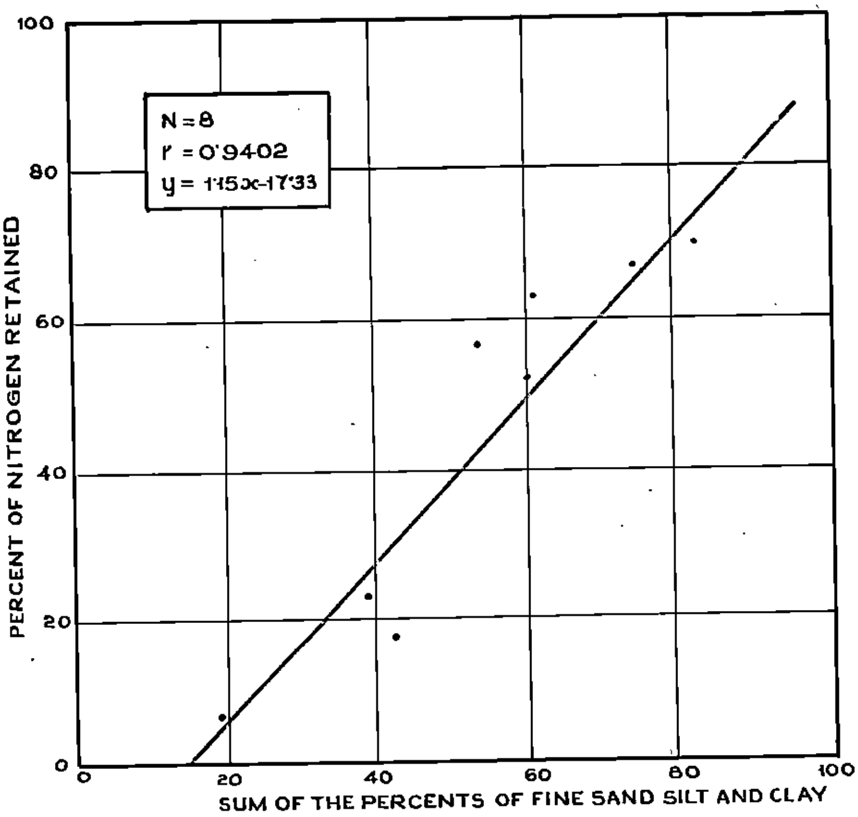

FIG. 12

PLATE I
RICE SEEDLINGS GROWN FOR THE EVALUATION
OF AVAILABLE PHOSPHORUS
"NEUBAUER TECHNIQUE"

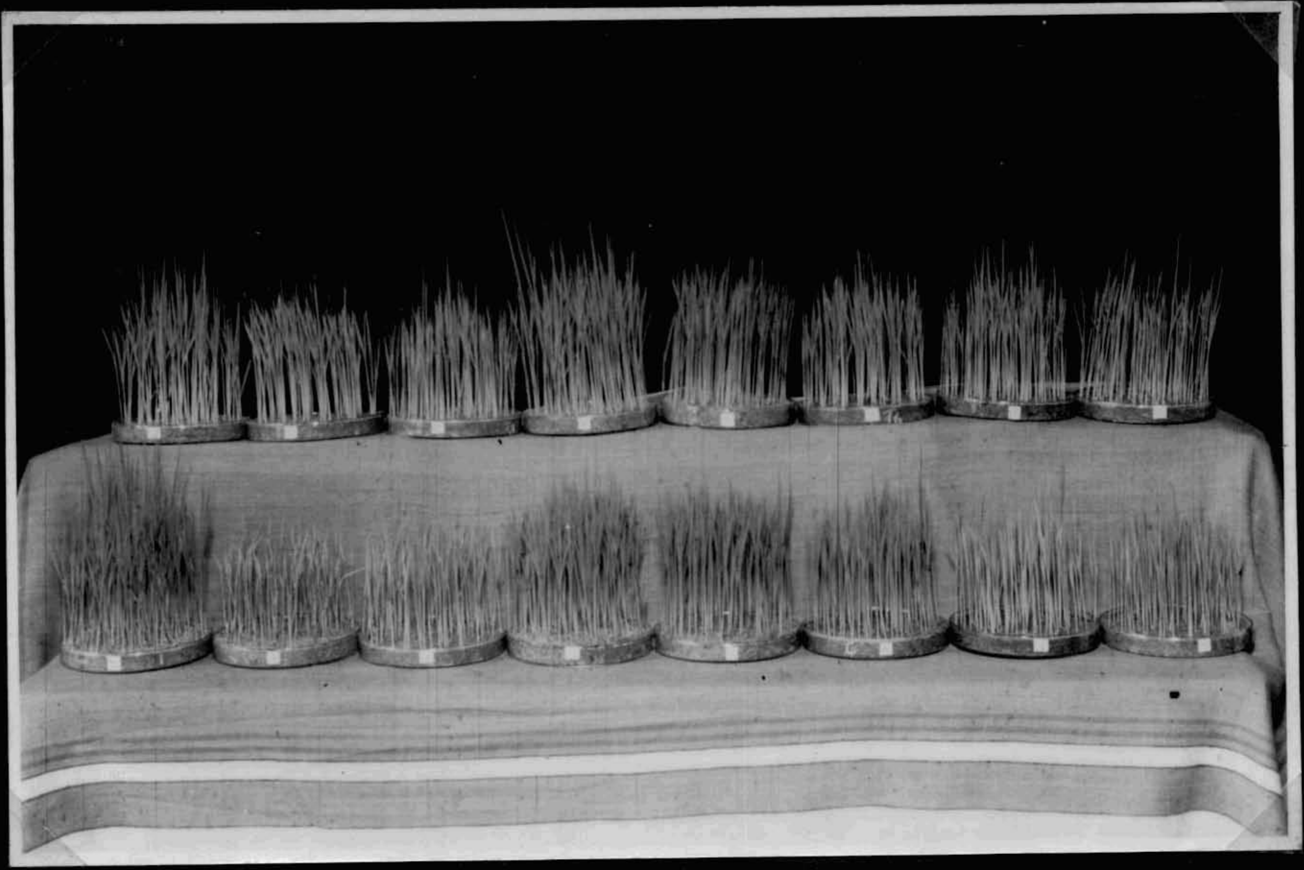

PLATE I
RICE SEEDLINGS GROWN FOR THE EVALUATION
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