EVALUATION OF AVAILABLE PHOSPHATE RESERVE OF SOIL BY CHEMICAL METHODS

BY

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THESIS
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DECLARATION

I hereby declare that this thesis entitled "Evaluation of available phosphate reserve of soil by chemical methods" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellanikkara,
22 September, 1979.

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CERTIFICATE

Certified that this thesis is a record of research work done by Shri. Mathew Jacob K., under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

INTRODUCTION

Phosphorus is considered to be the most critical and important element among the major plant nutrients, next to nitrogen. Apart from the vital role played by phosphorus in most of the metabolic functions of the plant, the profound influence on the proper and efficient utilisation of other nutrients confers on phosphorus a pivotal position and special status in the chemistry of plant nutrients.

Much emphasis on the chemistry of phosphorus in soils arises from the variety and complexity of soil reaction associated with its transformations in soils. Estimation of that fraction of soil phosphorus which can be considered available to plant has been a matter of controversy even after the accumulation of voluminous literature on this subject. This is due to the fact that phosphorus availability to plants depends upon the conditions under which the plant is grown. This cannot be precisely reproduced in another occasion. Even the most sophisticated isotopic dilution techniques fail to measure accurately the total amount of available phosphate reserve of the soil. This is because the amount of soil phosphorus that can be taken up by a plant or that comes into equilibrium with the applied phosphorus is a function of soil properties and the power of the test crop to take up soil phosphorus, which considerably vary depending upon the population density or the root pressure on the soil, the duration of the crop, continuity of cropping etc. In otherwords, the term available phosphorus refers to that fraction of phosphorus available to a crop under specified soil and plant conditions. Obviously, it is rather difficult to make an estimate of available phosphorus each time by growing plants and studying the uptake. Therefore laboratory indices of phosphate availability are made use of in evaluating tho phosphorus status of the soil for the purpose of advisory works. The most popular indices are chemical extractants, the Bray No.I extractant being the one employed in the soil testing laboratories in the State. These extractants are employed on the assumption that phosphorus extracted by them are correlated with the phosphorus uptake of a test crop grown in the soil. Very often the phosphorus determined by these extractants, though correlated with phosphorus uptake by plants, is not useful in assessing the need of phosphorus application or the possibility of skipping phosphorus application to a crop grown in the soil. This is because these methods are selected simply based on the correlation between phosphorus extracted by them and uptake of phosphorus by the test crop. Then again the phosphorus uptake of a test crop does not necessarily reflect the total available phosphate reserve of the soil and as a result the correlations established is of no use in assessing the phosphate supplying power of the soil on a long term basis. Pisharody et al.(1977) observed that, in the soils of Rice Research Station, Pattambi, phosphate application to rice has no response in terms of yield, but when the application of phosphate was skipped for a few seasons plants did respond to the application of phosphorus. They also observed that phosphorus estimated by Bray No.1 extractant could not give any indication on the possibility of skipping of phosphorus application in the soil. The situation therefore warrants evolving a method of estimation of soil phosphorus which will be correlated with the total available phosphate reserve of the soil rather than the uptake of phosphorus in the test crop immediately grown. For this purpose plants should be grown in the soil continuously till a stage is reached that the soil can supply no more phosphorus to meet the minimum requirement of the crop as reflected by the deficiency level of phosphorus in the plants. The total amount of phosphorus removed from the soil by the plants continuously grown till this stage will then be the total available phosphate reserve of the soil. It is with this value of available phosphate reserve, correlations to be established with the amount of phosphorus extracted by the chemical methods.

Among the different types of chemical extractants, mineral acids in chelated system can be preferred to other extractants, since the acid conditions under which the extraction takes place can be considered some what comparable to that of the field condition under which phosphorus is taken up by plants from the acid laterite soils of the State.

Once a suitable extractant is found out in estimating the available phosphate reserve of the soil, it will be then possible to predict the extent of skipping of phosphorus application possible in the soil, making use of the regression equation established between the amount of phosphorus extracted and the available phosphate reserve of the soil.

The present study was therefore undertaken with the following objectives in view:

1. To evolve a suitable chemical extractant for the estimation of available phosphate reserve of the soil; and
2. To examine the possibility of skipping of phosphorus application in soil making use of the relationship established between phosphorus extracted by the extractants newly evolved and the available phosphate reserve of the soil.

The results of this investigation are presented and described in the following pages.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

1. Estimation of available P in soil by chemical methods

A large number of chemical techniques for measuring the so-called available soil phosphorus have been suggested during the last century and innumerable review articles have been published by so many workers. Some of them are Anderson (1960), Hanna and Flannery (1960), Hester (1960), Kramprath and Fitts (1960), Nelson *et al.*(1960), Schrader (1960), Wolf (1960), Hesse (1971), Bingham (1975) and Chopra and Kanwar (1976).

Eventhough several methods have been evaluated extensively, the problem of selecting an appropriate method is not always solved easily. For example, the National Soil and Fertiliser Research Committee on soil testing (1956) compared a number of chemical soil tests, using soils of known phosphate requirement. In all, 74 widely varying soils were involved, the committee noted that the chemical tests agreed better with green-house tests than with field trials. They also found that weak extractants such as water and carbonic acid were more suitable for alkaline soils than for acid soils. The strong acid extractants were found to be more satisfactory for testing acid soils (Bingham, 1975).

Out of a large number of laboratory indices of absorption of soil phosphorus by plants, the chemical technique has received much attention, which is the extraction of phosphorus with one or more solution. The principle involved is that the extractant is capable of dissolving that fraction of soil phosphorus which is considered available to plants. The extractants recommended cover the whole gamut between concentrated acid and concentrated alkali.

1.1 Chemical extractants used so far

Various extractants and concepts have been used to assess the phosphorus supplying power of soils. The displaced soil solution was first used as an index of phosphorus availability by Pierre and Parker (1926). They found a poor correlation between concentration of soil-solution phosphorus and plant response to phosphorus fertilisation. In fact in none of the early experiments soil-solution phosphorus was successfully correlated with plant growth (Adams, 1974).

Water has been proposed as an extractant for available soil phosphorus. Blenkinsop (1938), Burd and Murphy (1939), Burd (1948), Bingham (1949), Hashed et al. (1957), Thompson et al. (1960), Van Diest (1963), Paauw and Sissingh (1968), Paauw (1971), Sissingh (1971) and Gibson (1976) used water for extracting, on the assumption that the quantity of phosphorus soluble in an equilibrium water extract of soils is indicative of available phosphorus. Martin and Buchanan (1950) evaluated this method and found that the method works equally well on acid and alkaline soils. Martin and Mikkelsen (1960) observed that the water soluble and bicarbonate soluble phosphorus values in California soils agreed well with plant response.

Carbon dioxide saturated water was used as an extractant by Puri and Asghar in 1936. Mc George (1939), Stanberry (1949) and Sen Gupta and Cornfield (1963) found that the phosphorus extracted by carbonic acid was well correlated with plant response. At wider soil : solution ratios, distilled water was as efficient as carbonic acid (Forsee, 1945). Abbott (1978) proposed carbonic acid as an extractant for organic phosphorus in calcareous soil.

Dyer (1894) used 1 per cent citric acid solution as an extractant for the estimation of available phosphorus. Dyer's method has been adopted with slight modifications by a large number of workers (Jones, 1949; Paauw, 1956; Thompson et al. 1960; Balasubramanian, 1966; Ahmed et al. 1967; Reddy 1967; Misra and Ojha, 1969; John, 1970 and Weaver, 1974).

Mineral acids like hydrochloric acid, nitric acid and sulphuric acid have also used. Baver and Bruner (1939) reported that 0.314 N hydrochloric acid is a better extractant for soil available phosphorus. Olsen (1946) suggested 0.7 N hydrochloric acid as an extractant. Fraps (1909) used 0.2 N nitric acid and Von Sigmond (1929) used 0.01 N nitric acid. Truog (1930) extracted soil with 0.002 N sulphuric acid buffered to pH 3 with ammonium sulphate for 30 minutes using a soil solution ratio of 1 : 200. Peech et al. (1947) modified Truog's method by employing a 1 : 100 soil : solution ratio. Kerr and Von stieghts (1938), Beater (1949) and Bandroff (1952) used sulphuric acid at the strengths of 0.01 N, 0.05 N and 0.20 N respectively. Fitts (1956) reported a close correlation between phosphorus extracted with 0.05 N hydrochloric acid in 0.025 N sulphuric acid and phosphorus estimated by 'A' value technique. Pritchett (1976) concluded that the above extractant was the best for predicting responses over a period of 5 to 10 years or more.

Another important type of extractant used is a weak acid buffered salt solution. Morgan (1937) and Hester *et al.* (1937) used acetic acid in sodium acetate solution; Egner (1941) used 0.02 N calcium lactate in 0.01 N hydrochloric acid (pH 3.5) and Egner *et al.* (1960) used 0.1 M ammonium lactate in 0.4 M acetic acid. Suetov (1968) employed 0.5 N acetic acid (Chirkov's method) to extract available phosphorus from soil. Acetic acid of varying strength has been recommended by Brown (1940), Ghani (1943) and Peech and English (1944). Williams (1950) used 2.5 per cent acetic acid containing 8-hydroxyquinoline to prevent readsorption of phosphorus by iron and aluminium. Sik (1964) described a method of extracting phosphorus from soil using a solution of boric acid and borax buffered to pH 7.6. Schuller (1969) suggested 0.1 M calcium lactate and 0.1 M calcium acetate in 0.3 M acetic acid. Gachon (1966) extracted the soil with oxalic acid. Berlan and Berdeiasu (1968) used a solution of 0.07 N EDTA and 0.005 N oxalic acid as the extractant for the estimation of available phosphorus.

The chelating action of EDTA has been used to extract soil phosphorus by Kanwar (1953), Viro (1955a, 1955b), Wallance *et al.* (1955), Alexander and Robertson (1972), Nnadi (1975) and Sahrawat (1977).

Salt solutions were also employed as an extractant for available phosphorus. They are 0.2 M ammonium oxalate (Joret and Herbert, 1955; Owens, 1977), calcium chloride (Aslyng, 1954; Aslyng, 1964; Gachon, 1966; Baker and Hall, 1967; Wainwright and Sowden, 1977), normal potassium chloride (Puri and Swarnakar, 1969), 0.5 per cent potassium sulphate and 0.5 per cent ammonium molybdate (Ginsburg and Astamonova, 1966), ammonium acetate (Breland and Nesmith, 1968; Quddus, 1968; Ogot, 1970), sodium acetate (Breland and Nesmith, 1968), and dilute stannous chloride solution (Wendt and Corney, 1974).

Rapidly soluble and adsorbed phosphorus has been extracted with fluoride containing solutions. Bray and Kurtz (1945) while attempting to extract available phosphorus from different soils by different methods removed acid soluble phosphorus with 0.1 M hydrochloric acid, adsorbed phosphorus with 0.5 M ammonium fluoride and acid soluble plus adsorbed phosphorus by first shaking with dilute acid and then shaking again after adding solid ammonium fluoride. Dupuis (1950) modified the Bray and Kurtz procedure by shaking 1 g soil with 8 ml of 0.03 N ammonium fluoride solution in 0.025 N hydrochloric acid and the method was modified further by Smith *et al.* (1957) by using a 1 : 50 soil : solution ratio. The three Bray and Kurtz reagents now in use are 0.03 N ammonium fluoride in 0.025 N hydrochloric acid (Bray No.1), 0.03 N ammonium fluoride in 0.1 N hydrochloric acid (Bray No.2) and 0.5 N ammonium fluoride in 0.1 N hydrochloric acid (Bray No.4). Ammonium fluoride has been used as a selective extractant by Uriyo and Kesseba (1972). Agboola and Corey (1975) used Bray No.1 solution as an extractant and got good correlation with yield of maize and the soil test values. Miller and Alexy (1956), Robertson (1962) and Kaser *et al.* (1967) estimated available phosphorus using sulphuric acid and ammonium fluoride. Datta and Kamath (1959) extracted soil with a solution of 0.03 N ammonium fluoride containing 1.0 per cent EDTA.

Alkaline extractants were also tried for extracting available phosphorus from soil. Das (1930) suggested 1.0 per cent potassium carbonate (pH 8.5). Sodium bicarbonate as an extractant was used by Webber and Mattingly (1970), Walmsley and Cornforth (1973), Matar and Samman (1975), Barrow and Shaw (1976a, 1976b) and Bowman and Cole (1978).

Other extractants recommended are ammonium bicarbonate (Dirks and Scheffer, 1928), 0.5 N sodium hydroxide (Jones, 1949), hot 0.1 N sodium hydroxide (Saunder, 1956), and calcium bicarbonate (Warren and Cooke, 1962). Al-Abbas and Barber (1964) suggested extraction with 17 ml of 0.3 ml of 0.3 N sodium hydroxide and 3 ml of 0.5 N sodium oxalate using a soil : solution ratio of 1 : 20. Ammonium carbonate at 1.0 per cent concentration was used as an extractant by Bobrus and Kim (1969) and Radov and Filippova (1970).

2. Evaluation of the methods

The performance of different extracting solutions in estimating available phosphorus has often been compared.

Their relative efficiency was judged by the degree of correlation obtained with phosphorus uptake by plants in either green-house or field trials. The literature on this subject has been reviewed by Brind (1950a, 1950b) and Nelson _et al_. (1953). The popularity of this approach is due to the fact that comparison of soil test values with analyses of plant grown on the soil offers a simple and rapid method of evaluating the soil tests under a wide variety of conditions especially where data on response to fertiliser are limiting or lacking (Pack and Gomes, 1956).

Semb _et al_. (1965) found that in soils of pH less than 6.3 the correlations between "L- value" and phosphorus extracted by different extractants were in the decreasing order of 0.01 N calcium lactate in 0.1 N hydrochloric acid, 0.1 M ammonium lactate in 0.4 M acetic acid, Bray No.1 reagent and Olsen's extractant. Samonte and Mamaril (1966) reported that available phosphorus extracted by Bray No.2 gave the highest correlation with rice yield and seemed best suited for phosphorus analysis in paddy soils.

Layese and Tilo (1970) compared Bray, Olsen and Ayres-Hagihara methods of phosphorus determination and evaluated against rice response to phosphorus addition in 14 widely different soils. They found that Olsen method has a wider range of applicability to low land rice soils and it was not affected by soil pH or clay content.

Oke (1970) extracted 15 soils with 17 different acid, base and salt solutions and determined phosphorus in the extract as an index of its availability. He found that 0.01 N sulphuric acid was the best extractant and gave significant correlations with the soluble phosphorus content of maize leaves.

Catani and Nakamura (1971) extracted several soil samples with 4 solutions in conjunction with 3 soil solution ratios as 5 : 100, 10 : 100 and 20 : 100 keeping constant the length of extraction period for 15 minutes. They found that soil : solution ratio had a marked influence on the phosphorus extraction and a decrease of 50 per cent or more in the amount of P extracted was noted when the ratio was varied from 5 : 100 to 20 : 100. In soils of pH 5.7 or less and sesquioxides less than 17 per cent, 0.05 N sulphuric acid in 0.025 N ammonium fluoride solution extracted more phosphorus than 0.05 N sulphuric acid in 0.025 N ammonium fluoride solution extracted more phosphorus than 0.05 N sulphuric acid and 0.05 N hydrochloric acid in 0.025 N sulphuric acid.

Walmsley and Cornforth (1973) tried and compared 9 methods of measuring available soil phosphorus using dry matter yield response and phosphorus uptake data from maize grown in 155 West Indian soils in a green-house experiment. Olsen's (0.5 N $NaHCO_3$) method gave the best estimate of available phosphorus and was also least sensitive to changes in soil properties like texture, pH, C.E.C., percentage base saturation. Amer's resin method was also as good except that it was unsuccessful with soil of low base saturation.

Kanapathy *et al.* (1973) with 7 soils having 3 levels of phosphate tried to correlate plant uptake of phosphates with soil analysis. Three crops of *Eleusine* were grown and before the second and third crops the soils were analysed for phosphate by 12 different methods. Almost all methods showed good correlation but Bray and Kurtz No.2 extractant and Olsen's method appeared to be the best.

Marguelash Vili and Chitishvili (1974) compared various methods for determining available phosphorus in cinnamon forest soil. Available phosphorus content of 100 samples of field soil to which various amounts of superphosphate had been applied was determined by extraction with 1 per cent ammonium carbonate (Bobrus & Kim), 0.5 N sodium bicarbonate (Olsen), calcium carbonate, magnesium carbonate & sulphuric acid in 0.0003 N ammonium fluoride (Bray and Kurtz as modified by Miller and Axel) or 1.0 per cent ammonium sulphate in 0.25 per cent ammonium molybdate (Ginzburg and Artamonova). The coefficient of correlation between the rate of application of superphosphate and the increase in the content of available phosphorus in the soil was 0.98 for the third method and 0.95 for the fifth.

Titterington and Varsa (1974) compared phosphorus extraction methods using 5 soil series of Rio Grande do sul, Brasil in a green-house experiment in which grain sorghum was grown. Two levels of lime and four levels of phosphorus were given. The phospherus was then extracted using N. Carolina (0.05 N HCl in 0.025 N H_2SO_4) 1 : 10 and 1 : 20 for 16 h, modified Bray No.2 (0.1 N HCl in 0.1 N NH_4F) 1 : 10 for 1 minute, modified Bray No.1

(0.05 N HCl in 0.05 N NH_4F) 1 : 30 for 16 h. The result showed that lime had little influence on the amount of phosphorus extracted by each method. Bray methods removed significantly greater phosphorus, but less highly correlated with phosphorus uptake. Yield was highly correlated with these solutions in the decreasing order Bray No.2, modified Bray No.1, N. Carolina 1 : 20 and N. Carolina 1 : 10.

Ballard and Pritchett (1975) evaluated soil testing methods for predicting growth and response of <u>Pinus elliotti</u> to phosphorus fertilization using acid coastal plain soils. The amounts of phosphorus extracted by water and NH_4OAC (pH 4.8) were the most closely correlated with height, growth and response to phosphorus fertilization after one year of growth in field as well as green-house trials. The effectiveness of these methods declined after longer growth periods. Methods which extracted larger amounts of phosphorus were 0.5 M sodium bicarbonate, 0.05 N hydrochloric acid in 0.025 N sulphuric acid; 0.03 N ammonium fluoride in 0.025 N hydrochloric acid and were more effective predictors of response to phosphorus fertilization over growth periods of 3 and 5 years in the field. Phosphorus extracted by Bray No.1 extractant was the most closely correlated with response recorded after 5 years. Stronger extractants were suited to green-house grown plants.

Ekpete (1976) extracted phosphorus from water-logged and air-dried samples obtained from unfertilised traditional swamp rice soils using Bray No.1, Bray No.2, Truog, EDTA and Olsen method. The data was correlated with percentage dry matter yield, phosphorus uptake from unfertilised soil and available phosphorus obtained for rice ctops grown under water-logged conditions in the green-house. It was found that all methods extracted more phosphorus from water-logged soils than air-dried soils. Olsen was found as the best and correlated very highly with yield response of rice grown under water-logged conditions.

Rudd and French (1976) compared 9 methods of measuring available soil phosphorus in soils of South Australia, many of which contained large amounts of free lime. For all soils 0.5 M Na HCO_3 extractant was found to be the best, hydrochloric acid in ammonium fluoride was good for non-calcareous soils.

Abdel aal *et al.* (1977) tested 14 alkaline soil samples of the Arab Republic of Egypt. The results obtained with the different extraction methods were compared with the uptake of alfalfa plants *Medicago sativa* and the best extractant they obtained was anion exchange resin and the next best was the water extractant.

Enwezor (1977) compared 7 chemical extractants for determining available soil phosphorus. Sodium hydroxide at 0.1 N concentration extracted larger amounts of phosphorus but was the least precise in predicting yields. Extraction with dilute acids and an anion exchange resin gave lowest values for available phosphorus but resin extraction was superior to dilute acids in predicting the yield. Olsen and Bray No.1 solutions were equally precise in predicting percentage of yields. Phosphorus extracted with 0.03 N ammonium fluoride in 0.1 N hydrochloric acid gave the highest correlation with percentage yield.

Kadeba and Boyle (1978) evaluated 6 extraction methods for available phosphorus. Extractants like 0.002 N sulphuric acid (pH3), 0.025 N hydrochloric acid in ammonium fluoride, 0.5 N sodium bicarbonate (pH 8.5), in ammonium acetate (pH 4.8), anion exchange resin and water were tried with soils from a plantation of red pine. Uptake of phosphorus by corn and Monterey pine seedlings grown in green-house culture was correlated with soil phosphorus extracted by the different methods. The most successful of the extractants for predicting phosphorus uptake was resin extractable phosphorus. Phosphorus uptake by pine correlated significantly with 0.002 N $H_2 SO_4$-P, N NH_4 OAC-P, H_2O -P and Al-P and Fe-P, while phosphorus uptake by corn correlated with 0.002 N $H_2 SO_4$-P and H_2O-P and organic-P. Percentage phosphorus in pine seedlings tops correlated significantly with 0.002 N sulphuric acid, resin and N NH_4OAC extractable P.

Maida (1978) found that the amounts of soil phosphorus extracted by the methods of Olsen, Bray, Williams and Stewart, Morgan, Aslyng, anion exchange resin, Saunder, Dyer and North Carolina were significantly interrelated. A high proportion of the inorganic phosphorus was accounted for by Fe bound and reductant soluble phosphorus fractions. The extraction of Al-P by the chemical soil tests was in the decreasing order of Dyer > North Carolina > 0.1 M NaOH extractable > 0.5 M CH_3COOH > Olsen > Bray > anion exchange resin.

Fe-P was the second most important variable contributing to the total variation in 0.1 M sodium hydroxide extractable-P, Olsen-P, North Carolina-P, resin extractable-P and Dyer-P values.

Thus, though extensive work has been done in selecting the best extractant atleast for a type of soil, though not for all soils, the results obtained by various workers are quite contradictory. Some of the workers in this field are Sherrell (1970), Alban (1972), Habibi et al. (1974) in calcareous forest soil, Amhed and Islam (1975) in humid tropical soils, Hernando and Diez (1975) in spanish soil from different climatic areas.

3. Soil phosphate reserve in soils

Demolon (1968) stated that from an agronomic stand point, each field presents a phosphate level of its own related to its cropping history much more than to its inherent soil type. This built up and varying phosphorus status result from the repeated application of phosphates over a sufficiently long period, at rates exceeding both removals by the crops and other losses of different kinds.

Devine and Holmes (1964) found that soils with high phosphorus levels gave higher yields than soils with low levels even after heavy fertiliser application. Tisdale and Nelson (1967) found that to produce top yields by row application of phosphorus fertiliser is difficult on soils low in phosphorus but there is some advantage in buildingup soil fertility in a long term fertilizer programme.

Russel (1960), Young et al. (1960), Djokoto and Stephens (1961) and Kanwar and Prihar (1962) reported that continuous application of phosphatic fertiliser resulted in the built up of soil phosphorus. Cooke (1967) by analysing the results of long term experiment in Agdell and at Cockle Park found the built up of phosphate reserves in soil. Gachon (1976) reported that due to regular nitrient application, PO_4 ions are fixed in soil by strong bonds which ultimately makes a very large nutrient pool to bring sufficient PO_4 ions in contact with roots. Werner and Wiechmann (1972) and Barbarina (1978) also reported the built up of phosphate reserves in soil.

In 1976, Gladko va using ^{32}P determined available as well as soluble reserve phosphorus in USSR soils. The result showed that 22.6 per cent fertiliser phosphorus had been accumulated in soils in available forms. The correlation and regression coefficients for the relationships between the pool of available phosphorus and the pool of labile phosphorus of soils have been calculated. The data indicated a high degree of agreement with the solubility of soil phosphorus.

Result of a long term field experiment proved that the more positive the phosphorus balance of a soil, the more its phosphorus supplying power and less fresh phosphorus addition is needed to reach a maximum crop yield (Sarkadi *et al.*, 1976).

G"Rbushev (1977) reported that the built up of optimum phosphate levels is an efficient method of regulating the phosphorus supply to the plants and of increasing the coefficient of phosphorus utilisation.

Hbbott and Tucker (1973) studied the persistence of manure phosphorus availability in calcareous soil. Research workers who studied residual phosphorus and use of chemical and biological methods to evaluate phosphorus availability include

Gisken *et al.* (1972), Johnston *et al.* (1975), Sadler and Stewart (1975), Bailey *et al.* (1977), Read *et al.* (1977) and Sparrow and Russel (1977). In all the above mentioned studies, successive cropping was not used to desorb the total plant available phosphorus from the soil.

Brams (1973) studied residual phosphorus using continuous cropping for 3 years in tropical West Africa. Read *et al.* (1973) did an excellent job of studying the residual value of phosphatic fertiliser on chernozemic soils in Manitoba and Saskatchewan, Canada. Five to 19 crops were removed with addition of 100-400 kg P/ha. In all instances the soil available phosphorus (Olsen-P) decreased to approximately 10 ppm. Total plant phosphorus uptake, however, was not assessed.

Interaction between phosphorus fertiliser residues and fresh phosphorus dressings in chernozem soil was studied by Sarkadi and Kadar (1974). The more phosphorus residues that were present in the soil, the less was the marginal efficiency of new phosphorus dressings.

Sadler and Stewart (1975) studied the changes with time in form and availability of residual fertiliser phosphorus in a catenary sequence of chernozemic soils. Results indicated that an appreciable portion of residual fertiliser phosphorus in chernozemic soils may persist for years in readily available forms. Soil pH strongly influenced residual phosphorus form and availability. In a long term experiment at Rothamsted and Woburn Johnston (1976) reported the accumulation of unused residue of added phosphorus in the soil. Similar results were reported by Watanabe and Olsen (1974) and Bowman _et al_. (1978).

Olsen and Flowerday (1971) in a review article emphasised that intensity is the main factor controlling uptake of phosphorus by plants but that capacity and diffusion are determining factors as well.

Most experiments on the use of extraction methods in plant phosphorus uptake studies have been concerned mostly with predictive correlations between those methods and plant yield or phosphorus desorbed by one particular crop. Thus, Gupta and Singh (1975) got positive correlation with low land rice paddies, Sarangamath _et al_. (1975) got significant positive correlation with grain yield and phosphorus uptake in lateritic, red and black soils in which rice was grown and Rastogi et al. (1976) got positive correlation with sorghum grain yield in field phosphorus fertility studies with great success using Olsen extraction method. On the other hand Butegwa et al. (1975) found that Bray extraction method was well correlated with plant yield and extracted more phosphorus than ammonium lactate/acetic acid solution with a pH of 3.75 and hot 0.1 N sodium hydroxide solution with a pH of 12.18 in some East African soils.

Duangpatra and Koamtong (1973) found that straw yield, phosphorus content of straw and total phosphorus uptake in straw showed highly significant correlation with the available phosphorus content of the soil as determined by Bray No.1 and Olsen methods.

Levels of soil phosphorus in 24 Hong Kong soils were determined using 7 different methods. The levels of phosphorus extracted were significantly correlated with total uptake by 4 successive crops. Soil phosphorus levels determined by Truog's, Mehlich's and an anion exchange resin technique were substantially correlated with dm yields, the degree of relationship increasing as the numbers of crops taken into account were increased. Relationships were poor in respect of modified Bray No.1 and 2, Olsen's and the total phosphorus methods (Stephen and Lin, 1974).

Khan and Zende (1976) reported that available phosphorus as estimated with Olsen extractant in the medium black soil and Bray P extractant in the lateritic soil was highly correlated with dm yield and the content and uptake of phosphorus in maize as well as dry matter yield in the subsequent sorghum.

Dalal and Hallsworth (1976) evaluated the parameter of soil phosphorus availability in predicting yield response and phosphorus uptake. They found that carbonate (soil phosphorus extracted for 16 h with 0.25 M NaOH in 0.1 M $Na_2 CO_3$ at a soil : solution ratio of 1 : 100) was found to be the best parameter of the quantity factor when the soils containing high amounts of haematite-goethite ($>$20%) were excluded. The parameters of the intensity factor (0.01 M $CaCl_2$ soluble phosphorus, aH_2PO_4 and phosphate potential) were significantly correlated with phosphorus uptake at early growth (35 days) whereas the parameters of the capacity factors were better correlated with phosphorus uptake at the later stage (150 days). In acid organic soils dilute acid (0.05 N HCl in 0.025 N $H_2 SO_4$) extractable phosphorus was the best indicator of potential phosphorus supply (Daughtrey et al., 1973).

Lin et al. (1977) studied grain yield and phosphorus uptake of rice as related to the phosphorus fraction in the soils of central Taiwan. They found that, correlations between soil phosphorus contents and uptake of phosphorus by rice, (Fe-P was the main source of phosphorus adsorbed by the plant) the factors like Ca-P, soil organic P content, soil pH, soil clay and organic matter content were negatively correlated with uptake.

Fixen and Carson (1977) studied relationship between soil test and small grain response to phosphorus fertilisation in South Dakota field experiments. Yield data from 74 small grain field experiments over 13 year period were used to evaluate the relationship between various soil tests and phosphorus response. The highest correlation between soil test value and yield response to phosphorus fertilization was found with the Bray No.1, 1 : 50 soil water ratio.

Novais and Kamprath (1978) showed that extractable phosphorus values obtained with the North Carolina, Bray No.1 and Olsen extractants, after each crop was plotted as functions of accumulative amounts of phosphorus removed by cropping, were linear and correlation coefficients were all significant at 5 per cent level.

MATERIALS AND METHODS

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1. Collection of soil samples

A large number of soil samples from various paddy fields in the midland of Kerala which are lateritic in nature, were collected. The main idea was to get soil samples differing widely in phosphorus status, and properties associated with P fixation and availability.

Samples were collected to a depth of six inches from the surface of the soil making a 'V' shaped cut, with one side perpendicular to the surface, and scraped out soil from the perpendicular side with the help of a spade. Eight to ten kg of well mixed soil was collected out of 20 to 25 pits from a plot representing a soil type.

The samples were dried in shade, powdered the large aggregates using a mortar and pestle, and sieved through a 2 mm sieve. Approximately six kg of the sieved sample was kept for the pot culture experiment. One kg of the sample was further processed to pass through a 1 mm sieve and used for chemical analysis.

From these soils, 18 soils were finally selected for the study assuring maximum variation in total phosphorus content and properties relating to P fixation and availability. Details of the location and texture of the soils selected for the study are given in Appendix I.

2. Analytical procedures

The soils were analysed for total phosphorus, phosphorus fixing capacity, pH, electrical conductivity and organic carbon. Available phosphorus was determined by employing Bray No.1, Bray No.2, Bray No.4, Olsen's and Truog's extractants.

2.1 Preparation of HCl extract

Ten g of soil was digested with HCl having constant boiling point for two hours on a rose head flame, filtered, washed free of acid, and filtrate made up to 250 ml.

2.2 Total phosphorus

An aliquot of the HCl extract of the soil was evaporated to dryness. The residue was roasted on a rose head flame to dehydrate the silica. The chocolate brown colured residue left behind was treated with 1 : 1 nitric acid and kept over night. The content was filtered and washed with 1 : 1 nitric acid. To the filtrate, added dilute ammonia to make the medium distinctly alkaline. Phosphorus was precipitated in this solution as ammoniumphosphomolybdate in HNO_3 medium. Dissolved the yellow precipitate in known excess of standard alkali and back titrated with standard acid. The phosphorus content was calculated from the volume of alkali consumed.

2.3 Phosphate fixing capacity

Five g of soil, passed through a 0.2 mm sieve, was placed in a 100 ml centrifuge tube. Added 50 ml of 0.01 M ammonium dihydrogen phosphate solution adjusted to pH 7.0. The content was shaken for 24 hours. The suspension was centrifuged and phosphorus content in the clear filtered supernatant solution was determined by vanadomolybdophosphoric yellow colour method in nitric acid system (Jackson, 1958). The decrease in concentration was taken as the amount of phosphorus fixed.

2.4 pH and electrical conductivity

pH of the soil was determined in a Systronics, model 322 needle type pH meter using a soil : water ratio of 1 : 2.5. The electrical conductivity of the 1:2.5 saturation extract was measured in an Elico soil bridge, model CM-84.

2.5 Organic carbon

Organic carbon was determined by the method of Walkley and Black described by Piper (1942). The soil was digested with standard potassium dichromate and sulphuric acid. The excess chromic acid was back titrated against standard ferrous sulphate in the presence of orthophosphoric acid using diphenylamine indicator.

2.6 Available phosphorus

For the determination of available phosphorus the soils were extracted with Bray No.1, Bray No.2, Bray No.4, Olsen's and Truog's extractants. Phosphorus in the extract was determined by the chlorostannous reduced molybdophosphoric blue colour method in hydrochloric acid system in the case of Bray No.1, Bray No.2, Bray No.4, and Olsen's methods and in sulphuric acid system in the case of Truog's method (Jackson, 1958).

3. Estimation of available P reserve of soils by successive cropping (Ra-value)

The total plant removable P content (Ra-value) of the soils was determined by growing rice crops continuously in soils taken in pots, till the content of P in plants became below the critical or deficiency levels. The cumulative P uptake by successive crops was then found out. The pot culture experiment was so planned that maximum removal of phosphorus from soils was effected in a short period of time. The experiment was laid out in C.R.D. The details of the lay out were as follows:

Total number of treatments (soils) : 18
Number of replications : 3
Total number of treatment pots : 54
Pot size (volume) : 572 sq cm^3
Number of plants per pot:
  for the first and second crop : 75
  for the rest four crops : 25

500 g of soil was taken in 600 ml corning glass beaker. The soils were treated with nutrient solution proposed by Hewitt (1963) which was modified to the extent that it contained no phosphorus. For comparison, a control pot was maintained for each soil, in which the Hewitt solution containing all the nutrients was added. For each crop, 200 ml of the nutrient solution was given, 100 ml before planting and the rest 30 days after sowing or 20 days after transplanting. The medium duration, fast growing, high yielding rice variety "IR-8" was used as the test crop. Six crops were raised successively, the details of which are given in Appendix II.

For the first and second crop, germinated seedlings were used as the seed material, while for the rest of the crops seedlings raised on acid-washed sand were used in order to avoid the influence of seed phosphorus on the phosphorus uptake by plant. Under each crop, the plants were grown only for a period of 45 to 60 days, since the rate of growth and the P accumulation in plants thereafter become slow (Mandal, 1976). The plants were cut at the ground level by using a sharp rasor and the wet weight was recorded immediately. The harvested plant material was dried in an electric oven for 3 days at 105°C. It was then weighed and dry weight recorded.

3.1 P uptake by plants

0.5 g of the powdered material was transferred into a 100 ml volumetric flask. Digested the content in triple acid mixture consisting of perchloric, sulphuric and nitric acids in the ratio of 1 : 2 : 9, till the content turned colourless. The extractant was diluted with water, the volume made up, kept aside for one day, and filtered when the whole silica was settled down. Phosphorus in an aliquot of the extract was determined by vanadomolybdophosphoric yellow colour method in nitric acid system (Jackson, 1958).

The percentage of phosphorus in plant material and phosphorus uptake by plants were then calculated.

4. Screening of chemical extractants as indices of total available P reserve of soil (Ra-value)

To evolve a suitable laboratory chemical extractant for the estimation of soil phosphate reserve the following extractants were tried.

4.1 Preliminary screening of mineral acid extractants

Hydrochloric and sulphuric acids were tried independently and in combination at the strengths given below as extractants

HCl concentrations (4 nos)

1. 0.04 N
2. 0.06 N
3. 0.08 N
4. 0.10 N

H_2SO_4 concentrations (5 nos)

5. 0.02 N
6. 0.04 N
7. 0.06 N
8. 0.08 N
9. 0.10 N

H_2SO_4 and HCl combinations (20 nos)

10. 0.02 N in 0.04 N
11. 0.02 N in 0.06 N
12. 0.02 N in 0.08 N
13. 0.02 N in 0.10 N
14. 0.04 N in 0.04 N
15. 0.04 N in 0.06 N
16. 0.04 N in 0.08 N
17. 0.04 N in 0.10 N
18. 0.06 N in 0.04 N
19. 0.06 N in 0.06 N
20. 0.06 N in 0.08 N
21. 0.06 N in 0.10 N
22. 0.08 N in 0.04 N
23. 0.08 N in 0.06 N
24. 0.08 N in 0.08 N
25. 0.08 N in 0.10 N
26. 0.10 N in 0.04 N
27. 0.10 N in 0.06 N
28. 0.10 N in 0.08 N
29. 0.10 N in 0.10 N

Thus, 29 mineral acid extractants were used for the preliminary screening of the acid concentrations.

The periods of equilibration employed with each extractant were 5, 10, 15, 30, 45 and 60 minutes. Only a single soil solution ratio of 1 : 10 was tried.

Five g of soil was taken in a 250 ml conical flask and 50 ml of extractant solution was added. The content was shaken for different periods as mentioned earlier in a mechanical shaker. Immediately after shaking, the content was filtered through Whatman No.42 filter paper. Phosphorus in filtrate was determined colorimetrically by the chlorostannous reduced molybdophosphoric blue colour method in hydrochloric acid system (Jackson, 1958).

4.2 Selected mineral acid concentrations for chelated system of extraction

Graphs were plotted taking period of equilibration in the X-axis and phosphorus values in the Y-axis for each extractant solutions. Similarly graphs were drawn plotting concentration of reagents on the X-axis and phosphorus values on the Y-axis. From the nature of the curves obtained, a few acid concentrations were selected for chelated system of extraction using organic acids. They are:

HCl concentrations

1. 0.06 N
2. 0.08 N

H_2SO_4 concentrations

3. 0.02 N
4. 0.04 N
5. 0.06 N
6. 0.08 N
7. 0.10 N

H_2SO_4 and HCl combinations

8. 0.02 N in 0.06 N
9. 0.04 N in 0.06 N
10. 0.06 N in 0.06 N
11. 0.08 N in 0.06 N
12. 0.10 N in 0.06 N
13. 0.02 N in 0.08 N
14. 0.04 N in 0.08 N
15. 0.06 N in 0.08 N
16. 0.08 N in 0.08 N
17. 0.10 N in 0.08 N

4.3 Selection of organic acids and their concentrations for chelated system

The organic acids used for chelation were oxalic, acetic and citric acids. For the selection of the best organic acid and its concentration, the following procedure was adopted. The three organic acids each at two strengths of 0.05 N and 0.10 N were tried in combination with three selected mineral acid extractants, 0.06 N hydrochloric acid, 0.06 N sulphuric acid, and

0.06 N sulphuric acid in 0.06 N hydrochloric acid, as a pilot study. Only three representative soils were used for this purpose, but all the six periods of equilibration were followed. Thus the mineral acid-organic acid combinations employed were.

1. 0.06 N HCl in 0.05 N oxalic acid.
2. 0.06 N HCl in 0.10 N oxalic acid.
3. 0.06 N HCl in 0.05 N acetic acid.
4. 0.06 N HCl in 0.10 N acetic acid.
5. 0.06 N HCl in 0.05 N citric acid.
6. 0.06 N HCl in 0.10 N citric acid.
7. 0.06 N H_2SO_4 in 0.05 N oxalic acid.
8. 0.06 N H_2SO_4 in 0.10 N oxalic acid.
9. 0.06 N H_2SO_4 in 0.05 N acetic acid.
10. 0.06 N H_2SO_4 in 0.10 N acetic acid.
11. 0.06 N H_2SO_4 in 0.05 N citric acid.
12. 0.06 N H_2SO_4 in 0.10 N citric acid.
13. 0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid.
14. 0.06 N H_2SO_4 & 0.06 N HCl in 0.10 N oxalic acid.
15. 0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N acetic acid.
16. 0.06 N H_2SO_4 & 0.06 N HCl in 0.10 N acetic acid.
17. 0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N citric acid.
18. 0.06 N H_2SO_4 & 0.06 N HCl in 0.10 N citric acid.

Graphs were drawn plotting periods of equilibration on X-axis and phosphorus concentrations on Y-axis and based on their performance oxalic acid at the strength of 0.05 N was selected as the best chelating agent for employing with all the 17 mineral acid combinations selected, in all the soils at all the six periods of equilibration.

Thus the finally selected 17 mineral acid - organic acid chelated extractants were

1. 0.06 N HCl in 0.05 N oxalic acid.
2. 0.08 N HCl in 0.05 N oxalic acid.
3. 0.02 N H_2SO_4 in 0.05 N oxalic acid.
4. 0.04 N H_2SO_4 in 0.05 N oxalic acid.
5. 0.06 N H_2SO_4 in 0.05 N oxalic acid.
6. 0.08 N H_2SO_4 in 0.05 N oxalic acid.
7. 0.10 N H_2SO_4 in 0.05 N oxalic acid.
8. 0.02 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid.
9. 0.04 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid.
10. 0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid.
11. 0.08 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid.
12. 0.10 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid.
13. 0.02 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid.
14. 0.04 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid.
15. 0.06 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid.
16. 0.08 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid.
17. 0.10 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid.

The performance of the above 17 extractants was studied using the 18 soils at 6 periods of equilibration. Phosphorus in solution was estimated colorimetrically by the chlorostannous reduced molybdophosphoric blue colour method in hydrochloric acid system (Jackson, 1958).

RESULTS AND DISCUSSION

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Response of crops to applications of phosphorus to the soils of the state which are mainly lateritic in nature, was highly inconsistent. Very often the available phosphorus in soil extracted by chemical methods does not correlate with the plant response. One of the reasons for the poor response of the crops to phosphorus fertilisation is that the soil contains sufficient quantity of phosphate required to maintain the crop at a phosphate level above the critical range. Even skipping of phosphate application for a definite period in soils containing a good build up of reserve phosphates has been thought of. But at present there is no easy and quick method to estimate precisely the total phosphate reserve of the soil that can be mobilised as available phosphorus under a continuous cropping system. Continuous raising of crops in a soil till all its available phosphate reserve is exhausted as indicated either by phosphate deficiency symptoms or the critical level of phosphate in the plant cannot be resorted to as a regular analytical procedure for advisory work due to the cumbersome and time taking nature of the experiment involved in the study. Therefore evolving a quick chemical method for the estimation of the total available phosphorus reserve of the soil called as "Ra-value" is highly warranted.

The chemical method employed for the estimation of available phosphorus in soil by the soil testing laboratories of the State is extraction of soil by 0.03 N ammonium fluoride in 0.025 N hydrochloric acid as originally suggested by Bray and Kurtz (1945). This extractant was suggested based on the correlation between the amount of phosphorus extracted by the reagent and the total phosphorus uptake by plants. But the efficiency of this extractant in estimating that fraction of soil phosphorus which will be made available to crops when grown successively (Ra-value) has not been examined. When we consider the possibility of skipping phosphorus application it is not sufficient to know only the availability of phosphorus to a crop immediately grown in that soil. But we should assess the total phosphorus reserve of the soil which can be made available to successive crops so as to predict the number of crops that can be grown in the soil without the addition of phosphorus fertilisers. Pisharody _et al_.(1977) reported that application of phosphates to rice grown in Pattambi soils had no response in terms of yield and skipping of phosphate application for a definite period of time did not affect the plant performance till the phosphorus content of the plant became critical. They also reported that available phosphorus extracted by Bray No.1 had no value in predicting the possibility of skipping phosphorus application.

The present investigation was therefore planned to evolve a chemical method which will extract a fraction of phosphorus from the soil which will be well correlated with that fraction of phosphorus made available to plants when cropped continuously and after the release of which the crop will run deficient of phosphorus. The investigation was therefore oriented to estimate the "Ra-value" by continuous cropping till the phosphate level of the plant became critical and to correlate the "Ra-value" with the amount of phosphorus extracted from the soil by different chemicals employed at varying concentrations and varying period of time.

Soil samples were collected from rice fields representing different parts of the State, from which 18 soils were finally selected for the study assuring maximum possible variation in soil properties relating to phosphorus fixation and availability.

The general chemical properties of soils selected for the study are presented in Table 1 and the properties relating to the behaviour of phosphorus in Table 2. The coefficients of correlation with the total uptake of phosphorus by successive crops of rice grown in the soil and the properties of soils are given in Appendix III and IV. The pH of the soils ranged from 3.8 to 5.8. All the soils selected were non-saline, the EC of the saturation extract ranging from 0.05 to 0.60 mmhos/cm. The organic carbon content ranged from 0.3 to 1.56 per cent. The mean C : N ratio of the soils selected was 9.8 : 1.

The soils highly varied in their phosphorus fixing capacity, the range being 21.1 to 161.8 mg P/100 g soil. Similarly maximum variation was also obtained in the total phosphorus content of the soil. Soil No.16 registered a value of 2046 ppm phosphorus while the phosphorus content of soil No.17 was as low as 360 ppm. Similarly soils varied very much in their status of available phosphorus estimated using Bray No.1, Bray No.2, Bray No.4, Olsen and Truog methods. The mean values for available

Table 1. General chemical properties of the soil

Soil sample No.	Percentage, moisture free basis			pH in water	EC of 1:2.5 saturation extract (mmhos/cm)
	Moisture	Organic carbon	Total nitrogen		
1.	1.3	0.69	0.058	3.8	0.4
2.	5.6	1.23	0.141	4.2	0.2
3.	5.3	1.19	0.133	4.1	0.25
4.	5.7	1.16	0.112	4.2	0.2
5.	2.8	1.19	0.104	4.3	0.15
6.	4.2	1.17	0.123	4.2	0.2
7.	8.1	1.43	0.167	4.1	0.005
8.	4.3	1.56	0.142	4.7	0.2
9.	2.7	0.99	0.100	3.9	0.2
10.	5.3	1.05	0.110	5.7	0.1
11.	4.1	0.66	0.059	4.6	0.1
12.	2.2	0.30	0.029	5.0	0.2
13.	4.1	0.41	0.050	4.3	0.2
14.	5.3	0.47	0.058	4.4	0.15
15.	6.0	0.89	0.091	5.8	0.6
16.	4.2	0.87	0.088	4.6	0.3
17.	5.1	1.37	0.140	4.8	0.05
18.	6.2	0.99	0.103	4.1	0.25
Mean	4.58	0.98	0.100	4.5	0.21

Table 2. Properties relating to the behaviour of phosphorus in soils

Soil sample No.	Total P fixing capacity, mg/100g soil	Total P content, ppm (HCl extract)	Available phosphorus, ppm				
			Bray-1	Bray-2	Bray-4	Olsen	Truog
1.	100.7	722	4.48	11.21	14.57	15.69	2.53
2.	97.8	1804	7.84	18.49	24.48	8.96	1.35
3.	97.8	601	9.52	17.93	14.01	14.57	7.40
4.	67.3	1083	11.20	37.62	25.77	6.72	3.88
5.	97.8	763	11.20	32.49	17.28	14.57	2.53
6.	96.9	1043	11.20	25.77	12.33	5.6	7.40
7.	79.0	922	7.84	10.08	22.41	10.64	2.53
8.	80.4	1685	53.78	66.11	58.27	64.43	3.12
9.	161.8	1725	23.53	22.97	33.61	7.28	9.77
10.	64.9	521	12.24	17.93	15.69	9.52	8.56
11.	21.1	481	20.17	31.93	25.69	14.01	8.56
12.	71.0	481	21.29	22.41	21.46	21.29	8.56
13.	61.6	802	19.61	34.18	28.01	11.21	12.3
14.	49.8	441	22.41	28.57	22.97	13.45	3.80
15.	84.7	1925	50.98	85.72	76.75	50.42	10.94
16.	72.9	2046	40.34	79.56	72.83	36.42	8.18
17.	80.0	360	8.96	11.77	12.33	3.36	12.29
18.	80.4	1123	22.40	31.97	39.22	11.77	9.40
Mean	81.4	1029	19.94	32.60	29.90	17.77	6.80

phosphorus extracted by Bray No.2 and Bray No.4 were relatively higher than the mean values of phosphorus extracted by Olsen and Bray No.1 extrectants. This is obviously because of the higher strength of the reagents employed in Bray No.2 and Bray No.4 as compared to Bray No.1. Phosphorus extracted by 0.002 N sulphuric acid (Truog) was considerably low with a mean value of 6.8 ppm. It was interesting to note that the available phosphorus expressed as percentage to the total phosphorus was markedly low. The mean values being 1.94, 3.17, 2.96, 1.73 and 0.66 per cent for Bray No.1, Bray No.2, Bray No.4, Olsen and Truog methods respectively.

The chemical extractants employed in this study were mineral acids at different strengths at a constant soil : solution ratio. The acids were selected on the assumption that they will suit the acid laterite soils in their ability to extract soil phosphorus without drastically affecting the chemical nature of the soil. Different mineral acids and their combinations were screened in selecting a chemical index of phosphorus availability by different workers (Truog, 1930; Kerr and Von Stieghts, 1938; Bandroff, 1952). Mehlich (1953) employed a combination of hydrochloric acid and sulphuric acid as an extractant for available phosphorus in certain acid soils of the United States. But all these workers gave importance to the relationship between phosphorus extracted and the phosphorus uptake by plants without referring to the total available phosphate reserve, the "Ra-value".

It is often noticed that the quantum of phosphorus extracted by Truog, Olsen and Bray No.1 extractants, in soils containing relatively small amount of phosphorus is so small that the error involved in the analytical procedures is relatively high. The strength of acids employed in the present study was so determined that they should invariably extract a fraction of soil phosphorus which will be always higher than that extracted by Bray No.1, the most common method adopted in the State. Hydrochloric acid at the strength of 0.04 N, 0.06 N, 0.08 N and 0.10 N and sulphuric acid at the strength of 0.02 N, 0.04 N, 0.06 N, 0.08 N and 0.10 N were employed as extractants. Also, combinations of these two acids at all the strengths noted were tried as extractants.

While studying the pattern of phosphorus release from soil, Jose (1972) observed that during the initial period of equilibration the release of phosphorus into solution would be at a rapid rate, the rate of release being logarithmic in nature. After this initial release of phosphorus at a faster rate, the rate of release then became slow and linear with respect to the increased period of equilibration. This linear release continued indefinitely or for a longer period of time. He observed that only the amount of phosphorus released during the initial period of equilibration which represented the curved region of the graphs, when phosphorus values were plotted on Y-axis and period of equilibration on X-axis, need be considered in estimating the phosphorus availability of the soil. Since the release of phosphorus after this initial period will be at a constant rate with a linear function and continues for a longer period of time, this part of the graph does not decisively affect the estimate of available phosphorus in soil, for most of the soils the major part of the phosphorus that can be extracted by a solution will be released within the initial period of equilibration. In the present study the soils were equilibrated with each extractant employed for varying periods of time so as to select the optimum equilibration period suited to that particular extractant. The optimum equilibration period will be the one by which the release of phosphorus into the extractant solution will be almost complete and after which further release of phosphorus will take place at a constant rate with a linear function. Equilibration periods viz., 5, 10, 15, 30, 45 & 60 minutes were employed with each extractant with a view to selecting the best equilibration period suited to that extractant. Equilibration periods more than 60 minutes were not employed since such longer periods may not suit analytical procedures oriented to advisory works. Moreover, from the initial studies it was understood that with these extractants the linearity of the graph is established in most of the cases within a period of 60 minutes.

The amount of phosphorus extracted by various strengths and combinations of acids is presented in Tables 3 to 31.

1.1 Hydrochloric acid as extractant

Hydrochloric acid was employed as extractant at 0.04 N, 0.06 N, 0.08 N and 0.10 N strengths. As regards the efficiency of hydrochloric acid in extracting the soil-P, it was seen that 0.06 N hydrochloric acid extracted the highest quantity of phosphorus when the effects of soils and periods of equilibration were pooled. The values for phosphorus extracted by 0.04N, 0.06N, 0.08 N and 0.10 N hydrochloric acid were 9.5, 13.7, 13.3 and 7.4 ppm P respectively. This shows that the increase in strength of hydrochloric acid employed has little effect on the amount of phosphorus extracted from the soil. It should be pointed out that hydrochloric acid at these concentrations was a poor extractant of soil-P and extracted only smaller quantities of phosphorus as compared to that of Bray No.1. This is obviously because Bray No.1 employs ammonium fluoride which is a selective extractant for Al-P.

The coefficients of correlation between the phosphorus extracted by different concentrations of hydrochloric acid and uptake of phosphorus by rice were not statistically significant. Regarding the influence of period of equilibration on the release of phosphorus into solution, it was observed that equilibration for a period of 30 minutes was sufficient to extract the major portion of phosphorus that can be released into the

Table 3. P extracted by 0.04 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	10.1	9.0	9.0	8.8	8.4	7.8
2.	9.0	10.6	7.8	7.8	9.0	12.3
3.	8.4	8.4	10.1	7.8	8.4	9.0
4.	9.0	10.6	7.8	8.4	8.4	8.4
5.	12.3	8.4	9.0	9.0	8.4	8.4
6.	9.5	8.4	7.8	8.4	9.5	10.1
7.	9.0	10.6	7.8	8.4	9.0	9.0
8.	10.6	14.6	9.5	8.4	9.5	10.6
9.	9.5	6.7	7.8	7.3	9.0	9.0
10.	9.0	9.5	9.0	9.5	11.2	9.5
11.	9.5	8.4	9.0	8.4	9.0	7.8
12.	9.0	8.4	11.0	13.5	15.7	20.7
13.	9.0	10.1	9.0	10.6	10.6	12.3
14.	9.0	12.3	10.1	9.5	11.2	12.3
15.	10.1	10.1	10.1	10.1	11.2	11.2
16.	9.0	10.1	7.8	9.5	11.2	9.0
17.	2.4	8.4	8.4	7.8	8.4	9.0
18.	8.4	9.0	9.0	8.4	9.0	10.1
Mean	9.0	9.6	8.9	9.0	9.8	10.4

Table 4. P extracted by 0.06 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	10.1	6.7	11.2	7.8	11.2	11.2
2.	7.8	6.2	10.1	10.6	13.5	17.9
3.	10.3	14.6	14.0	28.0	42.0	25.2
4.	10.8	12.9	6.7	17.9	14.9	15.7
5.	9.0	9.0	10.1	13.5	11.8	7.8
6.	9.0	9.0	11.2	13.5	11.2	24.7
7.	7.8	6.7	14.0	12.3	12.3	14.6
8.	13.5	9.5	14.0	13.5	18.0	22.4
9.	6.7	7.3	8.4	11.2	20.1	17.4
10.	7.8	12.9	10.1	26.9	12.3	8.4
11.	11.2	10.1	13.5	11.8	21.3	14.6
12.	12.5	14.0	9.0	17.9	19.6	20.1
13.	7.3	10.1	15.7	14.6	19.1	17.4
14.	19.1	13.5	15.7	16.8	20.2	23.0
15.	13.5	12.3	13.5	18.0	16.3	19.6
16.	23.5	10.6	13.5	12.9	12.9	17.4
17.	8.4	7.3	7.8	11.2	11.8	14.6
18.	14.6	9.5	10.1	11.2	14.0	15.1
Mean	11.3	10.1	11.6	15.0	16.8	17.1

Table 5. P extracted by 0.08 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	4.5	12.3	10.1	3.4	12.3	15.7
2.	9.0	10.1	3.5	3.4	5.6	14.1
3.	14.6	14.6	3.4	2.2	18.0	14.6
4.	19.1	19.1	5.6	4.5	15.7	13.5
5.	19.1	14.6	11.2	16.8	12.3	19.1
6.	2.2	19.1	2.2	11.2	14.6	11.2
7.	6.7	10.1	6.7	11.8	2.2	19.1
8.	20.2	11.2	14.6	18.0	16.8	21.3
9.	4.5	2.2	1.7	18.0	3.4	11.2
10.	4.5	7.3	1.1	6.7	13.5	12.3
11.	10.1	13.5	4.5	14.6	15.1	15.7
12.	10.1	18.0	12.3	29.1	15.7	29.1
13.	14.6	29.1	19.1	16.8	21.3	25.8
14.	4.5	12.3	6.7	17.9	23.5	23.5
15.	16.8	13.5	16.3	20.2	34.7	20.2
16.	10.1	6.2	12.3	18.0	21.3	19.1
17.	6.7	19.1	4.5	20.2	12.9	11.2
18.	14.6	16.8	16.8	16.8	19.1	18.5
Mean	10.7	13.8	8.5	13.9	15.4	17.5

Table 6. P extracted by 0.10 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	6.7	1.1	1.1	7.8	7.8	7.8
2.	3.4	1.1	2.2	2.2	4.5	2.2
3.	6.2	1.1	3.4	4.5	3.4	1.1
4.	3.4	1.1	2.8	7.8	6.7	3.4
5.	6.7	6.2	8.4	4.5	9.0	5.6
6.	3.4	1.7	3.4	1.1	3.4	1.1
7.	2.8	1.1	2.8	5.6	4.5	3.4
8.	11.8	12.3	15.7	16.8	22.4	24.7
9.	6.7	1.1	1.1	2.2	4.5	3.9
10.	3.4	1.1	1.7	2.2	5.1	1.1
11.	5.6	1.1	5.6	5.6	7.3	22.4
12.	12.3	10.1	12.3	17.4	15.4	22.4
13.	7.8	12.3	7.3	14.6	20.2	19.1
14.	9.0	6.7	9.0	12.3	15.7	14.6
15.	10.8	9.0	14.0	15.7	17.0	22.4
16.	10.8	7.8	11.2	14.0	13.5	11.8
17.	3.9	1.1	1.1	1.1	1.7	1.1
18.	5.0	5.0	5.0	6.7	11.8	7.8
Mean	6.7	4.5	6.0	7.9	9.7	9.8

extractant solution. However, equilibrium between soil-P and solution-P was not established within a period of 60 minutes employed in the experiment. The pattern of phosphorus release into the solution when examined as a function of period of equilibration revealed that in many soils the rate of release was very much fluctuating probably due to the sorption and desorption of phosphorus taking place simultaneously.

1.2 Sulphuric acid as extractant

Sulphuric acid at strengths of 0.02 N, 0.04 N, 0.06 N, 0.08 N and 0.10 N was employed as extractants. It was observed that increasing concentrations of sulphuric acid resulted in increasing amounts of phosphorus extracted from the soil. The mean values of phosphorus extracted by 0.02 N, 0.04 N, 0.06 N, 0.08 N and 0.10 N acid were 11.8, 17.5, 33.3, 28.8 and 40.9 ppm P respectively when the effects of soils and periods of equilibration were pooled. When the amounts of phosphorus extracted by hydrochloric acid and sulphuric acid at equal concentrations were compared, the values of phosphorus extracted by sulphuric acid were invariably higher showing that sulphuric acid was a stronger extractant of soil-P than hydrochloric acid.

Table 7. P extracted by 0.02 N H_2SO_4, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	3.4	4.5	12.3	9.0	18.0	10.6
2.	2.2	3.4	3.4	10.1	15.1	9.0
3.	5.6	6.7	11.2	9.0	12.3	9.5
4.	3.4	4.5	3.9	4.5	9.5	10.1
5.	9.0	12.3	15.7	9.5	10.1	12.3
6.	3.4	4.5	11.2	3.9	9.0	10.6
7.	3.9	4.5	14.6	7.3	10.1	9.0
8.	11.2	14.6	15.1	14.6	15.7	16.8
9.	10.1	10.1	14.6	4.5	13.5	11.2
10.	10.1	10.1	14.6	7.3	13.5	11.2
11.	10.1	11.2	12.3	9.0	13.5	12.9
12.	14.6	15.7	13.5	16.8	20.1	22.4
13.	5.6	6.7	15.7	13.5	14.6	14.6
14.	12.3	13.5	15.1	15.8	16.3	18.5
15.	20.1	21.3	11.2	19.1	34.2	19.1
16.	14.6	15.7	17.9	17.9	9.0	16.8
17.	13.5	15.1	16.1	11.2	10.6	10.9
18.	9.0	9.0	16.8	7.8	17.4	15.1
Mean	9.0	10.2	13.1	10.6	14.6	13.4

Table 8. P extracted by 0.04 N H_2SO_4, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	7.5	9.9	8.5	5.7	4.2	14.6
2.	8.7	38.6	5.9	7.5	14.6	9.9
3.	9.4	12.3	6.4	7.5	9.9	6.6
4.	10.1	29.2	29.7	10.1	9.9	12.5
5.	10.8	20.3	11.5	13.9	18.6	15.5
6.	7.3	10.1	6.8	5.9	7.5	6.8
7.	5.9	26.1	6.8	7.1	11.5	12.7
8.	26.4	46.6	25.6	25.9	20.5	28.7
9.	15.1	15.5	12.5	11.8	16.9	12.9
10.	10.4	22.8	7.8	5.4	15.1	10.4
11.	16.0	26.1	10.6	14.4	27.8	13.2
12.	15.3	20.2	18.1	23.5	28.7	28.2
13.	13.9	25.4	15.5	19.5	20.5	24.0
14.	9.9	48.2	19.5	19.1	10.4	22.1
15.	32.7	61.2	32.3	32.5	36.9	32.5
16.	30.6	38.6	29.7	27.8	14.2	18.6
17.	6.1	18.4	6.6	18.4	11.1	11.5
18.	11.3	41.7	14.8	17.7	17.2	17.4
Mean	13.7	28.4	14.9	15.2	16.4	16.6

Table 9. P extracted by 0.06 N $H_2 SO_4$, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	13.9	12.7	9.5	10.1	16.8	11.2
2.	13.2	12.2	15.7	15.7	17.9	3.4
3.	13.9	7.3	15.1	15.7	10.1	15.7
4.	15.5	16.0	21.3	12.9	18.5	12.3
5.	20.7	21.2	25.8	17.4	24.1	11.8
6.	8.9	12.0	7.8	16.8	12.3	15.7
7.	13.4	14.1	10.6	12.3	15.1	9.0
8.	44.0	43.7	52.0	52.7	52.1	42.6
9.	15.5	17.4	17.4	21.3	26.3	17.9
10.	13.2	15.1	14.0	10.6	17.4	16.8
11.	17.2	13.7	26.9	25.8	25.2	16.3
12.	20.7	25.4	29.1	31.4	41.5	34.7
13.	22.1	25.7	29.7	31.4	38.1	43.1
14.	18.8	25.2	29.1	31.4	16.8	26.9
15.	50.4	58.1	49.3	56.6	41.5	48.2
16.	49.4	51.8	51.5	33.1	51.5	34.7
17.	8.9	9.4	19.6	12.3	10.1	10.6
18.	19.8	20.9	33.1	22.9	30.8	14.6
Mean	21.1	22.3	25.4	23.9	25.9	21.4

Table 10. P extracted by 0.08 N H_2SO_4, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	6.7	11.2	21.3	24.1	15.1	13.5
2.	10.1	14.6	20.2	21.3	11.2	12.2
3.	6.7	13.5	16.8	20.7	16.8	11.8
4.	19.1	16.8	5.6	20.2	16.8	19.4
5.	24.7	24.1	29.7	37.0	30.1	34.7
6.	9.0	10.1	11.8	19.6	14.6	18.0
7.	11.2	20.7	22.4	25.2	23.5	14.6
8.	56.6	61.1	55.0	77.3	60.5	57.2
9.	20.2	25.8	13.5	34.7	35.9	34.2
10.	14.0	12.3	4.5	23.5	25.8	23.0
11.	16.3	20.2	22.4	24.7	21.3	37.0
12.	20.2	23.5	38.1	40.3	42.6	28.0
13.	20.1	26.6	38.1	40.3	32.5	50.4
14.	20.2	20.2	24.7	31.4	16.8	26.9
15.	59.4	67.2	70.6	78.4	71.7	75.1
16.	56.0	60.5	71.7	57.2	63.3	59.4
17.	3.4	9.0	3.9	15.1	8.4	16.8
18.	25.2	25.2	38.7	39.8	31.4	37.0
Mean	22.2	25.7	28.3	35.0	29.9	31.6

Table 11. P extracted by 0.10 N $H_2 SO_4$, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	29.1	20.2	23.0	25.2	30.8	30.3
2.	29.1	23.5	13.5	29.1	21.9	26.9
3.	21.3	23.5	24.1	26.9	28.6	26.3
4.	26.9	29.1	29.7	30.3	33.1	32.5
5.	45.9	40.9	38.1	44.8	34.7	37.0
6.	17.9	19.6	20.7	19.1	19.1	25.8
7.	24.7	24.6	27.5	34.7	31.4	27.5
8.	75.1	52.7	90.8	104.2	97.5	95.2
9.	30.3	44.3	38.7	38.1	44.8	39.2
10.	29.1	23.5	25.8	24.7	25.2	26.9
11.	30.3	32.5	32.5	39.2	37.0	43.7
12.	26.9	39.2	31.4	43.7	43.7	49.3
13.	37.0	50.4	35.9	56.0	17.9	53.2
14.	35.9	24.7	29.7	39.2	37.0	37.0
15.	86.8	94.1	75.1	100.9	74.1	100.9
16.	87.4	80.7	88.5	89.6	93.6	94.1
17.	11.2	14.6	21.9	14.6	13.5	11.2
18.	38.1	41.5	28.3	49.3	19.1	50.4
Mean	37.9	37.8	40.9	45.0	39.1	44.9

Values of phosphorus extracted by sulphuric acid at all the concentrations employed correlated with the amounts of total phosphorus removed from the soils by six successive crops of rice in the pot culture experiment. The pattern of phosphorus release during varying period of equilibration showed that the major part of the phosphorus that can be extracted by the reagent was released within 30 minutes, the rate of release being very slow thereafter as in the case of hydrochloric acid. Equilibrium between soil-P and solution-P was not established even after a period of 60 minutes. Also the values for phosphorus at different periods were fluctuating in many cases probably due to the release and resorption of phosphorus taking place simultaneously during equilibration.

1.3 Combinations of sulphuric acid and hydrochloric acid

The data furnished in Tables 12 to 31 show that combinations of sulphuric acid and hydrochloric acid could extract higher amounts of phosphorus from soil than that extracted by individual acids. Increasing concentrations of hydrochloric acid could not extract higher concentrations of phosphorus from the soil when employed individually but increasing concentration of hydrochloric acid in the presence of sulphuric acid increased the amount of phosphorus extracted from the soil. This influence was more profound at lower concentrations of sulphuric acid. The values for phosphorus extracted by 0.04 N, 0.06 N, 0.08 N and 0.10 N hydrochloric acid in 0.02 N sulphuric acid were 18.8, 23.2, 28.5 and 36.4 ppm respectively, showing the influence of increasing concentrations of hydrochloric acid in extracting increasing amounts of phosphorus in the presence of sulphuric acid. Similarly the amounts of phosphorus extracted by 0.04 N, 0.06 N, 0.08 N and 0.10 N hydrochloric acid in 0.04 N sulphuric acid were 40.5, 71.3, 87.8 and 120.7 ppm respectively. Thus combinations of the two acids extracted considerably higher amounts of soil-P than that extracted by the acids when employed independently at comparable concentrations. It was interesting to observe that the amount of phosphorus extracted from the soil increased with increasing concentration of sulphuric acid only upto a strength of 0.06 N when employed in combination with hydrochloric acid. Thus the influence of sulphuric acid and hydrochloric acid on the release of soil phosphorus appears to be different when employed independently and in combination. The highest amount of phosphorus (120.7 ppm) was extracted by the combination of 0.04 N sulphuric acid in 0.10 N hydrochloric acid. The pattern of phosphorus release during varying periods of equilibration showed that major part of the phosphorus that could be mobilised came into solution within a period of 30 minutes though equilibrium was not established even after a period of 60 minutes. The pattern of release when examined as a function of period of equilibration, the values for phosphorus were still fluctuating due to the expected release and resorption of phosphorus taking place during equilibration. However the degree of fluctuation was considerably smaller as compared to the pattern of release observed when the acids were employed independently. This is mainly because of the total amount of phosphorus brought into solution by the combinations of the mineral acids was much larger than that extracted by the individual acids. As a result, the degree of fluctuation due to the resorption of phosphorus into the soil became smaller when expressed in relation to the total phosphorus extracted.

The coefficients of correlation between phosphorus

Table 12. P extracted by 0.02 N H_2SO_4 in 0.04 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	6.7	5.6	13.5	7.8	16.8	19.1
2.	5.6	25.8	16.8	6.7	12.3	14.6
3.	7.3	7.8	19.1	2.8	16.8	16.8
4.	6.7	9.0	20.2	10.1	22.4	17.9
5.	14.6	15.7	22.4	15.7	25.8	22.4
6.	1.7	3.9	16.8	5.6	16.8	19.1
7.	7.8	6.7	9.0	7.8	16.8	15.7
8.	7.8	6.7	9.0	7.8	16.8	15.7
9.	12.3	13.5	13.5	9.0	25.8	19.1
10.	7.8	6.7	9.5	8.4	13.5	25.8
11.	14.0	11.8	22.4	14.0	47.1	23.5
12.	13.4	17.9	30.3	24.7	37.0	41.5
13.	19.0	16.8	28.0	23.5	37.0	33.6
14.	14.0	13.5	28.0	21.9	28.0	23.6
15.	37.5	37.0	44.8	38.1	51.5	47.1
16.	31.4	35.9	35.9	33.6	40.3	45.9
17.	3.4	1.7	14.6	4.5	12.3	17.9
18.	14.6	16.8	28.0	17.9	23.5	33.6
Mean	12.5	14.0	21.2	14.4	25.6	25.2

Table 13. P extracted by 0.02 N H_2SO_4 in 0.06 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	10.1	10.6	10.6	12.3	13.5	15.6
2.	7.8	7.8	14.9	12.3	11.8	10.1
3.	9.0	11.8	9.0	12.3	13.5	11.2
4.	15.7	12.3	15.7	15.7	16.8	16.8
5.	21.3	22.4	23.5	24.7	22.4	23.0
6.	7.8	9.0	10.1	10.1	9.5	9.5
7.	12.3	13.5	13.5	13.5	14.6	14.6
8.	43.7	51.0	53.8	58.3	56.6	60.5
9.	16.8	16.8	17.9	19.1	19.1	24.7
10.	10.6	10.6	12.3	11.2	13.5	12.9
11.	15.7	15.7	20.2	21.2	20.2	21.3
12.	17.9	21.3	26.3	29.1	32.5	35.9
13.	20.2	24.7	28.0	39.2	37.5	38.1
14.	16.8	19.1	23.0	26.9	29.1	26.9
15.	49.3	54.9	56.0	57.1	54.9	54.9
16.	50.4	50.4	52.1	48.2	48.2	52.1
17.	3.4	5.6	5.6	5.6	6.7	6.2
18.	21.3	25.2	26.9	25.8	26.9	28.0
Mean	19.5	21.3	23.3	24.6	24.9	25.7

Table 14. P extracted by 0.02 N H_2SO_4 in 0.08 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	10.1	10.6	10.6	12.3	13.5	15.6
2.	7.8	7.8	14.9	12.3	11.8	10.1
3.	14.6	14.3	13.5	13.5	15.7	13.4
4.	15.7	14.6	15.1	17.9	21.3	22.4
5.	26.9	29.7	28.0	29.1	31.4	30.3
6.	11.2	9.0	12.3	9.0	12.3	13.5
7.	14.6	18.0	16.3	19.1	17.4	20.7
8.	54.9	61.6	65.0	71.2	69.5	82.9
9.	21.3	22.4	19.1	21.3	23.5	25.8
10.	13.5	21.3	12.9	16.8	15.7	16.8
11.	22.4	25.6	20.1	28.0	24.7	28.0
12.	24.7	23.5	22.4	33.6	38.1	49.3
13.	26.9	25.8	28.0	42.6	49.3	60.5
14.	22.4	25.8	22.4	32.5	29.1	30.8
15.	61.6	67.2	67.2	69.5	76.2	82.9
16.	57.1	62.8	60.5	65.0	69.2	65.0
17.	5.6	9.0	7.3	6.7	9.0	6.7
18.	28.0	23.5	30.3	31.9	29.1	32.5
Mean	24.4	26.3	25.9	29.6	30.9	33.7

Table 15. P extracted by 0.02 N H_2SO_4 in 0.10 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	16.8	19.1	20.2	14.6	16.8	28.0
2.	30.8	14.6	10.1	16.8	16.8	15.7
3.	12.9	38.1	26.9	12.3	17.9	35.9
4.	21.3	22.4	19.1	15.7	19.1	19.1
5.	33.6	39.2	32.5	33.6	38.1	33.6
6.	12.3	25.7	19.1	26.9	6.7	24.7
7.	17.9	20.2	22.4	17.9	32.5	32.5
8.	71.7	109.8	74.0	99.7	104.2	98.6
9.	26.9	32.5	22.4	28.0	20.2	31.9
10.	23.5	24.7	15.7	16.8	21.3	25.8
11.	33.6	31.4	31.9	25.8	42.6	30.3
12.	23.5	39.2	32.5	25.8	32.5	45.9
13.	35.9	33.6	39.2	43.7	45.9	56.0
14.	17.9	38.1	19.1	31.4	29.1	41.5
15.	79.6	72.8	78.4	85.2	121.6	90.8
16.	75.1	78.4	76.2	78.4	77.3	98.6
17.	9.0	14.6	4.5	7.8	9.0	7.8
18.	32.5	33.6	43.1	34.7	47.6	49.9
Mean	31.9	38.2	32.6	34.2	38.8	42.6

Table 16. P extracted by 0.04 N H_2SO_4 in 0.04 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	44.8	22.4	20.2	20.2	11.2	23.5
2.	52.7	7.8	20.2	24.7	48.2	21.3
3.	30.3	21.3	16.3	21.3	39.2	21.3
4.	39.2	34.7	26.9	22.4	21.3	31.4
5.	23.5	33.6	32.5	42.6	33.6	34.7
6.	30.3	22.4	14.6	14.6	43.7	17.9
7.	5.6	22.4	25.5	22.4	11.2	23.5
8.	87.4	63.9	74.0	100.3	112.1	85.2
9.	86.3	33.6	38.1	29.7	11.2	31.4
10.	43.7	32.5	38.1	19.6	47.1	20.1
11.	42.6	26.9	29.7	28.0	62.8	34.7
12.	58.3	30.3	30.3	32.5	72.8	43.7
13.	50.4	37.0	66.1	51.5	76.8	53.8
14.	44.8	24.7	38.1	33.6	39.2	35.9
15.	25.8	72.8	94.1	85.2	121.6	90.8
16.	86.3	63.9	66.1	75.1	81.1	79.6
17.	9.0	5.6	2.8	6.7	7.8	9.0
18.	58.3	37.0	34.7	42.6	71.7	48.2
Mean	45.5	32.9	37.1	37.4	50.7	39.2

Table 17. P extracted by 0.04 N H_2SO_4 in 0.06 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	53.8	44.8	25.8	23.5	26.9	61.6
2.	86.3	37.0	33.6	58.3	51.5	61.6
3.	51.5	60.5	37.0	61.6	48.2	45.8
4.	50.4	87.4	41.5	32.5	39.2	50.4
5.	57.2	67.2	49.3	53.8	49.3	47.1
6.	51.5	50.4	30.3	53.8	50.4	32.5
7.	34.7	50.4	37.0	42.6	50.4	42.6
8.	120.00	123.2	94.1	145.7	116.5	135.6
9.	145.7	57.2	60.5	47.1	39.2	49.3
10.	53.8	50.4	66.1	45.9	70.6	80.7
11.	61.6	48.2	74.0	46.0	69.5	80.7
12.	68.4	62.8	49.3	51.5	76.2	84.0
13.	69.5	82.9	72.8	72.8	91.9	67.2
14.	58.3	50.4	44.8	43.7	65.0	72.9
15.	78.4	109.8	110.9	128.9	124.4	136.7
16.	104.2	90.8	89.6	97.5	102.0	127.7
17.	85.7	162.5	80.7	81.8	82.9	78.4
18.	118.8	113.2	116.5	126.6	131.1	136.7
Mean	75.0	75.0	61.9	67.4	71.4	77.3

Table 18. P extracted by 0.04 N H_2SO_4 in 0.08 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	62.8	66.1	50.4	52.7	48.2	106.5
2.	131.1	66.1	48.2	104.2	54.9	105.3
3.	71.7	87.4	48.2	47.1	55.5	83.5
4.	72.8	117.7	56.0	99.7	57.2	69.5
5.	98.6	100.9	67.2	65.0	65.0	69.5
6.	73.4	85.2	44.8	44.8	90.8	47.1
7.	62.8	77.9	59.4	59.3	90.8	63.3
8.	152.4	183.8	116.5	187.1	122.1	184.9
9.	81.8	79.0	79.6	67.2	67.2	67.2
10.	63.3	68.4	50.4	44.5	47.1	77.3
11.	79.6	81.8	95.2	62.8	75.7	126.6
12.	79.6	94.1	68.4	75.1	80.1	126.6
13.	84.6	135.6	78.4	96.1	107.6	79.6
14.	75.1	76.2	51.5	53.8	89.6	109.8
15.	130.5	153.5	131.1	188.2	130.0	189.4
16.	118.8	114.3	112.6	116.5	123.3	177.0
17.	71.7	53.2	52.1	42.6	30.3	116.5
18.	86.8	86.3	80.7	72.3	86.3	141.7
Mean	88.7	96.0	71.7	82.2	80.0	107.9

Table 19. P extracted by 0.04N $H_2 SO_4$ in 0.1 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	92.4	97.5	109.3	127.7	121.6	121.0
2.	136.1	97.5	88.5	87.4	81.8	113.2
3.	134.7	138.9	216.3	100.9	105.9	104.2
4.	99.7	100.9	115.4	93.0	119.3	103.1
5.	135.0	109.8	110.9	126.6	113.2	119.9
6.	95.2	102.0	86.3	102.0	95.2	95.2
7.	87.4	114.3	117.7	95.8	95.8	115.4
8.	149.0	167.0	193.9	202.8	191.6	215.1
9.	109.8	102.0	107.6	120.0	106.5	115.4
10.	82.9	100.9	116.5	65.3	106.5	100.9
11.	116.5	112.1	106.5	105.3	121.0	160.2
12.	106.5	99.7	103.1	119.9	108.7	116.5
13.	117.7	115.4	130.0	124.4	109.8	133.3
14.	92.4	105.3	97.6	100.9	108.7	107.5
15.	161.4	171.4	160.2	183.8	172.6	193.9
16.	187.1	168.6	117.0	150.2	169.0	186.0
17.	85.7	162.5	80.7	81.8	82.9	78.4
18.	118.8	113.2	116.5	126.7	131.1	136.7
Mean	117.1	121.1	120.8	117.5	119.0	128.7

Table 20. P extracted by 0.06 N H_2SO_4 in 0.04 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	35.3	55.3	107.1	51.8	43.5	58.8
2.	44.7	67.1	40.0	42.4	37.7	29.4
3.	63.5	49.4	56.5	40.0	37.7	37.7
4.	48.2	51.8	35.3	55.3	47.1	40.1
5.	80.0	69.4	36.5	56.5	51.8	38.8
6.	56.5	51.8	40.0	36.5	50.6	37.7
7.	47.1	51.8	44.7	47.1	47.1	49.4
8.	101.2	115.3	78.8	120.0	110.6	96.5
9.	87.1	69.4	51.8	56.5	54.1	57.7
10.	63.5	49.4	44.7	95.3	54.1	36.5
11.	56.5	56.5	55.3	63.5	50.6	58.9
12.	80.0	80.0	51.8	63.5	51.8	37.7
13.	69.4	87.1	63.5	71.8	70.6	62.4
14.	49.4	54.1	49.1	51.8	44.7	35.3
15.	108.2	154.1	81.2	103.5	115.3	90.6
16.	92.9	127.1	101.2	120.0	101.2	82.4
17.	45.9	40.0	30.6	47.1	30.6	37.7
18.	64.7	72.9	54.1	44.7	45.9	82.4
Mean	66.3	72.4	56.8	64.9	58.1	53.9

Table 21. P extracted by 0.06 N H_2SO_4 in 0.06 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	61.2	49.4	54.1	115.3	65.9	70.6
2.	40.0	23.5	22.4	50.6	45.9	51.8
3.	35.3	51.8	115.3	91.8	74.1	124.7
4.	44.7	63.5	158.8	34.1	51.8	51.8
5.	52.9	49.4	131.8	123.5	64.7	41.2
6.	40.0	44.7	61.2	91.8	129.4	117.7
7.	72.9	51.8	82.4	43.5	47.1	80.0
8.	115.3	135.3	94.1	169.4	130.6	195.3
9.	24.7	48.2	112.9	177.7	63.5	71.8
10.	49.4	50.6	87.1	98.8	63.5	56.5
11.	36.5	37.7	101.1	103.5	68.2	61.2
12.	50.6	40.0	30.6	132.9	58.8	38.8
13.	51.8	64.7	116.5	40.0	80.0	141.2
14.	63.5	54.1	171.8	112.9	52.9	61.2
15.	89.4	145.9	122.4	147.1	202.4	150.6
16.	105.9	134.1	98.8	129.4	122.4	103.5
17.	30.6	38.8	28.2	34.1	61.2	25.9
18.	52.9	56.5	37.7	110.6	68.2	134.1
Mean	56.5	63.3	90.4	100.4	80.6	87.7

Table 22. P extracted by 0.06 N H_2SO_4 in 0.08 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	49.9	51.2	52.4	84.9	62.4	64.9
2.	49.9	44.7	31.2	49.9	51.2	43.7
3.	87.4	53.7	74.9	77.4	62.4	87.4
4.	49.9	52.4	107.4	57.4	56.2	54.9
5.	94.9	53.7	99.9	94.9	64.9	54.9
6.	67.4	39.9	52.4	74.9	87.3	92.4
7.	67.4	49.9	67.4	72.4	53.7	69.9
8.	132.3	153.5	124.8	167.3	159.8	139.8
9.	42.4	99.9	87.4	119.8	66.2	94.9
10.	69.9	49.9	67.4	77.4	57.4	57.4
11.	47.4	44.9	82.4	82.4	64.9	67.4
12.	51.2	41.2	41.2	97.4	59.9	62.4
13.	67.4	64.9	94.9	52.4	69.9	124.8
14.	69.9	71.2	117.3	87.4	62.4	64.9
15.	127.3	154.8	132.2	157.3	204.7	164.7
16.	122.3	134.8	114.8	142.3	139.8	149.8
17.	30.0	31.2	31.2	33.7	47.4	26.2
18.	69.9	69.9	52.4	89.8	77.4	117.3
Mean	72.0	70.1	79.5	89.9	80.4	85.4

Table 23. P extracted by 0.06 N $H_2 SO_4$ in 0.10 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	31.8	45.9	42.4	47.1	51.8	51.8
2.	54.1	60.0	35.3	40.0	37.7	42.3
3.	127.1	49.4	38.8	54.1	38.8	40.0
4.	47.1	37.7	42.4	72.9	52.9	51.8
5.	124.7	54.1	56.5	58.8	58.8	61.2
6.	89.4	30.6	37.7	49.4	37.7	54.1
7.	54.1	40.0	44.7	91.8	54.1	54.1
8.	134.1	153.0	141.2	138.8	117.7	129.4
9.	54.1	138.8	52.9	49.4	61.2	112.9
10.	44.7	42.4	41.2	47.1	44.7	51.8
11.	54.1	44.7	54.1	51.8	52.9	65.9
12.	44.7	37.7	47.1	49.4	54.1	78.8
13.	75.3	56.5	63.5	58.8	74.1	91.8
14.	68.2	51.8	49.4	49.4	64.7	61.2
15.	148.2	145.9	127.1	148.2	183.5	160.0
16.	124.7	121.2	141.2	138.8	138.8	170.6
17.	22.4	18.8	29.4	28.2	28.2	23.5
18.	75.3	77.7	58.8	65.9	75.3	83.5
Mean	76.3	67.0	61.3	68.9	68.2	79.8

Table 24. P extracted by 0.08 N H_2SO_4 in 0.04 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	35.3	23.5	23.5	40.0	58.8	49.4
2.	30.6	37.7	35.3	40.0	37.7	42.4
3.	30.6	23.5	37.7	23.5	38.8	40.0
4.	25.9	28.2	42.4	50.6	40.0	52.9
5.	49.4	51.8	70.6	72.9	56.5	56.5
6.	27.1	42.4	37.7	32.9	42.4	35.3
7.	36.5	25.9	37.7	37.7	54.1	49.4
8.	112.9	101.1	141.2	138.8	117.7	129.4
9.	43.5	51.8	75.3	54.1	51.8	61.2
10.	31.8	21.2	30.6	28.2	35.3	30.6
11.	44.7	47.1	61.2	56.5	61.2	54.1
12.	37.7	30.6	32.9	54.1	49.4	61.2
13.	48.2	61.2	67.1	70.6	70.6	68.2
14.	32.9	48.2	30.6	42.4	49.4	54.1
15.	115.3	105.9	115.3	131.8	122.4	147.1
16.	108.2	98.8	103.5	122.4	112.9	141.2
17.	28.2	18.8	23.5	16.5	11.8	28.2
18.	30.6	58.8	36.5	51.8	82.4	70.6
Mean	48.3	48.7	55.7	59.2	60.7	65.1

Table 25. P extracted by 0.08 N H_2SO_4 in 0.06 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	36.0	32.5	35.0	47.4	59.9	54.9
2.	33.7	37.5	39.9	44.9	44.9	50.0
3.	39.9	35.0	35.0	35.0	42.4	42.4
4.	39.9	39.9	47.4	52.4	47.4	54.9
5.	54.9	57.4	69.9	74.9	62.4	62.4
6.	32.5	39.9	37.5	37.5	44.9	42.4
7.	39.9	39.9	44.9	42.4	54.9	49.9
8.	109.9	114.8	157.2	157.3	149.8	152.3
9.	47.4	54.9	57.4	62.4	62.4	72.4
10.	35.0	27.5	37.5	37.5	39.9	37.5
11.	47.4	49.9	59.9	59.9	62.4	59.9
12.	39.9	37.5	39.9	52.4	52.4	57.4
13.	49.9	62.4	67.4	77.4	77.4	74.9
14.	37.5	49.9	37.5	49.9	54.9	57.4
15.	132.3	127.3	132.3	152.3	147.3	149.8
16.	122.3	112.3	129.8	134.8	144.8	152.3
17.	25.0	22.5	25.0	20.0	20.0	25.0
18.	44.9	64.9	49.9	59.9	89.9	82.4
Mean	53.8	55.9	61.3	66.6	69.9	71.0

Table 26. P extracted by 0.08 N H_2SO_4 in 0.08 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	36.2	37.5	39.9	52.4	57.4	57.4
2.	35.0	31.5	39.9	47.4	49.9	52.4
3.	42.4	39.9	37.5	39.9	42.4	42.4
4.	49.9	49.9	49.9	54.9	52.4	54.9
5.	59.9	62.4	67.4	72.4	62.4	62.4
6.	35.0	39.9	37.5	37.5	47.7	47.4
7.	44.9	42.4	49.4	47.4	54.9	54.9
8.	104.9	122.3	162.3	162.3	162.3	164.8
9.	52.4	54.9	52.4	64.9	72.4	82.4
10.	35.0	35.0	39.9	42.4	42.4	42.4
11.	49.9	49.9	49.9	59.3	64.3	62.4
12.	42.4	39.9	39.9	52.4	52.4	57.4
13.	49.9	62.4	67.4	79.9	82.4	82.4
14.	44.9	47.4	44.9	52.4	57.4	59.9
15.	139.8	147.3	157.3	172.3	159.8	169.8
16.	129.8	132.3	144.8	152.3	169.8	174.8
17.	27.5	22.5	22.5	22.5	20.00	22.5
18.	54.9	67.4	72.4	74.9	92.4	87.4
Mean	57.5	60.3	55.3	71.5	74.6	76.6

Table 27. P extracted by 0.08 N H_2SO_4 in 0.10 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	36.2	39.9	44.9	54.9	57.4	62.4
2.	35.0	37.5	39.9	49.9	54.9	57.4
3.	47.4	44.9	37.5	44.9	42.4	42.4
4.	59.9	54.9	49.9	57.4	54.9	54.9
5.	62.4	64.9	68.7	69.9	64.9	62.4
6.	34.5	37.5	36.2	39.9	47.4	49.9
7.	47.4	49.9	53.7	52.4	54.9	57.4
8.	107.4	127.3	167.3	172.3	174.8	177.3
9.	56.2	54.9	54.9	68.7	82.4	92.4
10.	35.0	39.9	42.4	44.9	44.9	42.4
11.	49.9	49.9	52.4	59.9	62.4	62.4
12.	42.4	44.9	44.9	52.4	54.9	57.4
13.	49.9	59.9	64.9	82.4	84.9	87.4
14.	47.4	47.4	48.7	54.9	57.4	59.9
15.	144.8	157.3	164.8	182.2	187.2	192.2
16.	134.8	147.8	168.5	172.3	182.2	194.7
17.	25.0	22.5	22.5	25.0	25.0	22.5
18.	264.9	69.9	74.9	89.9	94.9	92.4
Mean	71.1	64.0	68.7	76.3	79.3	81.5

Table 28. P extracted by 0.10 N H_2SO_4 in 0.04 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	43.7	51.2	47.4	47.4	53.7	49.9
2.	41.2	54.9	44.9	49.9	47.4	54.9
3.	49.9	49.9	46.2	46.2	52.4	52.4
4.	44.9	57.4	58.7	49.9	56.2	74.9
5.	62.4	77.4	66.2	67.4	81.1	74.9
6.	37.4	57.4	41.2	47.4	43.7	48.7
7.	54.9	54.9	57.4	61.2	54.9	59.9
8.	126.1	157.3	154.8	137.3	161.0	169.8
9.	64.9	72.4	61.2	67.4	73.7	72.4
10.	44.9	59.9	42.4	42.4	64.9	54.9
11.	62.4	58.5	54.9	58.7	74.9	69.9
12.	54.9	71.2	49.9	54.9	68.7	62.4
13.	54.9	74.9	68.7	69.9	77.4	87.4
14.	49.9	53.7	47.4	57.4	54.9	54.9
15.	126.1	172.3	154.8	156.0	166.0	164.8
16.	128.7	156.0	139.8	132.3	164.8	177.3
17.	126.1	172.3	154.8	156.0	166.0	164.8
18.	128.7	156.0	139.8	132.3	164.8	177.3
Mean	72.3	89.3	79.5	79.7	90.4	92.9

Table 29. P extracted by 0.10 N H_2SO_4 in 0.06 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	35.0	37.6	42.4	47.4	54.9	59.9
2.	33.7	37.5	42.4	42.4	43.7	44.9
3.	35.0	37.5	39.9	42.4	44.9	47.4
4.	42.4	44.9	52.4	52.4	54.9	54.9
5.	62.4	64.9	69.9	64.9	67.4	67.4
6.	25.0	32.5	41.2	39.9	37.5	37.5
7.	44.9	47.4	49.9	49.9	52.4	52.4
8.	129.8	139.8	149.8	154.8	162.3	167.3
9.	59.9	62.4	64.9	69.9	74.9	77.4
10.	35.0	37.5	39.9	42.4	47.4	49.9
11.	44.9	49.9	52.4	52.4	49.9	54.9
12.	43.7	42.4	42.4	43.7	39.9	39.9
13.	43.7	52.4	62.4	64.9	62.4	67.4
14.	43.7	49.9	54.9	52.4	47.4	49.9
15.	142.3	157.3	167.3	174.8	182.2	184.7
16.	139.8	144.8	153.5	157.3	162.3	169.8
17.	23.7	22.5	22.5	22.5	25.0	25.0
18.	72.4	72.4	73.7	77.4	79.9	84.9
Mean	58.7	63.0	67.9	69.5	71.6	74.2

Table 29. P extracted by 0.10 N H_2SO_4 in 0.06 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	35.0	37.6	42.4	47.4	54.9	59.9
2.	33.7	37.5	42.4	42.4	43.7	44.9
3.	35.0	37.5	39.9	42.4	44.9	47.4
4.	42.4	44.9	52.4	52.4	54.9	54.9
5.	62.4	64.9	69.9	64.9	67.4	67.4
6.	25.0	32.5	41.2	39.9	37.5	37.5
7.	44.9	47.4	49.9	49.9	52.4	52.4
8.	129.8	139.8	149.8	154.8	162.3	167.3
9.	59.9	62.4	64.9	69.9	74.9	77.4
10.	35.0	37.5	39.9	42.4	47.4	49.9
11.	44.9	49.9	52.4	52.4	49.9	54.9
12.	43.7	42.4	42.4	43.7	39.9	39.9
13.	43.7	52.4	62.4	64.9	62.4	67.4
14.	43.7	49.9	54.9	52.4	47.4	49.9
15.	142.3	157.3	167.3	174.8	182.2	184.7
16.	139.8	144.8	153.5	157.3	162.3	169.8
17.	23.7	22.5	22.5	22.5	25.0	25.0
18.	72.4	72.4	73.7	77.4	79.9	84.9
Mean	58.7	63.0	57.9	69.5	71.6	74.2

Table 30. P extracted by 0.10 N H_2SO_4 in 0.08 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	37.5	39.9	44.9	52.4	49.9	54.9
2.	35.9	42.4	47.4	52.4	59.9	52.4
3.	37.5	42.4	44.9	49.9	44.9	52.4
4.	47.4	47.4	49.9	54.9	59.9	54.9
5.	64.9	67.4	69.9	72.4	87.4	74.9
6.	35.0	37.5	42.4	44.9	52.4	37.5
7.	49.9	52.4	52.4	54.9	57.4	59.9
8.	139.8	159.8	159.8	169.8	177.3	182.2
9.	62.4	67.4	67.4	74.9	77.4	82.4
10.	37.5	39.9	44.9	44.9	62.4	62.4
11.	49.9	52.4	57.4	62.4	52.4	57.4
12.	42.4	44.9	44.9	49.9	54.9	54.9
13.	42.4	54.9	67.4	72.4	82.4	74.9
14.	42.4	49.9	54.9	49.9	62.4	59.9
15.	159.8	164.8	174.8	187.2	219.7	224.7
16.	149.8	157.3	162.3	179.8	184.7	192.2
17.	25.0	27.5	25.0	30.0	25.0	27.5
18.	69.9	72.4	73.7	77.4	79.9	89.9
Mean	62.7	67.8	71.4	76.7	82.8	83.1

Table 31. P extracted by 0.10 N H_2SO_4 in 0.10 N HCl, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	38.7	42.4	48.7	58.7	47.4	49.9
2.	39.9	44.9	51.2	59.9	67.4	58.7
3.	43.7	46.2	49.9	52.4	44.9	59.9
4.	51.2	49.9	47.4	62.4	71.2	74.9
5.	71.2	72.4	72.4	77.4	102.4	79.9
6.	36.2	39.9	42.4	47.4	62.4	39.9
7.	52.4	54.9	54.9	58.7	59.9	66.2
8.	149.8	174.8	197.2	192.2	194.7	208.5
9.	64.9	69.9	72.4	81.1	79.9	89.9
10.	42.4	44.9	47.4	47.4	72.4	68.7
11.	57.4	58.7	59.9	67.4	58.7	62.4
12.	41.2	46.2	51.2	58.7	67.4	59.9
13.	42.4	57.4	73.7	81.1	106.1	77.4
14.	39.9	49.9	54.9	47.4	72.4	64.9
15.	173.5	182.2	191.0	199.7	249.7	264.6
16.	162.3	164.8	169.8	202.2	209.7	208.5
17.	30.0	30.0	28.7	35.0	25.0	31.2
18.	69.9	72.4	74.9	79.9	78.6	96.1
Mean	67.1	72.3	77.1	83.8	92.8	92.3

extracted by many of the combinations of the two acids and phosphorus removed by crops in pot culture experiments were found statistically significant. The highest correlations were obtained in the case of the extractants 0.06 N sulphuric acid in 0.06 N hydrochloric acid and 0.06 N sulphuric acid in 0.08 N hydrochloric acid.

2. Mineral acids in combination with organic acids as extractants

The pattern of release of soil-P in various extractants during varying periods of equilibration showed that the values of phosphorus recorded at different periods were fluctuating probably due to the simultaneous release and resorption taking place during extraction. It was therefore felt necessary that unless the resorption of the extracted phosphorus is effectively checked, the reproduceability of the results obtained would be very much affected. If resorption of the extracted phosphorus takes place then the amount of phosphorus finally remaining in the solution, may become a function of the period of shaking, time taken for centrifuging or filtering the soil water suspension and also the time taken for the associated dispensing procedures of the extractant employed. It is possible to standardise the period of equilibration and to recommend specific periods of extraction required under each analytical procedure. But variability in the amount of phosphorus in solution due to variation in the period of contact between soil and extractant solution after the equilibration, will lead to irregular results. Standardisation of the period of contact between soil and the extractant solution will be difficult under normal conditions. This difficulty can be overcome by employing chelates along with the extractant so that soil phosphorus once brought into the solution will not be resorbed by the soil. Acetate, oxalate and citrate are well known chelating organic anions which can be employed to prevent the resorption of phosphorus from the solution.

In the present study varying concentrations of acetic acid, oxalic acid and citric acid were employed in combination with different concentrations of hydrochloric acid and sulphuric acid. Out of the 29 mineral acid extractants employed and discussed earlier, three extractants were selected for trying their performances in combination with the three organic acids, as a pilot study. Thus 0.06 N hydrochloric acid, 0.06 N sulphuric acid and 0.06 N hydrochloric acid in 0.06 N sulphuric acid were employed as extractants in the presence of organic acids. Each organic acid was tried at two concentrations namely 0.05 N and 0.10 N. The influence of these 18 combinations of acids in the extraction of soil phosphorus was studied only in three selected soils (soil numbers 2, 8 and 13).

Data on the phosphorus extracted by 18 combinations of acids involving oxalic acid, acetic acid and citric acid at the concentrations of 0.05 N and 0.10 N are presented in Tables 32, 33 and 34. Observations revealed that the amount of phosphorus brought into solution by the mineral acids was markedly increased by the presence of organic acids, the effect of oxalic acid being much more dominant as compared to that of other organic acids. When 0.06 N hydrochloric acid extracted only 13.4 ppm phosphorus when employed independently, the corresponding value for the combination of 0.06 N hydrochloric acid in 0.05 N oxalic acid was 105.3. This drastic effect of oxalic acid in releasing phosphorus into solution can be assigned to (1) the chelating effect of oxalate anion on the phosphorus release into the soil thereby avoiding the possible resorption of phosphorus on the soil surface. This chelating effect of oxalate ion can be confirmed by the pattern of release of phosphorus observed over increasing periods of equilibration. Phosphorus extracted in the presence of organic acids continuously increased with period of equilibration. This shows that phosphorus once released into the solution has been effectively controlled from resorption by the soil. (2) Oxalic acid itself is an extractant for soil phosphorus which when in combination with a mineral acid extracts considerably higher amounts of phosphorus from the soil as compared to the mineral acids alone. Presence of acetic acid and citric acid also increased the phosphorus extracted by the mineral acids though their effects were not as significant as that of oxalic acid. The mean value of phosphorus extracted by the three mineral acid extractants was 43.9 ppm when the

Table 32. P extracted by extractants involving organic acids, ppm (Soil No.2)

Sl. No.	Extractant	Period of equilibration, min					
		5	10	15	30	45	60
1.	0.06 N HCl	7.8	6.2	10.1	10.6	13.5	17.9
2.	0.06 N HCl in 0.05 N OA	25.0	30.0	35.0	37.5	40.0	40.0
3.	0.06 N HCl in 0.10 N OA	16.5	21.0	26.9	35.7	42.8	48.7
4.	0.06 N HCl in 0.05 N AA	20.1	21.0	23.0	27.0	30.0	31.0
5.	0.06 N HCl in 0.10 N AA	18.1	21.3	23.2	26.2	29.0	32.0
6.	0.06 N HCl in 0.05 N CA	24.0	26.0	31.3	34.0	34.0	35.0
7.	0.06 N HCl in 0.10 N CA	18.0	20.1	22.5	23.0	25.0	25.5
8.	0.06 N $H_2 SO_4$	13.2	12.2	15.7	15.7	17.9	3.4
9.	0.06 N $H_2 SO_4$ in 0.05 N OA	39.9	44.9	47.4	52.4	52.4	54.9
10.	0.06 N $H_2 SO_4$ in 0.10 N OA	42.0	51.0	63.7	65.3	66.1	69.2
11.	0.06 N $H_2 SO_4$ in 0.05 N AA	22.5	24.9	27.4	37.5	37.5	39.9
12.	0.06 N $H_2 SO_4$ in 0.10 N AA	22.5	24.9	32.5	37.5	42.4	47.4
13.	0.06 N $H_2 SO_4$ in 0.05 N CA	29.9	35.0	42.4	47.4	47.4	47.4
14.	0.06 N $H_2 SO_4$ in 0.10 N CA	32.5	34.9	42.4	47.4	47.4	48.0
15.	0.06 N $H_2 SO_4$ in 0.06 N HCl	40.0	23.5	22.4	50.6	45.9	51.8
16.	0.06 N $H_2 SO_4$ & 0.06 N HCl in 0.05 N OA	47.4	49.9	54.9	62.4	62.4	62.4

(contd...)

(Table 32 contd..)

Sl. No.	Extractant	Period of equilibration, min					
		5	10	15	30	45	60
17.	0.06 N H_2SO_4 & 0.06 N HCl in 0.10 N OA	47.4	49.0	53.8	61.3	66.4	73.1
18.	0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N AA	37.5	37.5	44.9	57.4	59.9	64.9
19.	0.06 N H_2SO_4 & 0.06 N HCl in 0.10 N AA	39.9	44.9	49.9	64.9	67.4	67.4
20.	0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N CA	42.4	47.4	52.4	59.9	62.4	67.4
21.	0.06 N H_2SO_4 & 0.06 N HCl in 0.10 N CA	35.0	47.4	59.9	59.9	62.4	69.9

OA - Oxalic acid.
AA - Acetic acid.
CA - Citric acid.

Table 33. P extracted by extractants involving organic acids, ppm (Soil No.8)

Sl. No.	Extractant	Period of equilibration, min 5	10	15	30	45	60
1.	0.06 N HCl	13.5	9.5	14.0	13.5	17.9	22.4
2.	0.06 N HCl in 0.05 N OA	187.2	192.2	194.7	232.2	237.2	239.7
3.	0.06 N HCl in 0.10 N OA	29.7	69.2	106.3	227.4	264.5	304.0
4.	0.06 N HCl in 0.05 N AA	24.7	39.5	49.4	69.2	76.6	81.6
5.	0.06 N HCl in 0.10 N AA	37.1	51.9	61.8	76.6	76.6	81.6
6.	0.06 N HCl in 0.05 N OA	39.5	54.4	69.2	89.0	89.0	94.0
7.	0.06 N HCl in 0.10 N CA	32.1	51.9	71.7	79.1	89.0	98.9
8.	0.06 N H_2SO_4	44.0	44.8	52.1	52.7	52.1	47.6
9.	0.06 N H_2SO_4 in 0.05 N OA	234.7	239.7	244.7	274.6	284.6	292.1
10.	0.06 N H_2SO_4 in 0.10 N OA	215.0	259.5	308.9	311.4	308.9	311.4
11.	0.06 N H_2SO_4 in 0.05 N AA	69.2	76.6	86.5	113.7	111.2	128.5
12.	0.06 N H_2SO_4 in 0.10 N AA	69.2	81.6	98.9	118.6	116.2	116.2
13.	0.06 N H_2SO_4 in 0.05 N CA	91.5	111.2	131.0	148.3	148.3	148.3
14.	0.06 N H_2SO_4 in 0.10 N CA	101.3	106.3	111.2	128.5	133.5	145.8

(contd...)

(Table 33 contd..)

Sl. No.	Extractant	Period of equilibration, min					
		5	10	15	30	45	60
15.	0.06 N $H_2 SO_4$ in 0.06 N HCl	115.3	135.3	94.1	169.4	130.6	195.3
16.	0.06 N $H_2 SO_4$ & 0.06 N HCl in 0.05 N OA	254.6	264.6	279.6	309.6	319.6	337.0
17.	0.06 N $H_2 SO_4$ & 0.06 N HCl in 0.10 N OA	214.4	253.9	259.5	265.2	296.2	344.2
18.	0.06 N $H_2 SO_4$ & 0.06 N HCl in 0.05 N AA	118.5	121.3	149.5	183.5	197.5	211.6
19.	0.06 N $H_2 SO_4$ & 0.06 N HCl in 0.10 N AA	126.9	146.7	166.4	211.6	211.6	211.6
20.	0.06 N $H_2 SO_4$ & 0.06 N HCl in 0.05 N OA	135.4	152.3	172.1	191.8	203.1	214.4
21.	0.06 N $H_2 SO_4$ & 0.06 N HCl in 0.10 N CA	112.8	152.8	194.7	194.7	205.9	222.9

AA - Acetic acid.
OA - Oxalic acid.
CA - Citric acid.

Table 34. P extracted by extractants involving organic acids, ppm (Soil No.13)

Sl. No.	Extractant	Period of equilibration, min 5	10	15	30	45	60
1.	0.06 N HCl	7.3	10.1	15.7	14.6	19.1	17.4
2.	0.06 N HCl in 0.05 N OA	44.9	49.9	52.4	74.9	87.4	94.9
3.	0.06 N HCl in 0.10 N OA	9.3	22.1	34.0	73.0	84.9	96.8
4.	0.06 N HCl in 0.05 N AA	7.6	12.7	16.1	22.1	24.6	28.0
5.	0.06 N HCl in 0.10 N AA	11.9	17.0	19.5	24.6	25.5	28.0
6.	0.06 N HCl in 0.05 N OA	12.7	17.8	22.1	28.9	29.7	29.7
7.	0.06 N HCl in 0.10 N CA	10.2	17.0	23.0	25.5	28.9	32.3
8.	0.06 N H_2SO_4	22.1	25.7	29.7	31.4	38.1	43.1
9.	0.06 N H_2SO_4 in 0.05 N OA	64.9	67.4	69.9	82.4	102.4	117.3
10.	0.06 N H_2SO_4 in 0.10 N OA	76.8	93.0	110.5	110.5	110.5	111.9
11.	0.06 N H_2SO_4 in 0.05 N AA	24.3	27.0	31.0	40.5	43.1	45.8
12.	0.06 N H_2SO_4 in 0.10 N AA	24.3	28.3	33.7	41.8	43.1	45.8
13.	0.06 N H_2SO_4 in 0.05 N CA	32.3	39.1	47.2	52.6	53.9	53.9
14.	0.06 N H_2SO_4 in 0.10 N CA	36.4	37.8	39.1	45.8	47.2	52.6

(contd...)

(Table 34 contd..)

Sl. No.	Extractant	Period of equilibration, min 5	10	15	30	45	60
15.	0.06 N H_2SO_4 in 0.06 N HCl	51.8	64.7	116.5	40.0	80.0	141.2
16.	0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N OA	67.4	74.9	82.4	97.4	102.4	109.9
17.	0.06 N H_2SO_4 & 0.06 N HCl in 0.10 N OA	64.7	76.8	79.5	80.9	90.3	105.2
18.	0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N AA	36.4	37.8	45.8	55.3	60.7	64.7
19.	0.06 N H_2SO_4 & 0.06 N HCl in 0.10 N AA	39.1	44.5	51.2	64.7	66.1	67.4
20.	0.06 N H_2SO_4 & 0.06 N HCl in 0.05 H CA	41.8	45.8	52.6	58.0	62.0	64.7
21.	0.06 N H_2SO_4 & 0.06 N HCl in 0.10 N CA	33.7	45.8	59.3	60.7	63.4	67.4

AA - Acetic acid.

OA - Oxalic acid.

CA - Citric acid.

effects of soils and periods of equilibration were pooled, whereas in the presence of oxalic acid, acetic acid and citric acid the values were 126.8, 61.4 and 67.8 ppm P, respectively. The pattern of phosphorus release over varying periods of equilibration in the presence of acetic acid and citric acid was similar to that of oxalic acid. The values of phosphorus consistently increased with increasing periods of equilibration showing that resorption of the phosphorus once brought into solution on to the solid phase has been effectively controlled by the presence of acetic acid and citric acid also. This indicates that the ability of oxalic acid to extract exceedingly higher amounts of phosphorus in combination with mineral acids is not because of its ability to extract a portion of soil phosphorus but it is mainly due to its chelation effect.

When the amounts of phosphorus extracted in the presence of 0.05 N oxalic acid and 0.10 N oxalic acid were compared, it was seen that the higher concentration of oxalic acid would not increase the amount of phosphorus brought into solution, probably because oxalic acid at the strength of 0.05 N was sufficient to chelate all the phosphorus brought into solution. Similarly higher concentrations of acetic acid and citric acid would not increase the amounts of phosphorus extracted as compared to phosphorus extracted by the lower concentration of these acids.

The pilot study thus brought to light the following facts:

1) by employing organic acids resorption of phosphorus from solution can be effectively prevented since phosphorus values at increasing periods of equilibration increase consistently

2) the amounts of phosphorus extracted by the mineral acids can be increased by the presence of organic acids notably oxalic acid

3) organic acids at the strength of 0.05 N is as good as 0.10 N in their effects on the extraction of soil phosphorus mentioned above

Based on these observations only oxalic acid at the strength of 0.05 N was employed along with 17 mineral acid extractants selected from the 29 mineral acid extractants already studied and discussed.

The main criterion in selecting these extractants was the consistency in the pattern of phosphorus release by these extractants at increasing periods of equilibration. The pattern of phosphorus release by these 17 selected extractants in the presence of 0.05 N oxalic acid was observed at varying periods of equilibration with all the 18 soils employed in the study. The relationship between the phosphorus extracted by these extractants and the uptake of phosphorus by successive crops of rice grown in the soils were studied. The 17 extractants selected were comprised of hydrochloric acid at the concentrations of 0.06 N and 0.08 N and sulphuric acid at 0.02 N, 0.04 N, 0.06 N, 0.08 N and 0.10 N in the presence of 0.05 N oxalic acid. Combinations of sulphuric acid and hydrochloric acid at the strengths mentioned above were also tried. The results revealed that the amount of phosphorus brought into solution was considerably increased by the presence of oxalic acid as already seen in the pilot study. The mean values of phosphorus extracted by 0.06 N and 0.08 N hydrochloric acid were 13.7 and 13.3 ppm respectively when the effects of periods of equilibration and soils were pooled, while values for phosphorus extracted by them in the presence of oxalic acid were 81.6 and 83.4 ppm respectively. A similar effect was also noticed in the case of phosphorus extracted by sulphuric acid as well as combinations of sulphuric acid and hydrochloric acid in the presence of oxalic acid. When the percentage of increase in the amount of phosphorus extracted due to the presence of oxalic acid was observed it was seen that the influence was more pronounced at the lower concentrations of mineral acids. This is obviously because at higher concentrations of mineral acids larger amounts of phosphorus were brought into solution as a result the degree of phosphorus resorbed by the soil expressed as the percentage of total phosphorus in solution will be smaller.

Observations on the pattern of release of phosphorus into solution during varying periods of equilibration presented in Tables 35 to 51 showed that in the case of all the 17 extractants employed in the presence of oxalic acid, the major part of the phosphorus extraction was completed within a period of 30 minutes and only a slow rate of release continued thereafter. As a result, any period of equilibration not lesser than 30 minutes can be considered satisfactory in the extraction of phosphorus using the extractants employed. This observation is of much practical significance since equilibration for more than 30 minutes will be usually inconvenient for adopting the procedure in advisory works. The pattern of release of phosphorus by all the 17 extractants finally studied was much superior to the pattern of release observed with ammonium fluoride and hydrochloric acid (Bray No.1) solution. The amount of phosphorus extracted by 0.03 N ammonium fluoride in 0.025 N hydrochloric acid at varying periods of equilibration fluctuated very much, the mean values for 5, 10, 15, 30, 45 and 60 minutes extraction being 19.67, 17.22, 18.22, 17.58, 15.02 and 13.63 ppm P respectively. This shows that resorption of phosphorus takes place when the period of contract between soil and solution is lower in this method.

Table 35. P extracted by 0.06 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	22.5	27.5	32.5	35.0	37.5	37.5
2.	25.0	30.0	35.0	37.5	40.0	40.0
3.	27.5	32.5	37.5	42.4	45.0	47.4
4.	27.5	35.0	37.5	39.9	42.4	42.4
5.	47.4	52.4	54.9	79.9	92.4	102.4
6.	25.0	30.0	37.5	39.9	42.4	44.9
7.	25.0	30.0	35.0	37.5	39.9	39.9
8.	187.2	192.2	194.7	232.2	237.2	239.7
9.	52.4	59.9	62.4	87.4	102.4	112.3
10.	30.0	35.0	42.4	44.9	47.4	47.4
11.	44.9	49.9	49.9	72.4	84.9	89.9
12.	57.4	64.9	67.4	97.4	114.8	119.8
13.	44.9	49.9	52.4	74.9	87.4	94.9
14.	72.4	79.9	84.9	119.8	139.8	152.3
15.	192.2	197.2	199.7	237.2	242.2	244.7
16.	184.7	189.7	189.7	224.7	232.2	232.2
17.	22.5	27.5	32.5	35.0	37.5	39.9
18.	39.9	44.9	47.4	67.4	77.4	84.9
Mean	62.7	68.2	71.9	89.2	96.8	100.7

Table 36. P extracted by 0.08 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	37.5	44.9	49.9	54.9	57.4	57.4
2.	30.0	35.0	39.9	42.4	42.4	42.4
3.	44.9	52.4	59.9	62.4	64.9	67.4
4.	49.9	59.9	67.4	72.4	72.4	72.4
5.	37.5	39.9	42.4	59.9	64.9	74.9
6.	39.9	47.4	52.4	57.4	57.4	59.9
7.	25.0	27.5	32.5	35.0	37.5	37.5
8.	197.2	198.5	224.7	239.7	244.7	247.2
9.	35.0	39.9	42.4	49.9	57.4	62.4
10.	30.0	35.0	37.5	39.9	42.4	42.4
11.	44.9	49.9	52.4	74.9	82.4	87.4
12.	44.9	49.9	54.9	79.9	74.9	82.4
13.	49.9	54.9	57.4	79.9	89.9	102.4
14.	42.4	44.9	47.4	52.4	54.9	54.9
15.	237.2	237.2	264.6	284.6	292.6	294.6
16.	169.8	169.8	194.7	207.2	209.7	212.2
17.	49.9	57.4	67.4	69.9	72.4	74.9
18.	39.9	44.9	47.4	64.9	72.4	82.4
Mean	67.0	71.6	79.7	90.4	93.9	97.5

Table 37. P extracted by 0.02 N H_2SO_4 in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	30.0	32.5	35.0	42.4	44.9	44.9
2.	35.0	37.5	39.9	47.4	52.4	52.4
3.	27.5	30.0	31.2	37.5	39.9	42.4
4.	32.5	35.0	37.5	42.4	44.9	44.9
5.	52.4	54.9	57.4	82.4	97.4	112.3
6.	39.9	42.4	44.9	52.4	59.9	62.4
7.	39.9	42.4	47.4	54.9	59.9	62.4
8.	219.7	220.9	222.2	224.7	229.7	237.2
9.	47.4	49.9	52.4	72.4	84.9	99.9
10.	54.9	57.4	62.4	74.9	82.4	84.9
11.	52.4	53.7	57.4	77.4	92.4	97.4
12.	77.4	79.9	84.9	117.3	137.3	154.9
13.	52.4	54.9	57.4	79.9	94.9	109.9
14.	62.4	64.9	67.4	94.9	112.3	129.8
15.	312.1	314.6	314.6	319.6	327.0	337.0
16.	229.9	232.2	232.2	237.2	242.2	249.7
17.	62.4	67.4	72.4	84.9	94.9	97.4
18.	54.9	57.4	59.9	84.9	99.9	104.9
Mean	82.4	84.9	87.6	101.5	111.0	118.0

Table 38. P extracted by 0.04 N H_2SO_4 in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	22.5	27.5	27.5	30.0	32.5	32.5
2.	37.5	44.9	47.4	52.4	52.4	52.4
3.	25.0	31.2	32.5	37.5	37.5	39.9
4.	44.9	52.4	47.4	62.4	64.9	64.9
5.	47.4	47.4	49.9	59.9	72.4	84.9
6.	20.0	22.5	25.0	27.5	27.5	30.0
7.	30.0	37.5	39.9	42.4	44.9	44.9
8.	234.7	237.2	239.7	262.1	274.6	287.1
9.	44.9	44.9	47.4	57.4	67.4	79.9
10.	32.5	37.5	39.9	44.9	44.9	44.9
11.	57.4	57.4	59.9	72.4	87.4	102.4
12.	69.9	72.4	72.4	89.9	107.4	127.3
13.	62.4	62.4	64.9	79.9	94.9	112.3
14.	54.9	57.4	69.9	87.4	102.4	122.3
15.	307.1	312.1	314.6	344.5	359.1	377.0
16.	217.2	219.7	222.2	242.2	254.6	264.6
17.	32.5	37.5	39.9	44.9	47.4	47.4
18.	62.4	62.4	64.9	79.9	97.4	112.3
Mean	78.0	81.3	83.6	95.4	103.9	112.6

Table 39. P extracted by 0.06 N H_2SO_4 in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	37.5	42.4	44.9	49.9	52.4	52.4
2.	39.9	44.9	47.4	52.4	52.4	54.9
3.	42.4	47.4	54.9	54.9	57.4	59.9
4.	49.9	59.9	62.4	64.9	67.4	67.4
5.	42.4	42.4	44.9	52.4	64.9	74.9
6.	37.5	42.4	44.9	49.9	49.9	52.4
7.	37.5	42.4	44.9	49.9	52.4	52.4
8.	234.7	239.7	244.7	274.6	284.6	292.1
9.	39.9	39.9	42.4	49.9	62.4	72.4
10.	44.9	49.9	52.4	57.4	59.9	59.9
11.	42.4	44.9	44.9	54.9	67.4	77.4
12.	62.4	64.9	67.4	77.4	94.9	104.9
13.	64.9	67.4	69.9	82.4	102.4	117.3
14.	52.4	54.9	54.9	64.9	82.4	94.9
15.	244.7	249.7	254.6	284.6	297.1	304.6
16.	252.2	257.1	262.1	294.6	304.6	312.1
17.	35.0	39.9	42.4	47.4	49.9	49.9
18.	47.4	49.9	52.4	62.4	74.9	82.4
Mean	78.2	82.2	85.1	95.8	104.3	110.1

Table 40. P extracted by 0.08 N H_2SO_4 in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	44.9	49.9	54.9	57.4	59.9	59.9
2.	42.4	47.4	52.4	54.9	54.9	57.4
3.	44.9	47.4	49.9	52.4	54.9	54.9
4.	44.9	49.9	54.9	59.9	59.9	59.9
5.	57.4	59.9	62.4	74.9	97.4	117.3
6.	39.9	44.9	47.4	49.9	49.9	52.4
7.	54.9	62.4	69.9	72.4	74.9	74.9
8.	237.2	244.7	254.6	297.1	297.1	299.6
9.	52.4	54.9	57.4	69.9	87.4	107.4
10.	49.9	54.9	59.9	62.4	64.9	67.4
11.	44.9	47.4	49.9	59.9	77.4	92.4
12.	62.4	63.7	67.4	79.9	104.9	127.3
13.	67.4	69.9	72.4	87.4	112.3	137.3
14.	44.9	47.4	49.7	57.4	74.9	92.3
15.	272.1	282.1	292.1	342.0	343.3	344.5
16.	237.2	242.2	254.6	297.1	299.6	299.6
17.	27.5	30.0	32.5	35.0	35.0	37.5
18.	62.4	64.9	67.4	82.4	104.9	129.8
Mean	82.6	86.9	91.6	105.1	114.1	122.9

Table 41. P extracted by 0.10 N H_2SO_4 in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	44.9	49.9	52.4	62.4	62.4	64.9
2.	39.9	44.9	47.4	56.2	57.4	57.4
3.	42.4	47.4	49.9	57.4	59.9	62.4
4.	49.9	57.4	59.9	69.9	72.4	72.4
5.	72.4	74.9	77.4	82.4	89.9	99.9
6.	33.7	37.5	39.9	47.4	47.4	49.9
7.	47.4	52.4	52.9	66.2	67.4	67.4
8.	249.7	264.6	279.6	297.1	314.6	329.5
9.	69.9	72.4	72.4	79.9	87.4	117.4
10.	42.4	47.4	52.4	59.9	62.4	62.4
11.	64.9	67.4	69.9	72.4	79.9	99.9
12.	69.9	71.2	72.4	79.9	87.4	114.8
13.	74.9	74.9	77.4	84.9	92.4	124.8
14.	59.9	62.4	64.9	69.9	74.9	102.4
15.	257.1	272.1	287.1	307.1	324.6	339.5
16.	259.6	274.6	289.6	309.6	337.0	342.0
17.	25.0	27.5	27.5	35.0	35.0	37.5
18.	67.4	67.4	69.9	77.4	82.4	112.3
Mean	87.5	92.6	96.8	106.4	113.0	125.4

Table 42. P extracted by 0.02 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	44.9	47.4	49.9	54.9	62.4	62.4
2.	39.9	42.4	44.9	49.9	54.9	56.2
3.	39.9	44.9	46.2	52.2	57.4	57.4
4.	57.4	59.9	64.9	72.4	79.9	79.9
5.	42.4	47.4	52.4	59.9	77.4	99.9
6.	42.4	44.9	47.4	52.4	57.4	57.4
7.	64.9	69.9	74.9	82.4	89.9	92.4
8.	227.2	234.7	242.2	279.6	289.6	299.6
9.	69.9	74.9	79.9	87.4	97.4	99.9
10.	44.9	47.4	49.9	54.9	59.9	62.4
11.	35.0	39.9	44.9	49.9	64.9	84.9
12.	49.9	57.4	62.4	72.4	92.4	119.8
13.	57.4	64.9	72.4	82.4	107.4	137.3
14.	42.4	49.9	54.9	62.4	82.4	104.9
15.	229.7	237.2	244.7	282.1	292.1	302.1
16.	212.2	219.7	227.2	262.1	269.6	279.6
17.	20.0	22.5	22.5	25.0	27.5	30.0
18.	47.4	52.4	59.9	67.4	87.4	109.9
Mean	76.0	81.0	85.6	97.2	108.3	118.7

Table 43. P extracted by 0.04 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	30.0	32.5	35.0	37.5	42.4	44.9
2.	42.4	44.9	47.4	52.4	59.9	59.9
3.	39.9	42.4	43.7	47.4	54.9	54.9
4.	38.7	41.2	42.4	47.4	54.9	54.9
5.	42.4	44.9	47.4	49.9	52.4	52.4
6.	35.0	37.5	38.7	42.4	49.9	49.9
7.	37.5	37.5	39.9	39.9	39.9	39.9
8.	252.2	257.1	259.6	304.6	304.6	304.6
9.	52.4	59.9	69.9	72.4	79.9	94.9
10.	47.4	49.9	52.4	59.9	67.4	67.4
11.	49.9	57.4	67.4	68.7	77.4	87.4
12.	52.4	59.9	67.4	69.9	79.9	92.4
13.	59.9	69.9	79.9	82.4	92.4	109.9
14.	44.9	52.4	59.9	59.9	67.4	79.9
15.	234.7	239.7	242.2	279.6	284.6	284.6
16.	209.7	214.7	217.2	252.2	254.6	284.6
17.	27.5	30.0	31.2	35.0	39.9	39.9
18.	47.4	54.9	62.4	64.9	72.4	74.9
Mean	74.7	79.3	83.6	92.6	98.6	104.3

Table 44. P extracted by 0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	79.9	84.9	89.7	97.4	107.4	112.3
2.	44.9	47.4	49.9	54.9	59.9	62.4
3.	94.9	99.9	104.9	114.8	124.8	129.8
4.	77.4	82.4	87.4	94.7	104.9	107.4
5.	57.4	64.9	74.9	84.9	89.9	104.9
6.	92.4	97.4	102.4	112.3	122.3	127.3
7.	89.9	94.9	99.9	109.9	119.8	124.8
8.	252.2	257.1	264.6	307.1	314.6	324.6
9.	62.4	69.9	79.9	89.9	94.9	94.9
10.	77.4	82.4	87.4	94.9	104.9	107.4
11.	49.9	57.4	64.9	74.9	77.4	94.9
12.	44.9	49.9	57.4	64.9	67.4	79.9
13.	62.4	69.9	79.9	89.9	94.9	114.8
14.	64.9	72.4	84.9	94.9	99.9	119.8
15.	247.2	252.2	259.6	302.1	309.6	317.1
16.	207.2	212.2	219.7	249.7	254.6	267.1
17.	39.9	42.4	47.4	51.2	54.9	57.4
18.	57.4	64.4	74.9	84.9	87.4	99.9
Mean	94.6	100.1	107.2	120.7	127.2	135.9

Table 45. P extracted by 0.08 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	49.9	52.4	57.4	64.9	64.9	66.2
2.	47.4	49.9	54.9	62.4	62.4	62.4
3.	42.4	44.9	49.9	57.4	57.4	58.7
4.	52.4	54.9	62.4	69.9	69.9	72.4
5.	62.4	69.9	77.4	89.9	94.9	102.4
6.	43.7	46.2	52.4	57.4	58.7	59.9
7.	51.2	54.9	59.9	67.4	68.7	69.9
8.	254.6	264.6	279.6	309.6	319.6	337.0
9.	57.4	64.9	72.4	82.4	88.6	92.4
10.	39.9	42.4	47.4	52.4	53.7	53.7
11.	54.9	62.4	67.4	79.9	84.9	89.9
12.	44.9	52.4	56.2	64.9	69.9	74.9
13.	67.4	74.9	82.4	97.4	102.4	109.9
14.	47.3	52.4	57.4	67.4	72.4	77.4
15.	254.6	262.1	277.1	307.1	317.1	324.6
16.	239.7	249.7	264.6	292.1	302.1	317.1
17.	25.0	27.5	30.0	35.0	35.0	36.2
18.	63.7	59.9	69.9	92.4	97.4	104.9
Mean	83.3	88.1	95.5	108.3	112.2	117.2

Table 46. P extracted by 0.10 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	52.4	57.4	57.4	69.9	76.1	81.1
2.	47.4	49.9	49.9	62.4	67.4	72.4
3.	47.4	49.9	49.9	62.4	67.4	72.4
4.	57.4	62.4	63.7	76.1	82.4	88.6
5.	107.4	112.3	117.4	132.3	152.3	162.3
6.	41.2	42.4	43.7	47.4	49.9	51.2
7.	57.4	59.9	62.4	74.9	82.4	87.4
8.	274.6	282.1	292.1	332.0	337.0	342.0
9.	112.3	117.3	122.3	137.3	157.3	169.8
10.	48.7	51.2	52.4	54.9	57.4	57.4
11.	84.9	87.4	89.9	102.4	117.3	124.8
12.	69.9	72.4	74.9	79.9	82.4	84.9
13.	69.9	72.4	74.9	84.9	97.4	104.9
14.	82.4	84.9	87.4	99.9	114.8	122.3
15.	307.1	317.1	327.0	372.0	377.0	382.0
16.	282.1	289.6	299.6	339.5	344.5	382.0
17.	27.5	28.7	30.0	35.0	38.7	42.4
18.	127.3	132.3	137.3	154.8	177.3	192.2
Mean	105.4	109.4	112.9	128.8	137.7	145.6

Table 47. P extracted by 0.02 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	49.9	51.2	52.4	53.7	54.9	54.9
2.	42.4	42.4	44.9	44.9	47.4	47.4
3.	44.9	44.9	47.4	48.7	49.9	49.9
4.	57.4	59.9	62.4	63.7	63.7	63.7
5.	56.2	57.4	59.9	64.9	82.4	94.9
6.	36.2	39.5	39.9	39.9	41.2	41.2
7.	57.4	57.4	51.9	51.9	62.4	62.4
8.	234.7	252.2	269.6	292.1	294.6	299.6
9.	42.4	44.9	44.9	48.7	62.4	72.4
10.	52.4	52.4	54.9	54.9	57.4	58.7
11.	47.4	49.9	52.4	54.9	69.9	81.1
12.	61.2	62.4	64.9	68.7	89.9	102.4
13.	76.1	77.4	79.9	84.9	109.9	127.3
14.	52.4	53.7	54.9	57.4	77.4	88.6
15.	247.2	264.6	282.1	307.1	309.6	284.6
16.	219.7	234.7	252.2	272.1	274.6	279.6
17.	22.5	23.7	24.9	25.0	27.5	28.7
18.	56.2	57.4	59.9	63.7	79.9	84.9
Mean	80.9	84.7	88.9	94.3	103.1	106.8

Table 48. P extracted by 0.04 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	35.0	37.5	42.4	44.9	47.4	47.4
2.	44.9	47.4	54.9	59.9	62.4	62.4
3.	37.5	39.9	42.4	44.9	44.9	44.9
4.	42.4	43.7	49.9	54.9	57.4	57.4
5.	56.2	57.4	59.9	59.9	79.9	82.4
6.	35.0	35.0	42.4	44.9	47.4	47.4
7.	47.4	49.9	57.4	62.4	63.7	63.7
8.	249.7	284.6	322.1	344.5	357.0	367.0
9.	52.4	54.9	57.4	57.4	76.4	84.9
10.	30.0	32.5	37.4	41.2	42.4	42.4
11.	62.4	64.9	67.4	67.4	89.9	107.4
12.	62.4	64.9	66.2	67.4	87.4	104.9
13.	69.9	72.4	74.4	74.4	99.9	124.8
14.	54.9	57.4	59.9	62.4	77.4	94.9
15.	297.1	377.5	384.5	409.4	399.6	436.9
16.	247.2	279.6	312.1	324.6	344.5	352.0
17.	32.5	35.0	39.9	42.4	44.9	44.9
18.	67.4	69.9	71.2	72.4	94.9	114.8
Mean	84.7	94.7	102.3	107.5	117.6	126.7

Table 49. P extracted by 0.06 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	59.1	61.2	62.4	64.9	82.4	99.9
2.	44.9	44.9	47.4	49.9	62.4	74.4
3.	73.7	74.4	77.4	82.4	102.4	122.3
4.	62.4	64.9	67.4	69.9	87.4	104.9
5.	82.4	84.9	87.4	92.4	112.3	142.3
6.	68.7	69.9	72.4	77.4	94.9	112.3
7.	62.4	64.9	67.4	69.9	74.4	79.9
8.	249.7	269.6	292.1	314.6	324.6	337.0
9.	89.9	92.4	93.6	102.4	123.6	149.8
10.	54.9	62.4	64.9	67.9	72.4	77.4
11.	69.9	72.4	72.4	77.4	94.9	117.3
12.	57.4	59.9	62.4	64.9	78.6	94.9
13.	74.9	74.9	77.4	84.9	102.4	129.8
14.	84.9	87.4	84.9	94.9	114.8	139.8
15.	267.1	287.1	312.1	337.0	347.0	359.5
16.	229.7	247.2	267.1	289.6	297.1	307.1
17.	32.5	33.7	35.0	37.5	44.9	49.9
18.	62.4	63.7	64.9	69.9	82.4	99.9
Mean	95.9	100.9	106.0	113.7	127.7	144.4

Table 50. P extracted by 0.08 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	49.9	54.9	57.4	59.9	64.9	66.2
2.	44.9	49.9	52.4	54.9	59.9	59.9
3.	42.4	47.4	49.9	52.4	57.4	57.4
4.	54.9	59.9	64.9	67.4	72.4	72.4
5.	74.9	77.4	79.9	87.4	102.4	119.8
6.	42.4	47.4	49.9	52.4	54.9	54.9
7.	49.9	52.4	57.4	59.9	59.9	59.9
8.	254.6	274.6	294.6	334.5	339.5	339.5
9.	69.9	72.4	77.4	84.9	99.9	112.3
10.	42.4	44.3	47.4	49.9	49.9	49.9
11.	64.9	67.4	69.9	74.9	89.9	99.9
12.	49.9	54.9	57.4	57.4	63.7	64.9
13.	82.4	84.9	87.4	94.9	112.3	134.8
14.	57.4	62.4	62.4	69.9	82.4	94.9
15.	274.6	297.1	317.1	362.0	367.0	367.0
16.	262.1	282.1	304.6	344.5	349.5	349.5
17.	25.0	27.5	27.5	30.0	32.5	32.5
18.	87.4	89.9	92.4	99.9	119.8	139.8
Mean	90.6	97.0	102.8	113.2	121.0	126.4

Table 51. P extracted by 0.10 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid, ppm

Soil sample No.	Period of equilibration, min					
	5	10	15	30	45	60
1.	42.4	47.4	49.9	49.9	64.9	87.4
2.	44.9	49.9	49.9	49.9	69.9	92.4
3.	39.9	44.9	47.7	49.9	62.4	77.4
4.	49.9	54.9	54.9	57.4	63.7	77.4
5.	79.9	82.4	84.9	84.9	99.9	119.8
6.	39.9	42.4	42.4	44.9	59.9	79.9
7.	39.9	44.9	47.4	47.4	59.9	82.4
8.	259.6	294.7	312.1	322.1	339.5	362.0
9.	99.9	102.4	102.4	107.4	124.8	149.8
10.	44.9	52.4	54.9	54.9	62.4	69.9
11.	72.4	74.9	77.4	79.9	92.4	112.3
12.	64.9	67.4	67.4	69.9	79.9	97.4
13.	87.4	89.9	89.9	94.9	109.9	132.3
14.	69.9	72.4	74.9	77.4	89.9	107.4
15.	297.1	337.0	357.0	357.0	387.0	411.9
16.	269.6	307.1	324.6	334.5	352.0	374.5
17.	24.9	27.5	27.5	30.0	37.5	49.9
18.	102.4	104.9	107.4	109.9	127.3	154.8
Mean	96.1	105.4	109.6	112.9	126.8	146.6

3. Relationship between P extracted by acid extractants and uptake of P by successive crops of rice grown in the soil

In order to estimate the total available phosphorus reserve (Ra-value) of the soil that can be taken up by crops continuously grown in them, successive crops of rice were grown in the soil in pot culture experiment. Six crops were raised during the experimental period in each soil and the amount of phosphorus taken up from the soil by each crop was recorded. The cumulative phosphorus uptake by successive crops has been tabulated in Table 54. The percentage of phosphorus in the plant was also recorded with respect to each crop (Table 52). The cumulative phosphorus uptake by the end of sixth crop was grouped into 4 categories based on the percentage phosphorus in plant. These 4 categories represent the following 4 groups of soils.

1) in which the percentage phosphorus content in the plants falls below 0.025.
2) in which the percentage phosphorus content in the plants falls below 0.05.

3) in which the percentage phosphorus content in the plants falls below 0.10 and
4) in which the percentage phosphorus content in the plants falls below 0.20.

There were only 7 soils in which the percentage phosphorus in plants by the end of sixth crop ran below 0.025. In 11 soils the content of phosphorus in plants falls below 0.05%. There were 16 soils the plants of which contain less than 0.10 per cent phosphorus, while the plants in all 18 soils came under the fourth category with plant phosphorus percentage less than 0.20. Successive cropping by rice was effected in the soil with the idea of finding out the"Ra-value"or the total amount of phosphorus that can be taken up by the crop by growing continuously. Even in the sixth crop plants removed phosphorus from the soil though the percentage of phosphorus in the plant was considerably low. Since the"Ra-value"is defined as the total available reserve of the soil that can be taken up by plants, it is practically difficult to exhaust the soil by continuous cropping to an extent until no more phosphorus can be taken up from the soil by the plants. It was therefore necessary to establish an end point at

Table 52. Mean percentage of P in successive crops of rice grown in the soils

Soil sample No.	Percentage of P in rice crops, ppm					
	1	2	3	4	5	6
1.	0.479	0.753	0.471	0.137	0.128	0.045
2.	0.462	0.838	0.462	0.248	0.171	0.040
3.	0.539	0.898	0.479	0.222	0.359	0.128
4.	0.616	0.821	0.409	0.240	0.385	0.171
5.	0.907	0.718	0.479	0.240	0.359	0.050
6.	0.889	0.873	0.454	0.214	0.308	0.100
7.	0.445	0.787	0.479	0.265	0.043	0.001
8.	0.838	0.873	0.590	0.411	0.043	0.020
9.	0.616	0.753	0.359	0.257	0.103	0.001
10.	0.779	0.744	0.419	0.223	0.051	0.012
11.	0.761	0.787	0.462	0.282	0.111	0.082
12.	0.787	0.958	0.497	0.308	0.179	0.020
13.	0.712	0.941	0.376	0.282	0.034	0.045
14.	1.181	0.830	0.642	0.291	0.120	0.083
15.	0.769	0.838	0.548	0.325	0.128	0.062
16.	0.393	0.804	0.445	0.376	0.180	0.091
17.	0.778	1.112	0.445	0.201	0.222	0.002
18.	0.565	0.702	0.551	0.240	0.154	0.020
Mean	0.695	0.835	0.465	0.265	0.171	0.054

Table 53. Mean P uptake in successive crops of rice grown in the soils

Soil sample No.	P uptake of rice crops, ppm					
	1	2	3	4	5	6
1.	11.86	17.84	15.62	7.06	3.80	1.19
2.	10.76	20.66	13.70	10.62	5.10	2.29
3.	13.56	18.96	14.54	9.96	10.40	6.69
4.	16.90	18.06	12.84	11.48	11.80	10.89
5.	23.36	15.52	16.08	13.34	12.68	3.62
6.	22.28	18.26	14.22	8.20	8.10	4.87
7.	11.56	19.74	19.48	13.04	1.44	0.06
8.	18.76	18.70	19.42	19.64	3.70	1.15
9.	16.86	17.48	12.58	11.48	1.40	0.06
10.	20.08	14.80	16.02	10.28	3.04	0.53
11.	15.66	18.42	11.40	11.68	5.70	1.70
12.	16.32	18.50	14.26	13.44	0.94	0.72
13.	16.26	18.76	15.28	12.34	4.14	2.03
14.	24.80	16.20	21.44	11.24	4.78	3.59
15.	17.52	20.38	17.82	16.48	5.14	3.68
16.	9.54	17.04	15.78	18.78	7.82	5.33
17.	17.56	24.06	13.26	7.66	0.86	0.09
18.	13.40	15.18	11.60	11.10	4.32	0.99
Mean	16.50	18.25	15.30	12.10	5.29	2.79

Table 54. Cumulative P uptake by successive cropping, ppm

Soil sample No.	Crop No.					
	1	1 & 2	1 - 3	1 - 4	1 - 5	1 - 6
1.	11.86	29.70	45.32	52.38	56.18	58.16
2.	10.76	31.42	45.12	55.74	60.84	63.13
3.	13.56	32.52	47.06	57.02	67.42	74.11
4.	16.90	34.96	47.80	59.28	71.08	81.97
5.	23.36	38.88	54.96	65.04	77.72	81.34
6.	22.28	40.54	54.76	62.96	71.06	75.93
7.	11.56	31.30	50.78	63.82	65.26	65.32
8.	18.76	37.46	56.88	76.52	80.22	81.37
9.	16.86	34.34	46.92	58.40	59.80	59.86
10.	20.08	34.88	50.90	61.18	64.22	64.75
11.	15.66	34.08	51.58	63.26	68.96	70.66
12.	16.32	34.82	49.08	62.52	63.46	64.18
13.	16.26	35.02	45.94	58.28	62.42	64.45
14.	24.80	41.00	62.44	73.68	78.46	82.05
15.	17.52	37.90	55.72	72.20	77.34	81.02
16.	9.54	26.58	42.36	61.14	68.96	74.29
17.	17.56	41.62	54.88	62.54	63.40	63.49
18.	13.40	28.58	40.18	51.28	55.60	56.59
Mean	16.50	34.76	50.15	62.07	67.36	70.15

which the removal of the available phosphorus reserve of the soil can be considered practically completed by the plant based on the level of phosphorus in plants of the last crop. According to Aiyar (1946) a leaf phosphorus percentage in the range 0.016 to 0.021 is considered deficient in the case of rice. In the present study phosphorus percentage in leaves of plants grown in 7 soils was less than 0.025 at the end of sixth crop and therefore these 7 soils were treated as group No.1 for the purpose of examining the relationship between "Ra-values" and phosphorus extracted by the methods. Values for phosphorus percentage in plant in the range of 0.036 to 0.046 are considered intermediate at which response to phosphorus application can be expected. Soils in which plant phosphorus percentage was less than 0.05 per cent were therefore treated as another group in the present study so as to separately examine the relationship between "Ra-values" and phosphorus extracted by chemical extractants in this group of soils. The grouping based on the plant phosphorus per cent 0.10 followed in the study was quite arbitrary, the value being in multiple

Table 55. Coefficients of correlation between P extracted by selected extractants and P uptake by successive crops of rice

Period of equilibration, min	P uptake by crops					
	1	1 & 2	1 - 3	1 - 4	1 - 5	1 - 6
1. <u>0.06 N HCl in 0.05 oxalic acid</u>						
5	-0.016	-0.016	0.197	0.618**	0.558*	0.486*
10	-0.011	-0.012	0.200	0.621**	0.560*	0.489*
15	-0.001	-0.001	0.213	0.629**	0.565*	0.492*
30	0.043	0.018	0.229	0.642**	0.568*	0.487*
45	0.072	0.032	0.238	0.646**	0.569*	0.479*
60	0.103	0.052	0.251	0.652**	0.574*	0.479*
2. <u>0.08 N HCl in 0.05 N oxalic acid</u>						
5	-0.053	0.031	0.197	0.577*	0.535*	0.489*
10	-0.056	0.034	0.192	0.568*	0.530*	0.489*
15	-0.070	0.027	0.186	0.563*	0.526*	0.487*
30	-0.060	0.024	0.171	0.559*	0.521*	0.475*
45	-0.058	0.022	0.165	0.552*	0.515*	0.466
60	-0.052	0.022	0.151	0.541*	0.506*	0.455
3. <u>0.02 N H_2SO_4 in 0.05 N oxalic acid</u>						
5	-0.129	-0.097	0.086	0.528*	0.492*	0.449
10	-0.155	-0.099	0.095	0.524*	0.492*	0.454
15	-0.141	-0.104	0.093	0.518*	0.489*	0.453
30	-0.135	-0.102	0.087	0.523*	0.487*	0.445
45	-0.113	-0.092	0.089	0.534*	0.491*	0.443
60	-0.096	-0.083	0.096	0.542*	0.497*	0.444

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 56. Coefficients of correlation between P extracted by selected extractants and P uptake by successive crops of rice

Period of equilibration, min	P uptake by crops					
	1	1 & 2	1 - 3	1 - 4	1 - 5	1 - 6
4. 0.04 N H_2SO_4 in 0.05 N oxalic acid						
5	-0.040	0.022	0.200	0.584*	0.504*	0.432
10	-0.040	0.024	0.200	0.583*	0.503*	0.430
15	-0.038	0.028	0.204	0.586*	0.501*	0.426
30	0.002	0.050	0.218	0.599**	0.500*	0.411
45	0.034	0.072	0.233	0.609**	0.499*	0.402
60	0.068	0.094	0.249	0.622**	0.507*	0.403
5. 0.06 N H_2SO_4 in 0.05 N oxalic acid						
5	-0.065	-0.017	0.160	0.570*	0.318	0.446
10	-0.077	-0.021	0.160	0.569*	0.308	0.449
15	-0.061	-0.008	0.179	0.585*	0.312	0.454
30	-0.045	-0.001	0.181	0.589*	0.323	0.461
45	-0.033	-0.002	0.179	0.589*	0.336	0.452
60	-0.007	0.012	0.187	0.596**	0.350	0.448
6. 0.08 N H_2SO_4 in 0.05 N oxalic acid						
5	-0.126	-0.099	0.097	0.525*	0.314	0.428
10	-0.127	-0.099	0.101	0.527*	0.310	0.429
15	-0.139	-0.110	0.094	0.522*	0.303	0.425
30	-0.127	-0.103	0.094	0.524*	0.312	0.424
45	-0.105	-0.104	0.086	0.524*	0.332	0.410
60	-0.076	-0.096	0.078	0.519*	0.341	0.388

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 57. Coefficients of correlation between P extracted by selected extractants and P uptake by successive crops of rice

Period of equilibration, min	P uptake by crops					
	1	1 & 2	1 - 3	1 - 4	1 - 5	1 - 6
7. 0.10 N H_2SO_4 in 0.05 N oxalic acid						
5	-0.115	-0.116	0.085	0.528*	0.494*	0.439
10	-0.120	-0.117	0.088	0.530*	0.499*	0.447
15	-0.119	-0.118	0.09	0.530*	0.501*	0.450
30	-0.132	-0.125	0.082	0.523*	0.493*	0.444
45	-0.133	-0.132	0.074	0.518*	0.490*	0.411
60	-0.104	-0.196	0.073	0.523*	0.475*	0.415
8. 0.02 N H_2SO_4 & 0.06N HCl in 0.05 N oxalic acid						
5	-0.137	-0.112	0.095	0.531*	0.480*	0.431
10	-0.133	-0.110	0.098	0.537*	0.484*	0.433
15	-0.132	-0.115	0.092	0.535*	0.483*	0.431
30	-0.128	-0.111	0.095	0.539*	0.487*	0.436
45	-0.108	-0.108	0.096	0.546*	0.492*	0.437
60	-0.074	-0.094	0.104	0.557*	0.498*	0.432
9. 0.04 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid						
5	-0.084	-0.051	0.145	0.574*	0.514*	0.447
10	-0.079	-0.051	0.141	0.573*	0.509*	0.439
15	-0.077	-0.055	0.135	0.571*	0.499*	0.425
30	-0.079	-0.053	0.136	0.569*	0.502*	0.431
45	-0.076	-0.051	0.130	0.564*	0.496*	0.428
60	-0.095	-0.081	0.098	0.543*	0.472*	0.406

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 58. Coefficients of correlation between P extracted by selected extractants and P uptake by successive crops of rice

Period of equilibration, min	P uptake by crops					
	1	1 & 2	1 - 3	1 - 4	1 - 5	1 - 6
10. 0.06 N $H_2 SO_4$ & 0.06 N HCl in 0.05 N oxalic acid						
5	-0.077	-0.047	0.179	0.558*	0.542*	0.506*
10	-0.069	-0.046	0.180	0.561*	0.547*	0.511*
15	-0.052	-0.040	0.188	0.571*	0.556*	0.516*
30	-0.046	-0.032	0.194	0.580*	0.560*	0.515*
45	-0.045	-0.031	0.196	0.576*	0.560*	0.519*
60	-0.025	-0.025	0.209	0.596**	0.583*	0.537*
11. 0.08 N $H_2 SO_4$ & 0.06 N HCl in 0.05 N oxalic acid						
5	-0.123	-0.105	0.096	0.526*	0.500*	0.448
10	-0.114	-0.095	0.107	0.538*	0.516*	0.456
15	-0.114	-0.099	0.100	0.532*	0.508*	0.455
30	-0.117	-0.109	0.087	0.522*	0.498*	0.444
45	-0.110	-0.106	0.090	0.526*	0.499*	0.443
60	-0.105	-0.107	0.088	0.527*	0.501*	0.443
12. 0.10 N $H_2 SO_4$ & 0.06 N HCl in 0.05 N oxalic acid						
5	-0.083	-0.122	0.074	0.502*	0.475*	0.412
10	-0.085	-0.125	0.070	0.497*	0.472*	0.411
15	-0.082	-0.123	0.072	0.499*	0.473*	0.411
30	-0.096	-0.131	0.067	0.495*	0.473*	0.414
45	-0.085	-0.135	0.060	0.484*	0.466	0.405
60	-0.111	-0.170	0.025	0.453*	0.445	0.390

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 59. Coefficients of correlation between P extracted by selected extractants and P uptake by successive crops of rice

Period of equilibration, min	P uptake by crops					
	1	1 & 2	1 - 3	1 - 4	1 - 5	1 - 6
13. 0.02 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid						
5	-0.115	-0.098	0.111	0.544*	0.507*	0.457
10	-0.112	-0.091	0.115	0.547*	0.510*	0.459
15	-0.108	-0.088	0.114	0.544*	0.508*	0.462
30	-0.103	-0.083	0.116	0.545*	0.512*	0.462
45	-0.082	-0.076	0.122	0.559*	0.515*	0.454
60	-0.067	-0.081	0.115	0.562*	0.515*	0.448
14. 0.04 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid						
5	-0.112	-0.070	0.123	0.547*	0.499*	0.440
10	-0.114	-0.069	0.126	0.548*	0.499*	0.441
15	-0.113	-0.061	0.135	0.552*	0.503*	0.445
30	-0.110	-0.054	0.143	0.557*	0.507*	0.449
45	-0.132	-0.120	0.083	0.533*	0.485*	0.421
60	-0.091	-0.059	0.127	0.554*	0.492*	0.425
15. 0.06 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid						
5	-0.028	-0.024	0.186	0.592**	0.571*	0.517*
10	-0.027	-0.024	0.190	0.595**	0.564*	0.514*
15	-0.039	-0.029	0.180	0.588*	0.565*	0.508*
30	-0.035	-0.026	0.183	0.589*	0.569*	0.507*
45	-0.016	-0.015	0.188	0.589*	0.576*	0.523*
60	0.014	-0.001	0.192	0.588*	0.590**	0.544*

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 60. Coefficients of correlation between P extracted by selected extractants and P uptake by successive crops of rice

Period of equilibration, min	P uptake by crops					
	1	1 & 2	1 - 3	1 - 4	1 - 5	1 - 6
16. <u>0.08 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid</u>						
5	-0.122	-0.126	0.065	0.500*	0.479*	0.430
10	-0.123	-0.121	0.072	0.504*	0.483*	0.436
15	-0.130	-0.127	0.067	0.501*	0.481*	0.435
30	-0.122	-0.117	0.077	0.508*	0.486*	0.439
45	-0.114	-0.121	0.067	0.500*	0.481*	0.432
60	-0.096	-0.120	0.059	0.491*	0.475*	0.423
17. <u>0.10 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid</u>						
5	-0.091	-0.107	0.067	0.500*	0.463	0.404
10	-0.101	-0.110	0.072	0.504*	0.436	0.411
15	-0.102	-0.110	0.077	0.508*	0.464	0.415
30	-0.101	-0.106	0.077	0.509*	0.471*	0.415
45	-0.109	-0.114	0.068	0.499*	0.462	0.405
60	-0.122	-0.129	0.054	0.485*	0.447	0.389
18. <u>Bray No.1</u>	0.055	0.038	0.197	0.615**	0.503*	0.408
19. <u>Bray No.2</u>	-0.005	-0.037	0.093	0.499*	0.562*	0.559*
20. <u>Bray No.4</u>	-0.234	0.051	-0.074	0.380	0.335	0.303
21. <u>Olsen</u>	-0.037	-0.018	0.222	0.616**	0.542*	0.450
22. <u>Troug</u>	0.026	0.122	-0.136	-0.104	-0.237	-0.265

* Significant at 5 per cent level

** Significant at 1 per cent level

of 0.025 & 0.05 considered for categorising the other groups of soil.

3.1 Relationship between phosphorus extracted by the 17 acid extractants and cumulative phosphorus uptake at the end of the sixth crop in soils in which the percentage of phosphorus in plants ran below 0.025 per cent

The coefficients of correlation presented in Tables 61 to 66 showed that phosphorus extracted by all the extractants gave significant positive correlation with the cumulative phosphorus uptake in this group of soils except extractant number 12 (0.10 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid). In the case of extractant numbers 1, 6, 16 and 17 phosphorus extracted at the equilibration period of 60 minutes was not significantly correlated with cumulative uptake of phosphorus by plants. Similarly phosphorus extracted by extractant number 17 at the equilibration period of 5 minutes was not correlated with plant uptake. The coefficients of correlation between the phosphorus extracted by the extractant No.2 at the period of equilibration 5, 10 and 15 minutes; extractant No.3 at 5, 10, 15, 30 and 45 minutes; extractant No.4 at 5, 10, 15 and 30 minutes;

extractant No.7 at 45 minutes; extractant No.8 at 5 and 10 minutes; extractant No.9 at 5, 10 and 30 minutes; extractant No.10 at all the periods; extractant No.11 at 10 minutes; extractant No.13 at 5, 10, 15 and 30 minutes; extractant No.14 at 15 and 30 minutes; extractant No.15 at 15 minutes and phosphorus uptake by plants were significantly correlated at 1 per cent level. The coefficients of correlation were comparatively higher in the case of extractant numbers 3, 4, 10 and 13.

3.2 Relationship between phosphorus extracted by the 17 acid extractants at the end of sixth crop in soils in which the percentage of phosphorus in plants ran below 0.050 per cent

The amounts of phosphorus extracted by all the extractants employed except extractant No.12 and 17 were found to be significantly correlated at 5 per cent level with the cumulative phosphorus uptake in this group of soils. However, phosphorus extracted at certain periods of equilibration in the case of some of the extractants were not correlated with phosphorus uptake. They are extractant No.2 at period of equilibration 10 and 15 minutes; extractant No.5 at

45 and 60 minutes; extractant No.7 at 60 minutes; extractant No.8 at all periods except 60 minutes; extractant No.9 at all periods except 5 and 10 minutes; extractant No.10 at 5, 10 and 15 minutes; extractant No.11 at 10 minutes; extractant No.14 at 10 minutes; extractant No.16 at 60 minutes. In no case the coefficients of correlation were significant at 1 per cent level.

3.3 Relationship between phosphorus extracted by the 17 acid extractants and cumulative phosphorus uptake at the end of sixth crop in soils in which the percentage of phosphorus in plants ran below 0.10 per cent

It is interesting to note that phosphorus extracted by all the extractants at all the periods of equilibration was significantly and positively correlated with cumulative uptake of phosphorus by plants in this group of soils. The coefficients of correlation were significant even at 1 per cent level in the case of extractant No.1 at periods of equilibration 30, 45 and 60 minutes and extractant No.15 at the period of equilibration 60 minutes.

3.4 Relationship between phosphorus extracted by the 17 acid extractants and cumulative P uptake at the end of sixth crop in soils in which the percentage of phosphorus in plants ran below 0.20 per cent

This group represents all the 18 soils selected for the study. Significant positive correlation were obtained between phosphorus extracted by extractant No.1, 2, 10 and 15, phosphorus extracted at all periods of equilibration was correlated with cumulative phosphorus uptake whereas phosphorus extracted by extractant No.2 at periods of equilibration 45 and 60 minutes was not positively correlated with phosphorus uptake. It should be pointed out that only extractant numbers 1, 2, 10 and 15 gave significant correlation in all the 4 groups of soils. Among these 4 extractants, No.10 (0.06 N H_2 SO_4 & 0.06 N HCl in 0.05 N oxalic acid) and No.15 (0.06 N H_2 SO_4 & 0.08 N HCl in 0.05 N oxalic acid) may be considered superior to the other two in consideration of the higher values for the coefficients of correlation established between phosphorus uptake in different groups of soil and phosphorus extracted by these extractants at different periods of equilibration.

Table 61. Coefficients of correlation between P extracted by selected extractants and P uptake by rice (in groups based on the P% in leaves, 6th crop)

Period of equilibration, min	P% in leaves			
	<0.025	<0.050	<0.100	<0.200
1. <u>0.06 N HCl in 0.05 N oxalic acid</u>				
5	0.861*	0.655*	0.608*	0.486*
10	0.856*	0.649*	0.608*	0.489*
15	0.868*	0.650*	0.612*	0.492*
30	0.804*	0.646*	0.627**	0.487*
45	0.759*	0.631*	0.630**	0.479*
60	0.726	0.626*	0.637**	0.479*
2. <u>0.08 N HCl in 0.05 N oxalic acid</u>				
5	0.896**	0.615*	0.562*	0.489*
10	0.891**	0.597	0.553*	0.489*
15	0.898**	0.596	0.549*	0.487*
30	0.870*	0.610*	0.547*	0.475*
45	0.857*	0.605*	0.542*	0.466
60	0.832*	0.608*	0.536*	0.455
3. <u>0.02 N H_2SO_4 in 0.05 N oxalic acid</u>				
5	0.908**	0.623*	0.536*	0.449
10	0.915**	0.615*	0.535*	0.454
15	0.916**	0.615*	0.528*	0.453
30	0.907**	0.613*	0.530*	0.445
45	0.885**	0.613*	0.537*	0.443
60	0.866*	0.615*	0.546*	0.444
n	7	11	16	18

n = No. of pairs of observation used for finding correlations

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 62. Coefficients of correlation between P extracted by selected extractants and P uptake by rice (in groups based on the P% in leaves, 6th crop)

Period of equilibration, min	P% in leaves			
	<0.025	<0.050	<0.100	<0.200
4. 0.04 N H_2SO_4 in 0.05 N oxalic acid				
5	0.908**	0.641*	0.555*	0.432
10	0.908**	0.640*	0.554*	0.430
15	0.914**	0.638*	0.552*	0.426
30	0.857*	0.636*	0.560*	0.411
45	0.812*	0.624*	0.567*	0.402
60	0.777*	0.627*	0.579*	0.403
5. 0.06 N H_2SO_4 in 0.05 N oxalic acid				
5	0.854*	0.618*	0.545*	0.446
10	0.871*	0.617*	0.541*	0.449
15	0.871*	0.620*	0.556*	0.454
30	0.848*	0.610*	0.559*	0.461
45	0.808*	0.598	0.558*	0.452
60	0.765*	0.583	0.563*	0.448
6. 0.08 N H_2SO_4 in 0.05 N oxalic acid				
5	0.884**	0.637*	0.527*	0.428
10	0.890**	0.635*	0.526*	0.429
15	0.896**	0.633*	0.520*	0.425
30	0.877**	0.635*	0.525*	0.424
45	0.825*	0.634*	0.524*	0.410
60	0.753	0.609*	0.518*	0.388
n	7	11	16	18

n = No. of pairs of observation used for finding correlations

* Significant at 5 per cent level
** Significant at 1 per cent level

Table 63. Coefficients of correlation between P extracted by selected extractants and P uptake by rice (in groups based on the P% in leaves, 6th crop)

Period of equilibration, min	P% in leaves			
	<0.025	<0.050	<0.100	<0.200
7. 0.10 N H_2SO_4 in 0.05 N oxalic acid				
5	0.847*	0.651*	0.541*	0.439
10	0.860*	0.655*	0.543*	0.447
15	0.865*	0.657*	0.546*	0.450
30	0.872*	0.649*	0.536*	0.444
45	0.893**	0.653*	0.535*	0.411
60	0.794*	0.595	0.524*	0.415
8. 0.02 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid				
5	0.880**	0.585	0.509*	0.431
10	0.877**	0.588	0.514*	0.433
15	0.865*	0.584	0.513*	0.431
30	0.869*	0.593	0.518*	0.436
45	0.841*	0.593	0.525*	0.437
60	0.805*	0.602*	0.540*	0.432
9. 0.04 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid				
5	0.896**	0.624*	0.546*	0.447
10	0.882**	0.608*	0.542*	0.439
15	0.865*	0.589	0.535*	0.425
30	0.877**	0.598	0.535*	0.431
45	0.867*	0.580	0.530*	0.428
60	0.848*	0.551	0.515*	0.406
n	7	11	16	18

n = No. of pairs of observation used for finding correlations

* Significant at 5 per cent level
** Significant at 1 per cent level

Table 64. **Coefficients of correlation between P extracted by selected extractants and P uptake by rice (in groups based on the P% in leaves, 6th crop)**

Period of equilibration, min	P% in leaves			
	<0.025	<0.050	<0.100	<0.200
10. 0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid				
5	0.916**	0.591	0.565*	0.506*
10	0.909**	0.594	0.571*	0.511*
15	0.898**	0.599	0.581*	0.516*
30	0.896**	0.607*	0.585*	0.515*
45	0.899**	0.602*	0.583*	0.519*
60	0.895**	0.624*	0.611*	0.537*
11. 0.08 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid				
5	0.863*	0.637*	0.542*	0.448
10	0.876**	0.594	0.553*	0.456
15	0.865*	0.652*	0.550*	0.455
30	0.840*	0.638*	0.541*	0.444
45	0.833*	0.639*	0.544*	0.443
60	0.827*	0.642*	0.546*	0.443
12. 0.10 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid				
5	0.686	0.589	0.525*	0.412
10	0.682	0.586	0.522*	0.411
15	0.680	0.589	0.523*	0.411
30	0.683	0.587	0.520*	0.414
45	0.623	0.569	0.515*	0.405
60	0.588	0.551	0.498*	0.390
n	7	11	16	18

n = No. of pairs of observation used for finding correlations

*** Significant at 5 per cent level**
**** Significant at 1 per cent level**

Table 65. Coefficients of correlation between P extracted by selected extractants and P uptake by rice (in groups based on the P% in leaves, 6th crop)

Period of equilibration, min	P% in leaves			
	<0.025	<0.050	<0.100	<0.200
13. 0.02 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid				
5	0.902**	0.641*	0.542*	0.457
10	0.902**	0.640*	0.544*	0.459
15	0.899**	0.642*	0.546*	0.462
30	0.894**	0.645*	0.548*	0.462
45	0.871*	0.650*	0.556*	0.454
60	0.857*	0.657*	0.559*	0.448
14. 0.04 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid				
5	0.858*	0.626*	0.546*	0.440
10	0.868*	0.625*	0.544*	0.441
15	0.883**	0.628*	0.546*	0.445
30	0.890**	0.626*	0.547*	0.449
45	0.856*	0.627*	0.532*	0.421
60	0.824*	0.594	0.542*	0.425
15. 0.06 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid				
5	0.855*	0.664*	0.612*	0.517*
10	0.866*	0.665*	0.609*	0.514*
15	0.875**	0.668*	0.601*	0.508*
30	0.869*	0.663*	0.603*	0.507*
45	0.845*	0.662*	0.616*	0.525*
60	0.805*	0.665*	0.633**	0.544*
n	7	11	16	18

n = No. of pairs of observation used for finding correlations

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 66. Coefficients of correlation between P extracted by selected extractants and P uptake by rice (in groups based on the P% in leaves, 5th crop)

Period of equilibration, min	P% in leaves <0.025	<0.050	<0.100	<0.200
16. 0.08 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid				
5	0.802*	0.617*	0.529*	0.430
10	0.813*	0.618*	0.533*	0.436
15	0.821*	0.618*	0.529*	0.435
30	0.823*	0.622*	0.535*	0.439
45	0.781*	0.609*	0.532*	0.432
60	0.731	0.597	0.531*	0.423
17. 0.10 N H_2SO_4 & 0.08 N HCl in 0.05 N oxalic acid				
5	0.727	0.570	0.516*	0.404
10	0.764*	0.584	0.518*	0.411
15	0.776*	0.591	0.522*	0.415
30	0.775*	0.585	0.521*	0.415
45	0.758*	0.575	0.517*	0.405
60	0.727	0.552	0.506*	0.389
18. Bray No.1	0.715	0.459	0.530*	0.408
19. Bray No.2	0.716	0.653*	0.609*	0.559*
20. Bray No.4	0.534	0.306	0.379	0.303
21. Olsen	0.895**	0.641*	0.558*	0.450
22. Troug	-0.648	-0.403	-0.219	-0.265
n	7	11	16	18

n = No. of pairs of observation used for finding correlations

* Significant at 5 per cent level

** Significant at 1 per cent level

Regarding the optimum period of equilibration, a period of 30 minutes should be considered superior since this is the minimum period by which the major part of the phosphorus is brought into solution and thereafter there is only a slow release of phosphorus at a constant rate. Fixing the optimum period of equilibration as 30 minutes, extractant No.10 can be considered slightly superior to extractant No.15 since the coefficient of correlation between phosphorus extracted for the first group of soil and phosphorus uptake by plant is significant even at 1 per cent level in the case of extractant No.10, whereas the corresponding coefficient of correlation for extractant No.15 is significant only at 5 per cent level.

4. Comparison between the performance of Bray No.1 extractant and the acid extractants employed in the study.

Since 0.03 N ammonium fluoride in 0.025 N hydrochloric acid (Bray No.1) is a method adopted by the soil testing laboratories at present in estimating the available phosphorus in soil, a comparison between the pattern of phosphorus release by Bray No.1 extractants at different periods of time and that of the extractant employed in the study had been already made and discussed. The relationship between phosphorus extracted by Bray No.1 extractant and the cumulative phosphorus uptake by the crop was examined. Data presented in Table 66 shows that phosphorus extracted by Bray No.1 fails to correlate significantly with the phosphorus uptake by crops in soil groups No.1, 2 and 4 showing that Bray No.1 is not an efficient extractant for the estimation of total available phosphate reserve (Ra-value) of the soil. Thus the present study recommends the extractant 0.06 N sulphuric acid and 0.06 N hydrochloric acid in 0.05 N oxalic acid with an equilibration period of 30 minutes and soil solution ratio 1 : 10 as a better method for estimating the total available phosphorus reserve (Ra-value) of the soil.

5. Prediction of "Ra-value" using P extracted by the chemical extractant

Regression equations were established between phosphrus extracted by 0.06 N sulphuric acid and 0.06 N hydrochloric acid in 0.05 N oxalic acid for an equilibration period of 30 minutes and the cumulative phosphorus uptake at the end of sixth crop in different groups of soils. The linear regression equations were:

$Y = 0.0807X + 55.82$ for the first group of soils
$Y = 0.0714X + 58.36$ for the second group of soils
$Y = 0.0624X + 61.51$ for the third group of soils and
$Y = 0.0585X + 63.09$ for the fourth group of soils,

where X was the phosphorus extracted by the triple acid extractant in ppm and Y was phosphorus taken up by plants in ppm. In the case of group No.1 soils a unit increase in the phosphorus extracted by the triple acid results in 0.0807 unit increase in the cumulative uptake of phosphorus by plants. Similar coefficients of regression in the case of group No.2, No.3 and No.4 of soils were 0.0714, 0.0624 and 0.0585. Though these regression equations make the prediction of "Ra-values" possible, they do not satisfy the requirement for the determination of the extent of skipping phosphorus application possible. Considering the soil group No.1 for an extracted phosphorus value of 307.1 ppm which is the highest value recorded in the present study, the corresponding "Ra-value" will be 80.60 ppm and for an extracted phosphorus value of 51.2 which is the lowest value recorded in the study the corresponding "Ra-value" will be 59.95 ppm. Thus when the extracted values varied from 51.2 to 307.1 the calculated "Ra-values" varied from 59.95 to 80.60 ppm. This shows that the range of variation in "Ra-value" that can be covered by variation in the extracted phosphorus values is rather limited. With the example quoted the total variation in "Ra-value" is only 20.65 ppm which will correspond to 45.43 kg/ha which is only to the tune of the recommendation of a rice crop. In determining the possibility of skipping of phosphorus application this much variation may not be sufficient. This may be probably due to poor variation in the available phosphorus reserve (Ra-value) of soil present in the soil selected for analysis. As per these regression equations, when the curve is extrapolated, an extracted phosphorus value of 0 ppm will correspond to an "Ra-value" of 55.82 ppm in the case of first group of soil which will mean

122.80 kg/ha. Same is the case with regression equation observed in the other groups of soils. This shows that such a high amount of reserve phosphorus present in soil is not reflected by the values of phosphorus extracted and as a result skipping of phosphorus application for making use of this phosphorus reserve (Ra-value) cannot be precisely predicted by extracted phosphorus values by the method proposed. Though the triple acid method proposed gave better correlation its efficiency in employing as a tool for the prediction of skipping phosphorus application is not satisfactory probably because of the limited variation in the "Ra-values" in the soils selected for study. It therefore appears necessary to test the performance of this extractant in a group of soils which widely vary in their "Ra-values". However the triple acid method finally selected in the study can be considered as a definite improvement over the existing method (Bray No.1), since the triple acid method gave better correlations with P uptake and "Ra-values". Regression equation established between Bray No.1 extracted P and "Ra-values" also possessed the same draw back that when extrapolated, a value of

FIG.1 DESORPTION OF SOIL P IN 0.05 N H_2SO_4 AND 0.05 N HCl in 0.05 N OXALIC ACID

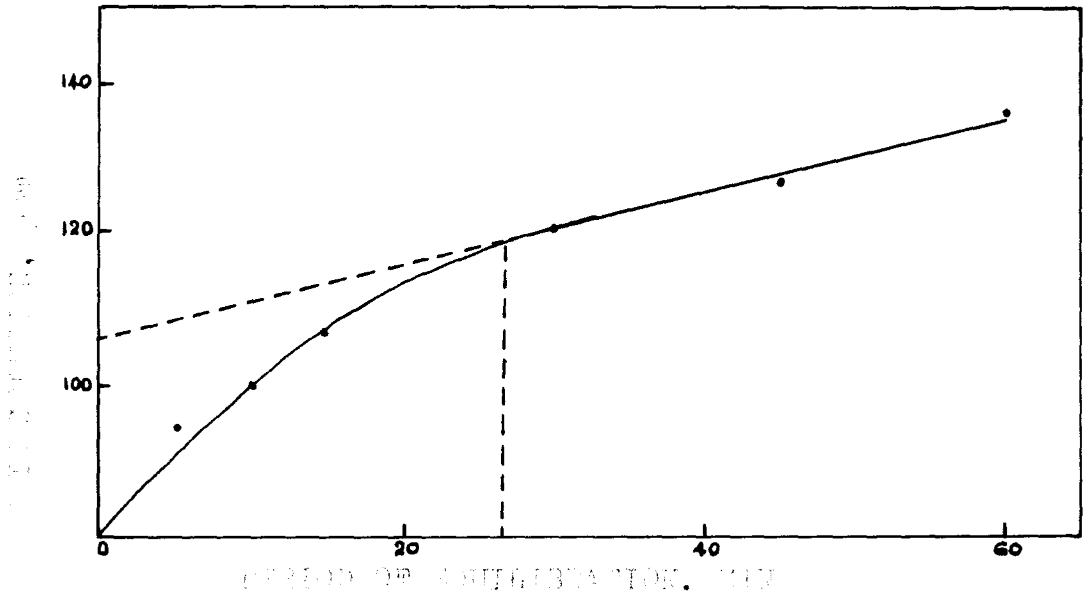


FIG.2 DESORPTION OF [illegible] IN [illegible] .1 [illegible]

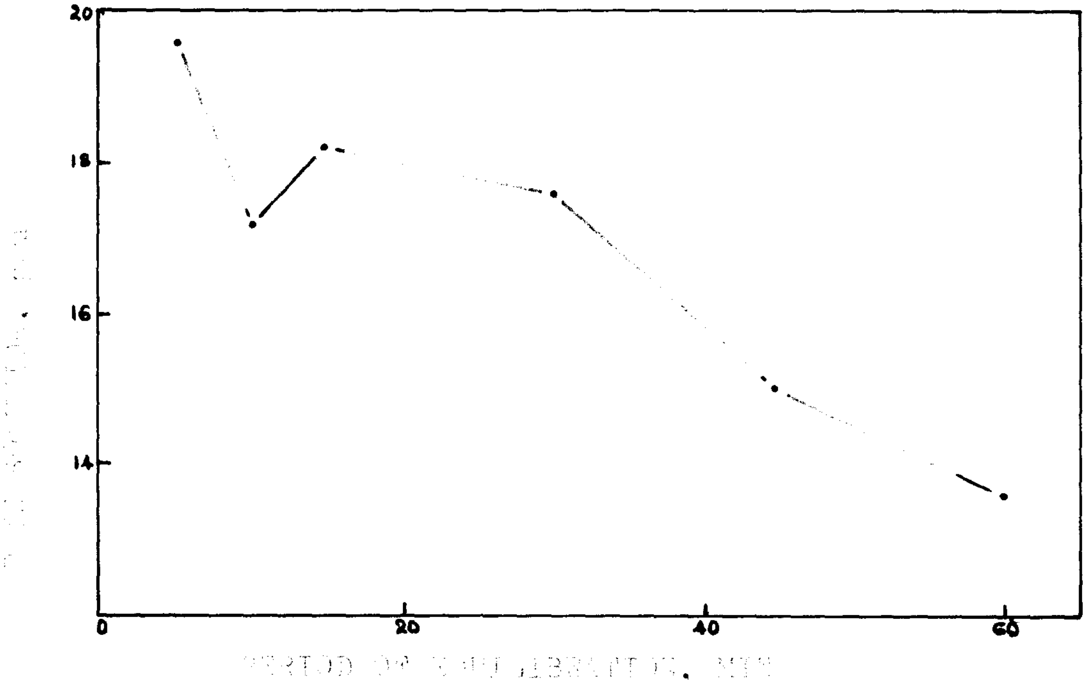


FIG. 3 RELATIONSHIP BETWEEN Ra-VALUE AND P EXTRACTED BY BRAY NO.1 SOLUTION

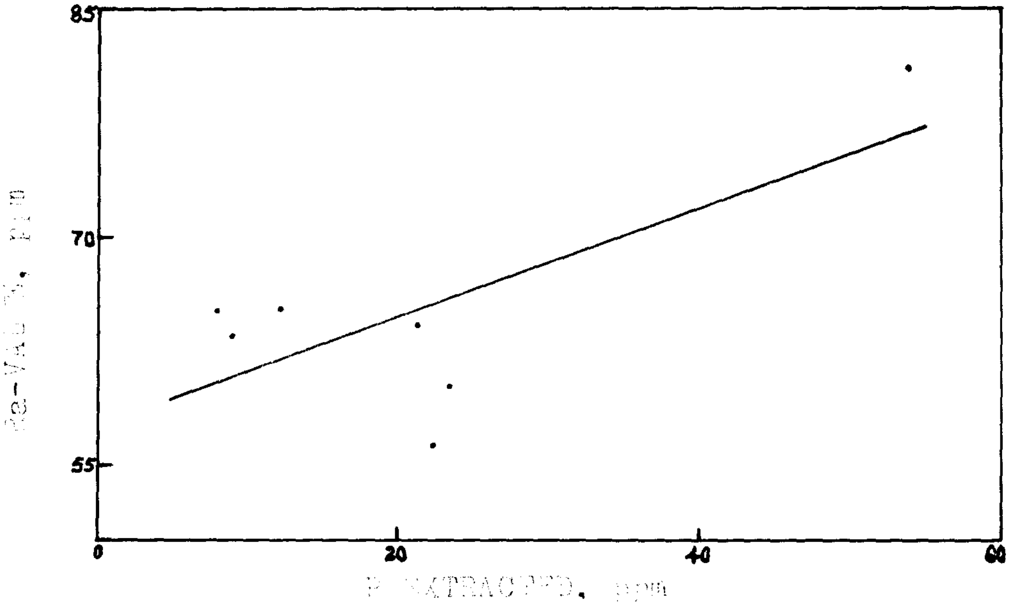
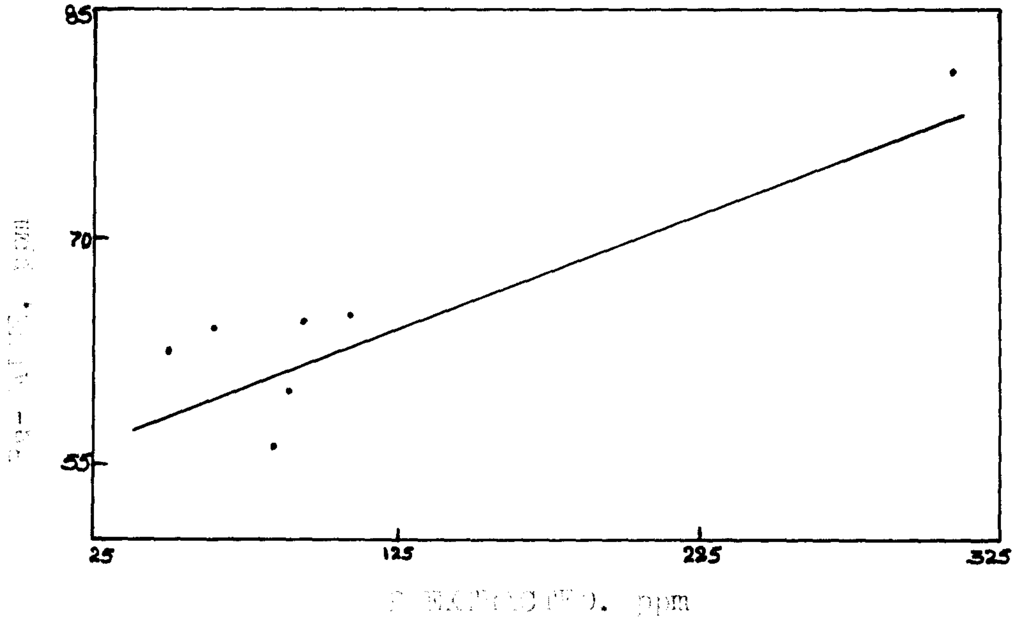


FIG. 4 RELATIONSHIP BETWEEN Ra-VALUE AND P EXTRACTED BY .06 N H_2SO_4 AND 0.06 N HCl IN 0.05 N OXALIC ACID



0 ppm extracted P corresponds to 57.42 ppm (126.32 kg P/ha) which is obviously not within the range of prediction for the purposes of skipping phosphorus application based on calculated "Ra-values".

SUMMARY

SUMMARY

A pot culture experiment and in vitro studies were conducted in lateritic soils of midland Kerala to evolve a suitable laboratory chemical method for the estimation of phosphate reserve (Ra-value) which will be available to the plants over a reasonably long period of time. The findings are summarised below:

1. Among the commonly used five extractants for the estimation of available phosphorus (Bray No.1, Bray No.2, Bray No.4, Olsen's and Truog's) Bray No. 2 and Bray No.4 extracted much higher quantities of phosphorus.

2. Increasing the strength of hydrochloric acid from 0.04 N to 0.10 N did not have any pronounced influence on the amount of phosphorus extracted. Among the various concentrations of hydrochloric acid tried 0.06 N acid extracted the maximum amount of phosphorus from the soil. Compared to Bray No.1 the performance of hydrochloric acid was very poor.

3. Sulphuric acid when employed at concentrations

analogous to that of hydrochloric acid extracted higher quantities of soil phosphorus. Phosphorus extracted at various concentrations correlated with the cumulative phosphorus uptake value at the end of the sixth crop.

4. In the case of both sulphuric and hydrochloric acid extractants, the major part of phosphorus was extracted within 30 minutes of equilibration and thereafter the release was very slow, at a constant rate.

5. Combinations of sulphuric acid and hydrochloric acid, extracted higher quantities of phosphorus from soil than the individual acids and the influence was more profound at lower concentrations.

6. The pattern of release of phosphorus by mineral acids during the varying periods of equilibration was highly fluctuating especially when the acids were used individually. However the degree of fluctuation was considerably less when the combinationsof acids were employed.

7. Among the mineral acid extractants,

phosphorus extracted by the combination of 0.06 N sulphuric acid in 0.06 N hydrochloric acid and 0.06 N sulphuric acid in 0.08 N hydrochloric acid possessed the highest degree of correlation with the "Ka-value".

8. Based on the results of the preliminary screening trial of mineral acid extractants, 17 of them were carried forward for further studies. The main criterion in selecting these extractants was the consistency in the pattern of phosphorus released by these extractants at increasing periods of equilibration.

9. A pilot study for the selection of organic acids and their concentration for chelated system revealed that resorption of phosphorus from solution can be effectively prevented by employing organic acids and the amount of phosphorus extracted by the mineral acids can be increased by the presence of organic acids. Oxalic acid was more effective than acetic and citric acids in this respect. Organic acids at the strength of 0.05 N were as efficient as at 0.10 N in extracting and chelating

phosphorus from the soil. Therefore oxalic acid at the strength of 0.05 N was employed along with the 17 mineral acid extractants selected.

10. For the mineral and organic acid combinations, a period of equilibration not less than 30 minutes was considered critical and optimum.

11. The coefficients of correlation obtained between phosphorus extracted by the chelated extractants and cumulative phosphorus uptake were significant in soils in which the percentage of phosphorus in plant ran below 0.025. Fixing the optimum period of equilibration as 30 minutes, extractant No.10 (0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid) was found to be superior to the remaining combinations.

12. Phosphorus extracted by Bray No.1 failed to correlate significantly with phosphorus uptakes by crops in soil groups in which the percentage phosphorus content of plants were below 0.025, 0.05 and 0.20 showing that Bray No.1 is not an efficient extractant for the estimation of "Ra-value"

of the soil. Thus the present study recommends the extractant 0.06 N H_2SO_4 and 0.06 N HCl in 0.05 N oxalic acid with an equilibration period of 30 minutes and soil solution ratio 1 : 10 as a better method for estimating the total available phosphorus (Ra-value).

13. Though the triple acid method proposed gave better correlation, its efficiency in employing as a tool for the prediction of skipping phosphorus application is not satisfactory since the regression equation established between phosphorus extracted and "Ra-values" is valid only for a short range of "Ra-values". This was due to the limited variation observed in the "Ra-values" of the soils selected for the study. The performance of this extractant in predicting the "Ra-value" of soils and the possibility of skipping phosphorus application can therefore be judged only after trying this method in a set of soils highly varying in their "Ra-values".

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* Originals not seen

APPENDICES

Appendix I. Location and texture of the soil selected for the study.

Soil No.	Location		Textural class
1.	Enamavu	C.F.	sandy loam
2.	Pattambi	R.R.S.	clay loam
3.	Pattambi	C.F.	silt loam
4.	Pattambi	R.R.S.	clay loam
5.	Pattambi	R.R.S.	clay loam
6.	Mannuthy	R.R.S.	loam
7.	Kozhinjampara	C.F.	silt loam
8.	Mannuthy	R.R.S.	loam
9.	Pattambi	R.R.S.	sandy clay
10.	Pudukkad	C.F.	silt loam
11.	Chittanjoor	C.F.	sandy loam
12.	Kunnamkulam	C.F.	sandy loam
13.	Chalakkudy	A.R.S.	clay loam
14.	Chittanjoor	C.F.	silt loam
15.	Madakkathra	C.F.	sandy clay loam
16.	Trichur	C.F.	silt loam
17.	Vellanikkara	C.H.	silty clay loam
18.	Palghat	C.F.	loam

C.F.	cultivators field.
R.R.S.	rice research station.
A.R.S.	agronomic research station.
C.H.	college of horticulture.

Appendix II. Details of rice crops grown

Crop No.	Date of sowing	Date of harvest	No. of days grown	No. of plants per pot	Seed material used
1	11-8-78	10-10-78	60	75	germinated seeds
2	21-10-78	20-12-78	60	75	germinated seeds
3	31-12-78	14-2-79	45	25	15 days old seedlings
4	16-2-79	2-4-79	45	25	15 days old seedlings
5	5-4-79	20-5-79	45	25	15 days old seedlings
6	22-5-79	6-7-79	45	25	15 days old seedlings

Rice variety grown - "IR-8"

Appendix III

Relationship between soil properties and P uptake by successive crops of rice (coefficients of correlation)

Sl. No.	Soil properties	P uptake by crops 1	1 & 2	1 - 3	1 - 4	1 - 5
1.	pH	0.262	0.299	-0.162	0.495*	0.344
2.	EC	-0.180	-0.146	0.106	0.004	0.266
3.	Organic carbon	-0.054	0.073	0.105	0.106	0.174
4.	Total P	-0.350	-0.305	0.364	0.099	0.122
5.	Available P					
	a) Bray No.1	0.055	0.038	0.197	0.615**	0.503*
	b) Bray No.2	-0.005	-0.037	0.093	0.499*	0.562*
	c) Bray No.4	-0.234	0.051	-0.074	0.380	0.335
	d) Olsen	-0.037	-0.018	0.222	0.616**	0.542*
	e) Truog	0.026	0.122	-0.136	-0.104	-0.237

* Significant at 5 per cent level

** Significant at 1 per cent level

Appendix IV **Coefficients of correlation between P extracted by mineral acids and P uptake by successive crops of rice**

Sl. No.	Extractants	P uptake by crops 1	1 & 2	1 - 3	1 - 4	1 - 5
1.	0.04 N HCl	0.205	0.168	0.250	0.436	0.269
2.	0.06 N HCl	0.084	0.045	0.136	0.283	0.331
3.	0.08 N HCl	0.163	0.162	0.125	0.355	0.352
4.	0.10 N HCl	0.103	0.062	0.205	0.553*	0.438
5.	0.02 N H_2SO_4	0.172	0.191	0.288	0.551*	0.359
6.	0.04 N H_2SO_4	0.029	0.051	0.176	0.571*	0.484*
7.	0.06 N H_2SO_4	0.008	-0.018	0.126	0.559*	0.478*
8.	0.08 N H_2SO_4	-0.062	-0.115	0.056	0.499*	0.442
9.	0.10 N H_2SO_4	-0.097	-0.141	0.057	0.513*	0.485*
10.	0.02 N H_2SO_4 in 0.04 N HCl	-0.085	-0.150	-0.075	0.219	0.226
11.	0.02 N H_2SO_4 in 0.06 N HCl	-0.026	-0.084	0.086	0.533*	0.481*

(Contd...)

(Appendix IV contd...)

Sl. No.	Extractants	P uptake by crops 1	1 & 2	1 - 3	1 - 4	1 - 5
12.	0.02 N H_2SO_4 in 0.08 N HCl	-0.014	-0.060	0.112	0.557^{*}	0.508^{*}
13.	0.02 N H_2SO_4 in 0.10 N HCl	-0.065	0.113	0.084	0.533^{*}	0.498^{*}
14.	0.04 N H_2SO_4 in 0.04 N HCl	-0.045	-0.142	-0.004	0.447	0.401
15.	0.04 N H_2SO_4 in 0.06 N HCl	-0.092	-0.046	-0.053	0.271	0.134
16.	0.04 N H_2SO_4 in 0.08 N HCl	-0.150	-0.114	0.024	0.457	0.425
17.	0.04 N H_2SO_4 in 0.10 N HCl	-0.182	-0.192	0.001	0.430	0.451
18.	0.06 N H_2SO_4 in 0.04 N HCl	-0.138	-0.185	-0.018	0.421	0.355
19.	0.06 N H_2SO_4 in 0.06 N HCl	0.134	-0.093	0.223	0.573^{*}	0.591^{**}
20.	0.06 N H_2SO_4 in 0.08 N HCl	0.045	-0.002	0.216	0.605^{**}	0.607^{**}
21.	0.06 N H_2SO_4 in 0.10 N HCl	-0.075	-0.139	0.016	0.446	0.456
22.	0.08 N H_2SO_4 in 0.04 N HCl	-0.092	-0.095	0.066	0.502^{*}	0.485^{*}
23.	0.08 N H_2SO_4 in 0.06 N HCl	-0.008	-0.133	0.051	0.493^{*}	0.481^{*}

(Contd...)

(Appendix IV contd...)

Sl. No.	Extractants	P uptake by crops				
		1	1 & 2	1 - 3	1 - 4	1 - 5
24.	0.08 N H_2SO_4 in 0.08 N HCl	-0.126	-0.292	0.021	0.466	0.436
25.	0.08 N H_2SO_4 in 0.10 N HCl	-0.155	-0.196	-0.008	0.441	0.434
26.	0.10 N H_2SO_4 in 0.04 N HCl	-0.132	-0.009	-0.003	0.273	0.163
27.	0.10 N H_2SO_4 in 0.06 N HCl	-0.123	-0.162	0.032	0.466	0.454
28.	0.10 N H_2SO_4 in 0.08 N HCl	-0.114	-0.142	0.050	0.485*	0.472*
29.	0.10 N H_2SO_4 in 0.10 N HCl	-0.104	-0.120	0.068	0.502*	0.532*

* Significant at 5 per cent level

** Significant at 1 per cent level

EVALUATION OF AVAILABLE PHOSPHATE RESERVE OF SOIL BY CHEMICAL METHODS

BY

MATHEW JACOB, K.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
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ABSTRACT

A laboratory study including a pot culture experiment was carried out using 18 lateritic soil to evolve a suitable laboratory chemical method as an index for the estimation of available phosphate reserve (Ra-value). The total plant removable phosphorus of the soils was determined growing rice (variety IR-8) continuously in soils taken in pots, till the content of phosphorus in plants became below the critical level. The pot culture experiment was designed in completely randomised design with 18 treatments (soils) and 3 replications.

To evolve a suitable extractant for the estimation of "Ra-value" H_2SO_4 and HCl at different concentrations and combinations were tried. Out of the 29 extractants employed, 17 were selected based on their consistence in the pattern of phosphorus release and the amount of phosphorus extracted. From a pilot study, in which different organic acids at different concentrations were screened, oxalic acid at the strength of 0.05 N was selected as the best chelating agent to be employed with the 17 mineral acid combinations.

The results showed that compared to Bray No.1, the performance of HCl was very poor and had only a little pronounced influence on the extraction of phosphorus.

Sulphuric acid at analogous concentrations extracted higher quantities of phosphorus and obtained better correlations with phosphorus uptake values at the end of 6th crop.

Combinations of mineral acids extracted higher quantities of phosphorus from soil than the individual acids, with a pronounced influence at lower concentrations.

The pattern of release of phosphorus fluctuated widely when the mineral acids were used individually, but the degree of fluctuation was considerably less when employed in combination. In all the above cases the major part of phosphorus was extracted within 30 minutes and thereafter the release was very slow.

The pilot study employed in the selection of organic acids for chelated system, to prevent the resorption of phosphorus into the soil from the solution, revealed that resorption of phosphorus from the solution can be effectively prevented by employing organic acids; the amount of phosphorus extracted by the mineral acids can be increased by the presence of organic acids notably oxalic acid and acids at the strengths of 0.05 N were as good as 0.10 N in their effects on the extraction of soil phosphorus.

A period of equilibration not less than 30 minutes was considered critical and optimum.

The extractant No.10 (0.06 N H_2SO_4 & 0.06 N HCl in 0.05 N oxalic acid) was found to be superior to the remaining combinations and gave better correlation with "Ra-values" of the soil. Phosphorus extracted by Bray No.1 failed to correlate significantly with phosphorus uptake by crops in soil groups in which the percentage phosphorus content of plants were below 0.025, 0.05 and 0.2 shewing that Bray No.1 is not an efficient extractant for the estimation of "Ra-value" of the soil. Thus the present study recommend the extractant 0.06 N H_2SO_4 and 0.06 N HCl in 0.05 N oxalic acid with an equilibration period of

30 minutes and soil solution ratio 1 : 10 as a better method for estimating the "Ra-value".

Regression equation between phosphorus extracted by this method and "Ra-value" was established. Since variation in "Ra-values" of the soils selected was rather narrow, the application of this equation in predicting the possibility of skipping phosphorus application in soils appeared very much limited.