PHOSPHORUS UPTAKE BY PLANTS AND READILY EXTRACTABLE PHOSPHORUS IN SOME RICE SOILS OF KERALA IN RELATION TO THEIR IMPORTANT CHEMICAL CHARACTERISTICS

BY

S PADMANABHAN NAIR

THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURE (AGRICULTURAL CHEMISTRY)
OF THE UNIVERSITY OF KERALA.

DIVISION OF AGRICULTURAL CHEMISTRY,
AGRICULTURAL COLLEGE AND RESEARCH INSTITUTE,
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C E R T I F I C A T E

This is to certify that the thesis herewith submitted contains the results of bonafide research work carried out by Sri. S. Padmanabhan Nair, under my supervision. No part of the work embodied in this thesis has been submitted earlier for the award of any degree.

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S. PADMANABHAN NAIR.

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INTRODUCTION

INTRODUCTION

From a practical stand point soil scientists are interested in plant nutrition in relation to soil composition, in order to develop relationships between the composition of the soil as determined in the laboratory and crop response obtained from added nutrients in the field. Such relationships serve as the basis for advising farmers concerning fertiliser applications.

A chemical method for determining available phosphorus in soils was suggested at the turn of this century and it did gain wide acceptance. Since then much progress has been made. But most of the soil phosphorus available to crops have been developed empirically rather than from an estimation of the phosphorus fractions which are actually related to availability. Any of these methods gives satisfactory results only within restricted groups of soils, and is not applicable in a general way to all groups of soils. (Soil Test Work Group, National Research Committee. Soil tests compared with field, green house and laboratory results. North Carolina Agr.Exp.Sta.Tech.Bull. 121.1956).

In order that test values for available phosphorus determined by various methods are useful to predict the phosphorus needs of a crop, it is essential to develop relationships between the test values on different soils and the response of the crop from added phosphorus.

Another problem which has received very little attention is the effect of drying the soil prior to sampling and testing. Air drying has shown markedly to alter the availability of nitrogen, phosphorus and potassium. There is considerable evidence to show that when soils are kept moist the available phosphorus increases. Basak and Bhattacharya (1961) have shown that there is an increase of 64 percent of available phosphorus in water-logged soils during the period from planting to tillering stage in the case of rice, a period of approximately twenty days to one month. For these reasons a sample tested after drying, especially in the case of rice soils, cannot be considered as representative of the field soils. This is an aspect that should be given due consideration in testing rice paddy soils for available phosphorus.

The rice soils of Kerala include a wide range of soil types, viz. laterite soils, found in Trivandrum, Quilon, Trichur, Palghat, Kozhikode and Cannanore District; Sandy soils (coastal alluvium) occurring in the Onattukara region of Quilon and Alleppey Districts; and Peat soils (Kari) riverborne alluvium (Karapadom) and lake bed soil (Kayal) of the Kuttanad region comprising Alleppey, Kottayam and Ernakulam districts.

The Kuttanad region in which the present study is projected, covers an area of about 400 sq. miles, mainly devoted to the cultivation of rice. The soils of this tract are submerged under water during the greater part of the year and are subject to periodical inundation with sea water.

The soil test summaries prepared by the Soil Testing Laboratory, Vellayani in respect of over 10,000 samples collected from Kuttanad, using Bray No. I Reagent as extractant, show that about 80 percent of the soils is low in available phosphorus. Studies conducted by Koshy and Brito Mutunayagom (1964) reveal that the fixation of phosphorus in these soils is primarily a chemical precipitation reaction involving iron and aluminium rather than an absorption type of reaction.

Field experiments conducted over a number of years by Agricultural Research Stations located in Kuttanad have given inconsistent results (Poti, 1964) or low response to phosphatic fertilisers (Annual reports of the C.M.A. Scheme 1964). The need was, therefore, felt for a reappraisal of the phosphorus test methods and related aspects of the problem and hence the present study was undertaken with following objectives:

(i) To evaluate some of the important extractants for the determination of available phosphorus, on airdried samples and on samples incubated at water holding capacity.

(ii) To study some of the important chemical characteristics of the soils of the area and their influence on the available phosphorus as determined by various extractants.

(iii) To correlate the available phosphorus estimated by chemical methods with that determined by Neubauer test method and pot culture experiments.

(iv) To determine response of rice plants grown on river borne alluvial soils (Karapadom soils) of Kuttanad having widely different test values for available phosphorus, to graded doses of added phosphorus.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Liebig (1840) and Way (1850) demonstrated that phosphorus might be retained in the soil in an unavailable form. Since then soil chemists have attempted to estimate the amount of available phosphorus in soils by various methods. These methods include different chemical reagents for extracting the soluble phosphorus. In many of these methods attempts were made to simulate conditions existing in the roots or surfaces between roots and soil particle. Inspite of this none of the methods so far suggested has been proved as a suitable one for determining plant available phosphorus in soils. Literature on this subject is rather voluminous and so only such works as are pertinent to the present study are reviewed here.

1. Use of dilute acids as extractants:

Various organic acids have been used by different workers as extracting reagents for available phosphorus. One of the earliest methods which is still in use is that of Dyer (1894) who used one percent citric acid. Egner (1941) and Riehm (1942) suggested the use of lactate buffer, while Hibbard (1931) employed acetic acid and Brown (1940) used acetate buffer as extractants for determining phosphate availability. Dilute mineral acids have been used by several workers for the extraction of available soil phosphorus. Von sigmond (1929) used 0.1 N Nitric acid whereas 0.2 N nitric acid was used earlier by Fraps (1904). Baver and Burner (1939) and Olson (1946) extracted available phosphorus with 0.3 N hydrochloric acid and 0.7 N hydrochloric acid mixed with ammonium molybdate respectively.

Truog (1930) used 0.002 N sulphuric acid buffered at pH 3 with Ammonium sulphate in a soil solvent ratio of 1:200 whereas the same extractant in the ratio of 1:100 was used by Peech et al (1947). Morgan (1935) used acetic acid buffered to pH 4.8 with sodium acetate for estimation of available phosphorus. Beater (1949) used N/21 sulphuric acid buffered with sodium borate at pH 1.5 for this purpose. Ghani (1943) employed 8 hydroxy quinoline in acetic acid as an extractant and recommended its use for acid soils containing higher proportions of active sequioxides.

2. Use of alkalies as extractants:

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

3. Use of ammonium fluoride as extractant:

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

4. Comparison of different methods used for extracting available phosphorus.

In calcareous soils Das (1926) found that extraction with potassium carbonate yielded more satisfactory results than when dilute acids were used as extractants. Hocken and Smith (1933) compared different soil testing methods in calcareous soils and found that phosphorus extracted by potassium carbonate showed high correlation with crop yields. Anderson and Noble (1937) compared different reagents on neutral and acid soils and found that phosphates extracted by acids gave generally better correlations with crop yields. Olson (1945) used 0.7 N hydrochloric acid as an extractant and correlation with yield of cotton was found to be erratic. Rubins and Dean (1946) compared Truogs, Morgans, Egner's and Neubauer's methods and found that there is a high degree of correlation between the different chemical methods. But the degree of correlation between neubauer method and different chemical methods was not close. Datta and Kamath (1959) compared nine different methods and evaluated them using percentage yield response and 'A' values. They found that the performance of sodium bicarbonate method to be the best. Bouyer (1959) compared different methods and obtained high correlation among the amounts of available phosphate determined by Bray and Kurtz (1945), Olsen (1954) and Saunder (1956) and total phosphoric acid content. Miller (1960) found that extraction with sulphuric acid ammonium fluoride reagent (both 0.1 and 0.03 N) gave the most satisfactory values for available phosphorus as determined by crop response. He also observed that soil type determined to a large extent the correlation between yield of the crop and phosphorus extracted by the different methods.

Swaminathan (1960) compared the amounts of phosphorus extracted from 14 potato soils by nine rapid chemical test methods and found that the reagents suggested by Troug, Spurway and Bray as well as 2.5 N acetic acid and 1 percent citric acid had similar capacities for extracting available phosphorus. Though the phosphorus index obtained from each test was positively correlated though not significantly with the average percentage yield values in each case, Olsen's method gave maximum degree of correlation with crop response in these soils. Eleven rapid methods for phosphorus were evaluated as to their desirability for predicting response to added phosphorus in two reddish brown laterite soils of Oregon by Alban et al (1964).

Available phosphorus in relation to soil phosphorus fractions.

A soil phosphorus test should provide a quantitative measure of the degree to which quantities of plant available phosphorus are related to the various soil phosphorus fractions. Since total amount of soil phosphorus can be accurately determined, its relationship to plant phosphorus availability may be utilized for improving the rapid phosphorus soil test techniques in vogue.

MATERIALS AND METHODS

Soil samples and chemical analyses:

34 samples of surface soils (0-6"), typical of the three soil types in Kuttanad viz. river borne alluvium (Karapadom), peat (Kari) and lake bed soil (Kayal) were collected for the present study. Of these 8 samples were of the kari type, 22 represented the karapadom region and 4 were from the kayal lands. The soils showed wide variation in characteristics, the pH values ranging from 3.9 to 5.9 and the organic carbon content from 0.9% to 16.63%.

A complete record of the past fertilisation that these soils received was compiled from the local cultivators, The data show that 12 fields had not received any phosphatic fertiliser though all the fields were under cultivation as single crop paddy lands for several years.

The samples were air dried, passed through a 2 mm sieve and stored in wide-mouthed glass bottles with screw caps prior to analysis. The results of chemical analysis are given in Table I.

The pH of the soils was measured in the fresh samples and after drying using a glass electrode in 1:2.5 dilution with distilled water.

Exchangeable aluminium, hydrogen and iron, were determined by the methods of Yuan (1959) and Coleman et al. (1959) as modified by Cate and Sukhai (1964). Water soluble aluminium and iron were determined by the methods described by Cate and Sukhai (1964). Organic carbon was estimated by the Walkley and Black method (Piper, 1950) and cation exchange capacity and anion exchange capacity by the method outlined in Piper (1950). Conductivity of 1:5 extracts was determined using the Solu-bridge (U.S.D.A. Hand book No.60).

Total phosphorus was determined by wet ashing one gram of soil with 10 ml. of sulphuric acid, 20 ml. of nitric acid and finally two or three ml. of perchloric acic to give a clear solution. The solution was made to 100 ml. and the phosphorus determined colorimetrically using stannous chloride as reducing agent. (Jackson, 1958).

Four soil test methods were used to evaluate the available phosphorus status in these soils. The methods employed with details of the constituents of the extracting solution, soil to solution ratio and time of shaking are given below:

Method	Extracting solution	Soil to solution ratio	Time of shaking
1. Bray No. 1	0.03 N ammonium fluoride in 0.025 N hydrochloric acid.	1:10	10 minutes
2. Bray No.2	0.03 N ammonium fluoride 0.1 N hydrochloric acid.	1:25	10 minutes
3. Olsen	0.5 M sodium bicarbonate adjusted to pH 8.5 with sodium hydroxide.	1:50	30 minutes
4. Saunder	0.1 N sodium hydroxide (Heated on steam bath)	1:50	60 minutes

The phosphorus concentration in all the extracts was determined by the molybdenum blue method of Dickman and Bray (1940). Stannous chloride was used as the reducing agent according to procedures described by Jackson (1958). Boric acid was added to Bray No.I and No. II extracts prior to colour development to reduce the interference of the fluoride iron.

In Saunder's method (Saunder, 1956) in which 0.1 normal hot alkali is used as extractant, clear extracts were obtained by adding a pinch of activated charcoal

(Darco. G.60) to the soils prior to extraction and coagulation of the organic matter by acidification of the extract. In fact, a combination of both these methods gave clear extracts despite the fact that many of the soils used in the present study were high in organic matter.

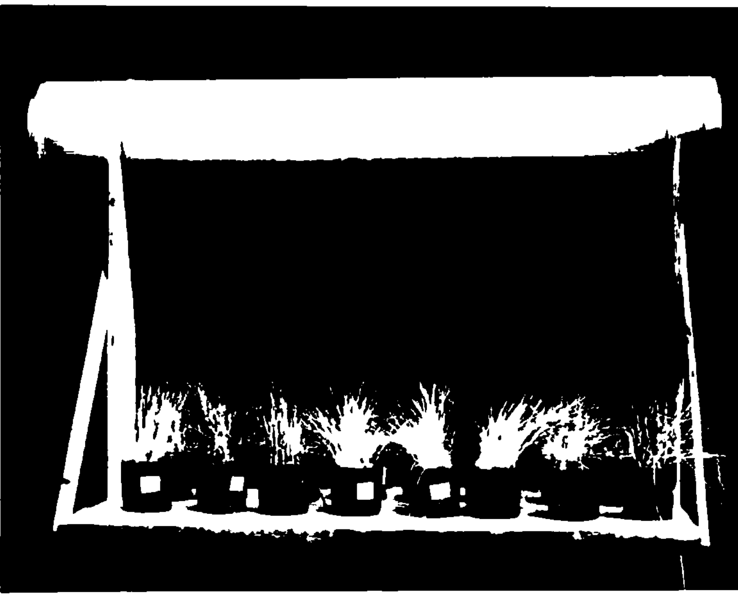
Incubation experiment.

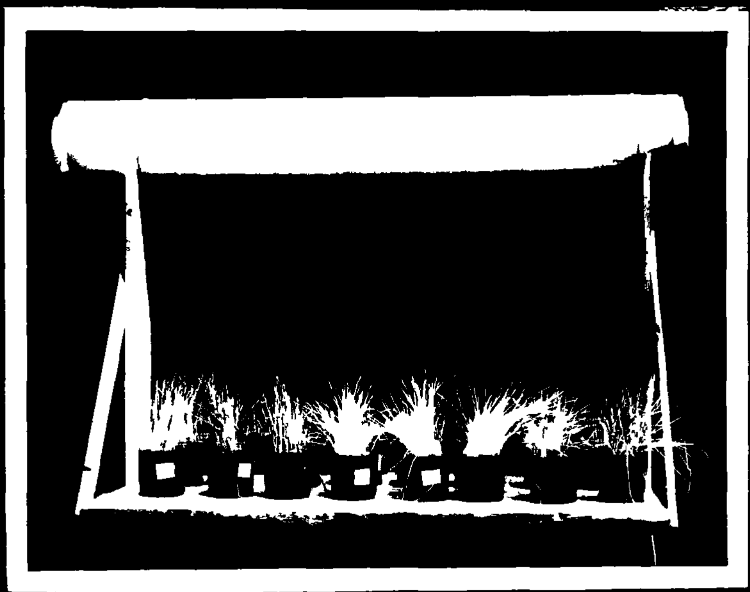
It is well known that continuous submergence of soils releases more of available phosphorus. When soils collected from rice fields are dried prior to soil test, there is a possibility of the reverse change taking place. To study this aspect 100 g. of each soil was moistened with distilled water to water holding capacity and incubated for 15 days at 30± 1°C in plastic containers. Giving due consideration for moisture status, sufficient quantity of soils was extracted with the various extractants listed in the previous page.

Plant growth experiments:

Experiment 1.

The available phosphorus in all the thirty four samples was determined by the standard Neubauer technique. 100 g. of the soil was mixed with 50 g. of acid washed quartz sand and placed in a plastic dish 11 cm. in diameter





and 7 cm. in height. 100 good quality (germination 100 percent) Swiss summer rye seeds were sown uniformly in each dish and 50 g. of quartz sand was uniformly spread on top of this to cover the seeds. Enough water was added periodically. The dishes were placed under flourescent lamp for 10 hours daily. A replication was kept for each soil. Controls were run side by side. Seventeen days after sowing the plants were harvested. Shoots and roots were separately dried, weighed and saved for chemical analysis.

'Field pot culture' Experiments:

A pot culture experiment was conducted to study the effect of different doses of phosphatic fertiliser (single super phosphate) on the growth and yield of rice plants. Soils from Karapadom lands having widely different soil test values for available phosphorus (Table II) were selected for this study.

Approximately 250 kg. of soil collected at a depth of 0-6" from the respective localities was transported to dried, crushed and passed through a 1/4" sieve. Earthenware pots to hold 10 kg. soils were used to grow the plants.

The experiment was conducted in randomised block design with four treatments of phosphorus at the rate of 0, 20, 40 and 60 kg. of P_2O_5 per acre and replicated five times. Nitrogen and potash (K_2O) at the rate of 60 kg. per acre were applied in the form of ammonium sulphate and muriate of potash respectively. A minimal dose of micronutrients was also added lest any one of them becomes a limiting factor. Sprouted seeds of rice (PTB. 10 of 90 days' duration) were sown in the pots and only three seedlings were allowed to establish in each pot. Sowing was done on 14-10-1964.

The pots were arranged in a field adjacent to the Soil Science and Agricultural Chemistry Division and not in a green house, since similarly conducted 'field pot culture experiments' have been found to conform to field condition to a greater extent than green house experiments. (Miller and Axley 1956).

The plants were irrigated with rain water using a rose can and a level of about 1" of water above the soil surface was maintained till 15 days prior to harvesting. The grain and straw from each pot were harvested separately on 13-1-1965 dried, weighed and saved for chemical analysis.

Analysis of total plant phosphorus:

The total phosphorus content of the plants from

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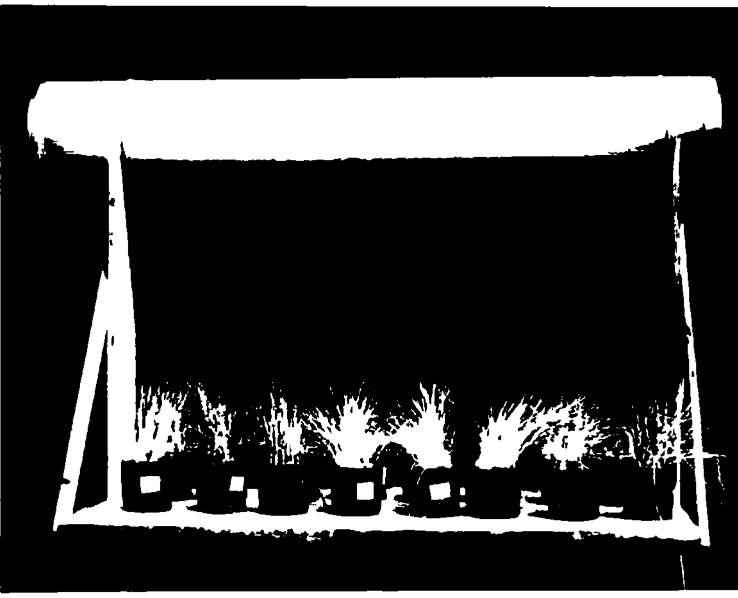

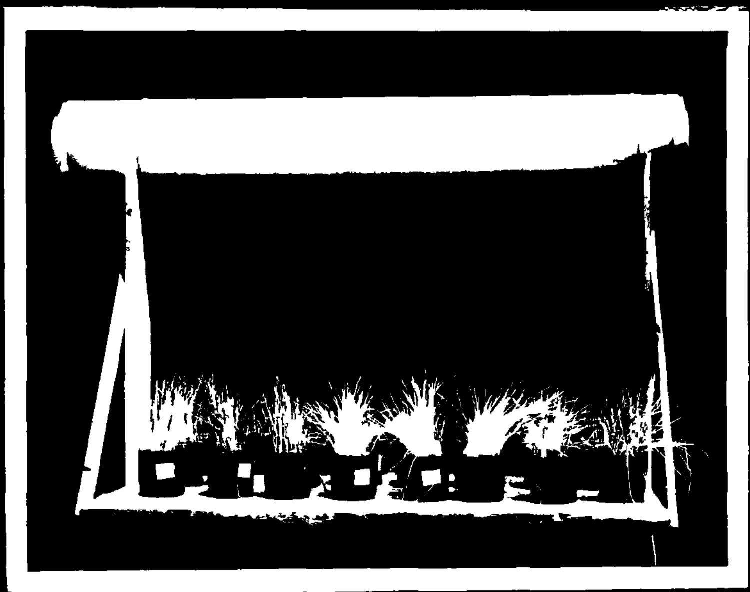

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Analysis of total plant phosphorus:

The total phosphorus content of the plants from experiment I and II was determined by wet ashing method. The dried and ground plant material (tops and roots from experiment I and grain and straw from experiment II) was wet ashed with 20 ml. nitric acid, 10 ml. sulphuric acid and finally digested to a clear colour with 2 ml. or more of perchloric acid. The solution was made to 100 ml. and the phosphorus determined colorimetrically as phosphomolybdate.

Statistical methods:

Linear correlation coefficients were worked out for relationships between the available phosphorus determined by various methods in the dried and sampled soils and as determined after incubating the soils at water holding capacity for 15 days with the phosphorus taken up by plants in the neubauer experiment (Experiment I) and in the pot culture experiment with rice plants (Experiment II).

Since pH, organic matter content, soluble and exchangeable aluminium soluble and exchangeable iron etc., influence phosphorus availability, a multiple regression was worked out with these soil characteristics as independent variables and available phosphorus values as determined by extractants which showed a significant leniar correlation with neubauer technique as dependent variables.

Response curves were fitted on the quadratic model $y = ax^2 + bx + c$ for the pot culture experiment on the four soils. Equations were worked out for the grain weight and total dry matter for the four soils.

Correlation coefficient for soil test values by various methods and percentage yield response were separately worked out to find out the most satisfactory method for determining available phosphorus.

RESULTS

RESULTS

Table. I presents the data on some of the important chemical characteristics of the 34 soil samples used for experiment I (Neubauer technique) and available phosphorus determination with chemical extractants. These data have a bearing on the availability and fixation of phosphorus. Usually in these soils the total phosphorus content is high ranging from 0.05 percent to 0.57 percent. The soil reaction is definitely acidic the value of pH ranging from 3.9 to 5.9. The soil contains a high percentage of organic matter as evidenced by the content of organic carbon which ranges from 0.9 to 16.63 percent. The conductivity ranges from 0.0 to 20 m. mhos per cm. Exchangeable iron and water soluble iron are also usually high but found to be varying in different soils. The exchangeable iron ranges from 7.1 p.p.m. to 38.5 p.p.m. while the water soluble iron varies from 0.0 p.p.m. to 20 p.p.m. Eschangeable aluminium ranges from 0.0 to 6.5 milli equivalents per 100 g. Exchangeable hydrogen also varies from 0.0 to 18.7 milli equivalents per 100 g.

Table II gives the mechanical composition and chemical characteristics of soil used in experiment II (pot culture experiment with rice plants). It could be

RESULTS

TABLE II

CHEMICAL AND MECHANICAL CHARACTERISTICS OF THE SOILS USED FOR POT CULTURE EXPERIMENT WITH RICE PLANTS

Location	Total P_2O_5 %	Available P_2O_5 by Olsen's method		pH	Conductivity	Organic carbon	Nitrogen %	Potassium %	Mechanical analysis			Clay
		Dry	Incubated						Coarse sand	Fine sand	Silt	
1. Mundar Kari	0.148%	2	125	3.9	3.2	3.9	0.112	0.05	Nil	1.8	21.5	69.9
2. Thakazhi	0.113%	50	100	5.5	0.9	0.98	0.073	0.052	7.73	19.84	14.82	57.6
3. Vellarkonam	0.075%	37.5	100	5.1	0.9	0.97	0.061	0.054	6.70	19.84	13.81	60.6
4. Pulokudukka	0.05%	5.2	25	5.2	0.8	0.97	0.085	0.046	8.12	20.00	15.50	56.10

CHEMICAL CHARACTERISTICS OF THE SOILS USED IN THE STUDY (Contd..)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
30	Thakashi	Clay loam	0.265	4.7	3.86	15.1	6.6	4.2	4.0	12.1
31	Mundar Kari	Clay	0.148	3.9	3.9	31.3	3.0	2.8	3.2	12.8
32	Thakashi	Clay loam	0.113	5.3	0.965	11.3	0.0	0.5	0.9	3.9
33	Vollarkonam	"	0.075	5.1	0.970	11.4	0.0	0.5	0.9	3.1
34	Pulakudukka	Clay	0.060	5.2	0.970	10.2	0.0	0.6	0.8	3.8

CHEMICAL CHARACTERISTICS OF THE SOILS USED IN THE STUDY (Contd..)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
15	Chennankari	Silt clay	0.300	5.8	13.16	28.0	4.5	10.8	4.5	2.1
16	Chempakulam	Clay loam	0.335	5.8	10.58	18.5	1.0	1.0	1.0	8.0
17	"	"	0.125	5.2	9.74	38.5	4.5	12.8	5.0	12.1
18	"	"	0.575	5.1	2.52	29.4	3.3	12.7	6.0	13.0
19	"	"	0.355	5.0	1.37	25.0	3.0	12.0	3.8	18.0
20	Kanjipadam	"	0.355	5.6	4.95	38.5	1.0	0.8	1.2	20.0
21	"	"	0.370	5.3	2.69	15.6	4.3	9.7	5.0	5.3
22	"	"	0.375	5.1	5.66	13.4	2.8	3.2	3.4	7.1
23	"	"	0.375	5.0	13.16	18.0	2.0	6.8	1.8	8.4
24	Pulakudukka	Clayey soil	0.400	5.9	4.10	23.1	0.0	0.2	1.5	14.2
25	"	"	0.370	5.3	1.91	12.0	0.0	0.5	3.3	6.1
26	"	"	0.125	5.8	10.86	12.5	2.5	4.3	1.8	3.3
27	"	"	0.100	5.1	16.63	12.8	0.0	0.5	5.1	3.1
28	Thakazhi	Clay loam	0.275	5.1	4.30	13.5	1.4	0.3	3.0	3.3
29	"	"	0.280	4.6	11.4	35.8	2.3	1.2	4.5	13.0

TABLE I

CHEMICAL CHARACTERISTICS OF THE SOILS USED IN THE STUDY

Sl. No.	Location	Soil Texture	Total phosphorous in %	pH	Organic carbon %	Exchangeable iron p.p.m.	Exchangeable Aluminium in me. equi.	Exchangeable Hydrogen	Conductivity	Water soluble iron
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	Roman Kari	Clayey	0.405	5.1	3.98	19.2	1.1	8.0	6.6	3.0
2	"	"	0.325	5.5	2.86	10.8	0.6	0.5	3.8	4.7
3	"	"	0.500	5.7	3.46	9.6	0.3	0.4	2.8	5.0
4	"	"	0.550	5.1	6.43	23.8	0.1	10.8	2.3	3.0
5	Vattapadam	Clayey loam	0.315	6.0	2.80	7.1	0.0	0.7	4.0	1.8
6	"	"	0.245	5.4	3.14	9.6	1.4	0.5	2.8	1.4
7	"	"	0.235	5.2	10.31	25.0	2.6	9.9	4.0	6.0
8	"	"	0.200	5.1	8.23	16.8	6.0	10.2	4.0	3.6
9	"	"	0.350	5.3	15.51	10.5	3.2	6.0	6.0	8.0
10	Chomemkari	Silt clay	0.265	5.0	4.10	25.0	4.1	16.7	4.5	11.0
11	"	"	0.286	4.9	2.91	35.7	1.5	0.5	3.0	3.3
12	"	"	0.565	4.5	11.26	17.2	3.0	0.8	6.6	1.9
13	"	"	0.500	5.2	1.68	34.4	4.6	11.7	5.0	1.9
14	"	"	0.360	5.9	11.26	20.8	0.0	0.25	3.0	0.0

from the results that the clay content varies from 56 to 69 percent. From the data on total nitrogen, total phosphorus, and total potassium, it could be seen that soil No. I appears to be well supplied with these nutrients. But, however, from the values obtained for available phosphorus it is seen that soil No. I is low in available phosphorus.

Table III summarises the data on the available phosphorus determined in the 34 samples of that were preconditioned by drying in air. It also presents the available phosphorus in these soils as determined by Neubauer technique. The available phosphorus content in the same soils that have been incubated for 15 days at water holding capacity at 30°C, has been determined and is given in Table IV. From the results it could be seen that the reagents Bray No. I and Bray No. 2 extract only very low amounts of phosphorus while Olsen and Saunder's reagents extract larger amounts of phosphorus. On incubation of the soils Olsen and Saunder's reagents extract increased amounts of phosphorus while Bray No. 1 and Bray No. 2 extract lesser amounts than those obtained with dry soils.

Data on the yield of grain in the pot culture experiment with rice plants are presented in Table V.

TABLE III

COMPARISON OF AVAILABLE PHOSPHORUS DETERMINED BY DIFFERENT METHODS FOR DRY SOILS

(Figures given are in parts per million)

Soil Number	Bray No.1	Bray No.2	Olsen's reagent	Saunder's reagent	Neubauer technique
1	20	33	52	119	11.5
2	28	45	90	110	23.5
3	15	37	53	149	1.4
4	2	14	27	112	22.5
5	7.5	10	62	181	11.25
6	2	9	25	166	9.5
7	2	7	24	198	2.4
8	2	2	2	95	6.5
9	2	2	2	121	9.4
10	2	2	17	112	9.5
11	7	30	2	110	11.0
12	7	13	19	98	11.5
13	8	9	2	125	5.5
14	6	42	13	161	5.4
15	2	15	2	172	3.4
16	10	2	2	156	17.5
17	2	60	75	145	18.5
18	2	10	24	161	11.0
19	2	2	2	163	5.5
20	2	2	2	128	23.5
21	2	2	2	172	22.5
22	2	2	3	98	17.5
23	13	2	2	85	16.5
24	20	2	4	78	13.5
25	2	2	3	110	13.4
26	2	2	2	124	4.6
27	2	2	2	127	5.5
28	2	2	2	132	5.6
29	2	2	2	161	6.6
30	2	5	3	94	6.6
31	2	2	2	238	5.5
32	10	30	50	268	14.5
33	2	37	37	181	11.5
34	2	26	18	238	10.5

TABLE IV

COMPARISON OF AVAILABLE PHOSPHORUS EXTRACTED
BY DIFFERENT METHODS FOR INCUBATED SOILS

(The figures are given in parts per million)

Soil Number	Bray No.1	Bray No.2	Olsen's reagent	Saunder's reagent
1	100	28	250	682
2	46	31	500	833
3	100	36	27	150
4	50	28	500	882
5	25	28	250	750
6	2	14	200	341
7	2	33	28	150
8	14	17	167	300
9	11	16	200	350
10	2	15	200	352
11	11	17	250	645
12	28	25	250	690
13	22	41	125	321
14	250	40	125	342
15	125	17	15	112
16	17	33	334	500
17	83	14	330	721
18	28	13	328	718
19	28	11	250	650
20	63	11	125	345
21	11	11	500	852
22	28	20	500	841
23	28	13	334	500
24	27	17	334	498
25	30	11	167	300
26	2	11	165	284
27	2	28	100	321
28	63	11	125	348
29	2	13	125	344
30	26	12	125	346
31	2	11	125	353
32	28	23	100	300
33	2	16	100	320
34	25	20	25	140

TABLE V

YIELD OF GRAINS FOR POT CULTURE EXPERIMENT ON RICE CROP

(The figures are in gms/pot and are the average of five replications)

Soil Number and name	Treatment of phosphorus in lbs/acre			
	0	20	40	60
31 Mundar Kari	9.5	18.6	16.2	18.46
32 Thakazhi soil	23.4	32.6	23.4	23.5
33 Veilarkonam soil	18.46	20.9	21.0	20.3
34 Pulakkudukka	18.36	22.6	21.18	25.2

It could be seen from this table and appendix I (Analysis of variance Table) that phosphorus fertilisation results in significant increases in grain yield. An interesting finding is that the higher levels of phosphorus application (40 and 60 pounds per acre) decrease the grain yield as compared with the lower dose of 20 pounds per acre. A quadratic equation, $y = ax^2 + bx + c$ has been fitted for the grain yield data from which optimum dose for maximum yield is worked out. The response curves are given in figures V, VI, VII and VIII. Optimum doses calculated from the equations are 44, 26, 45 and 99 lb./acre respectively.

Table VI presents data on the total dry matter in grams per pot in the pot culture experiment with rice. In general it could be seen that addition of graded doses of phosphorus significantly increase the total dry matter production, though with higher levels the response is either stationary or shows a decreasing trend. The results have been fitted into a quadratic model $y = ax^2 + bx + c$. The optimum dose to give a maximum yield has also been worked out. The response curves are given in figures IX, X, XI and XII. Optimum doses calculated from the equations are 35, 30, 40 and 65 lb./acre respectively.

TABLE VI

YIELD OF TOTAL DRYMATTER FOR POT CULTURE EXPERIMENT ON RICE CROP

(The figures are in gms/pot and are the average of five replications)

Soil number and place		Treatment of phosphorus in lbs/acre			
		0	20	40	60
31	Mundar Kari	21.48	36.7	28.32	30.5
32	Thakazhi soil	29.5	54.88	27.26	42.6
33	Vellarkonam	36.18	39.5	43.2	40.2
34	Pulakudukka	37.86	41.2	41.32	49.5

TABLE VII

UPTAKE OF PHOSPHORUS BY GRAIN AND STRAW

(Expressed in m.g./pot)

Serial Number	Soil	Uptake by grain Treatment				Uptake by straw Treatment			
		0	20	40	60	0	20	40	60
1	Mundar kuri	19.0	38	36.8	32.0	11.0	16.0	9.0	10.4
2	Thakazhi soil	23.4	39.6	43.7	43.7	14.5	16.5	20.5	17.0
3	Vellarkonam soil	36.1	52.5	46.4	50.0	14.5	17.0	14.5	17.0
4	Pulakkudukka	57.0	57.5	48.3	75	12.5	17.6	20.0	18.0

Table VII presents the uptake of phosphorus by grain and straw in mg. per pot. It could be seen from the results that there is an increasing trend in uptake of phosphorus by the grain and straw with increasing doses of phosphorus the rate of increase being greater in the case of the grain than in the case of the straw.

DISCUSSION

D I S C U S S I O N

Several criteria were used to evaluate four different soil test methods to determine available phosphorus in the typical acid rice soils of Kerala. The major criteria employed were the amount of phosphorus extracted by various extractants and the correlation of the same with the actual phosphorus taken up by plants in the Neubauer experiment. The influence of various soil chemical characteristics that affect the amount of phosphorus extracted by the extracting reagents, as well as their influence on the quantities of phosphorus taken up by plants in Neubauer experiments were also employed as criteria for finally choosing the method. Another important aspect investigated was the preconditioning that is to be given to soil samples prior to testing them for available phosphorus. The present method of testing soils in most of the laboratories in India and abroad except probably that at Iowa (Hanway, 1964) is to air dry them prior to testing. But at the Soil Testing Laboratory at Iowa, a slurry is made from the moist samples collected from the field, and aliquots of this are used for determination of available nutrients. In the present study the rice soils were incubated for 15 days at water holding capacity to assess the increase in available phosphorus. The results of these investigations are discussed in the following pages.

The available phosphorus extracted by the four extractants viz. Olsen's, Bray's No. 1, Bray's No. 2, and Saunder's, from 34 samples of the waterlogged rice soils, conditioned by air drying in the laboratory were correlated with the actual plant available phosphorus as determined by the Neubauer technique with rye as indicator plants (Table II). The correlation coefficients are given in (Table VIII).

TABLE VIII

Linear correlation coefficients for the relationship for available phosphorus as determined by four different soil test methods in air dried soils with the available phosphorus as determined by the Neubauer method.

Sl. No.	Method	Correlation coefficient	Regressions equation
1	Bray No. 1	0.255	Not significant
2	Bray No. 2	0.142	"
3	Olsen	0.276	"
4	Saunder	No correlation	"

None of the soil test methods shows any significant correlation though Olsen and Bray No. 1 indicate a positive trend. This shows that the form of phosphorus taken up by plants may be iron phosphates or aluminium phosphates as these are the two inorganic forms predominantly and respectively extracted by the two reagents. This lack of significant correlation, when viewed in the light of the works of Shapiro (1958) Islam and Elahi (1954) Kereszteny (1953) and Basak and Bhattacharya (1962) reveals, that the amounts of these forms extracted may be considerably less, whereas, the same soils after submergence show considerable increase in available phosphorus especially the sodium hydroxide soluble fraction (the iron fraction) (Paul and Delong, 1949). In this connection it is pertinent to note a similar increase in available phosphorus in soils observed by Mack and Barber (1960) on incubation of soils with lesser amounts of moisture regime in the soils in the Neubauer experiment of the present study, corresponds nearly to the levels of moisture in the experiments of Mack and Barber. It is mainly for these reasons that Hanway (1964) emphasised the need for testing the soil for the "major trio" in plant nutrition directly on samples collected from the field and prior to drying in the laboratory. If such a procedure is required for upland soils, the need for the same for waterlogged and acidic soils where fixation and availability of phosphorus are well known to be subtly controlled by the relative amounts of iron and aluminium needs no emphasis.

To clarify this point the soils were incubated at the water holding capacity for 15 days and available phosphorus determined by four different extractants (Table III) were correlated with the actual phosphorus taken up in Neubauer experiments (Table IX).

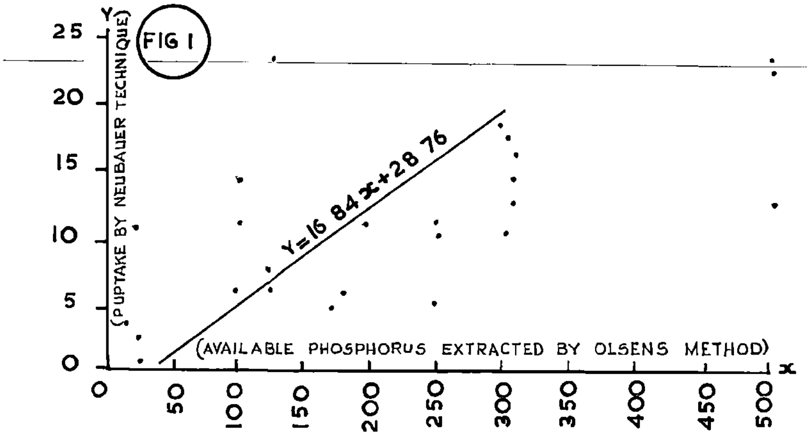
TABLE IX

Linear correlation coefficients for the relationship for available phosphorus as determined by four different soil test methods in incubated soils, with the available phosphorus as determined by Neubauer method.

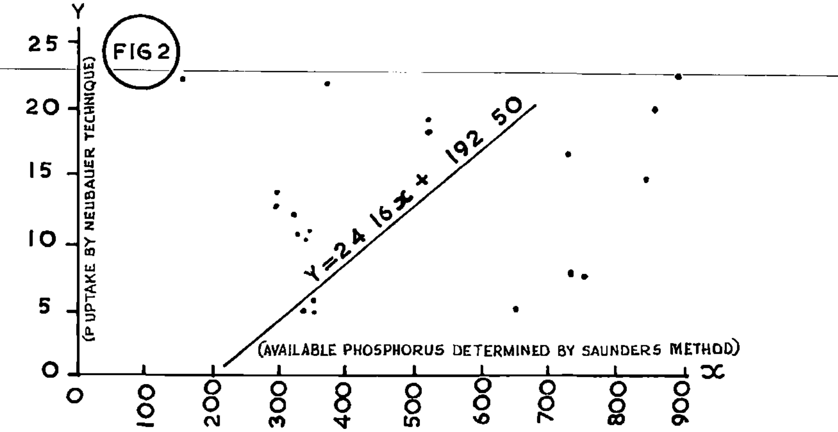
Sl. No.	Method	Correlation coefficients	Regression equation
1	Bray No. 1	No relation	..
2	Bray No. 2	No relation	..
3	Olsen's	0.753 ++	Y=16.84x+28.76
4	Saunder's	0.664 ++	y=24.16x+192.50

+ Significant at 5% level
++ significant at 1% level

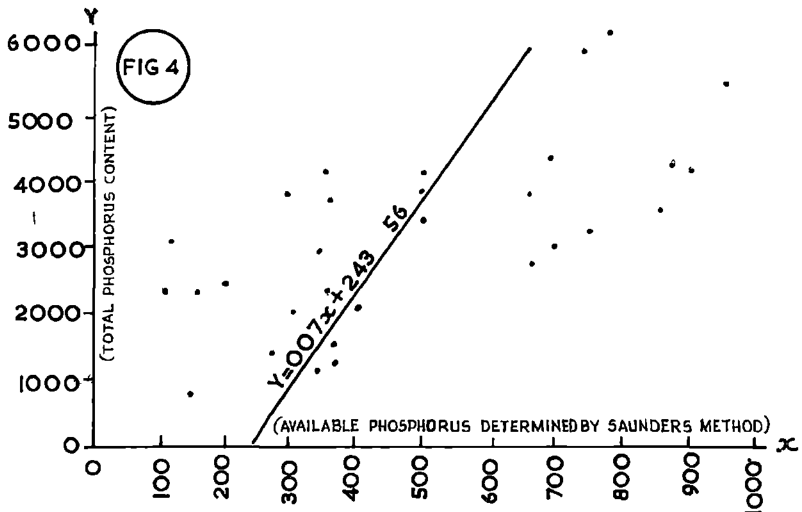
If could be seen that highly significant correlations are obtained for Olsen's method (0.5 M Sodium bicarbonate) and Saunder's (0.1 N Hot sodium hydroxide) method. This together with the lack of correlation in the earlier experiment on air dried soils shows that there



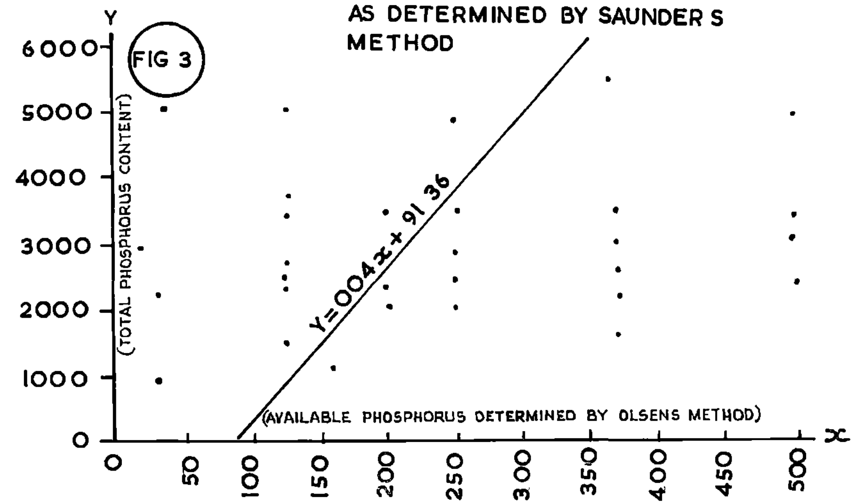
PHOSPHORUS UPTAKE IN NEUBAUER TECHNIQUE VS AVAILABLE PHOSPHORUS DETERMINED BY OLSEN'S O 5 M $NaHCO_3$ METHOD



INCUBATED SOIL-PHOSPHORUS UPTAKE BY NEUBAUER TECHNIQUE VS AVAILABLE PHOSPHORUS AS DETERMINED BY SAUNDER S METHOD



INCUBATED SOIL-TOTAL PHOSPHORUS VS AVAILABLE PHOSPHORUS AS DETERMINED BY SAUNDER'S METHOD



INCUBATED SOIL-TOTAL PHOSPHORUS CONTENT VS AVAILABLE PHOSPHORUS BY OLSENS O 5 M $NaHCO_3$

is an increase in the alkali soluble phosphorus. Again, the form and amounts that are extracted by the mildly alkaline extractant (sodium bicarbonate) and the 0.1 N sodium hydroxide solution bear a close proportionality with the form and amounts taken up by the plant in the Neubauer experiment. That this increase in available phosphorus is considerable could be seen from table II and III. The fact that ferric phosphates are less soluble in mild alkalies while ferrous phosphates are more soluble suggests that reducing conditions, typical of waterlogging, have been simulated in the experiment on incubation of the soils at waterholding capacity.

Comparison of the amounts extracted by Bray No. 1, before and after incubation, with the values for the Olsen and Saunder method before and after incubation show that it may even become necessary to redesignate some of the waterlogged soils that are now classed as low in available phosphorus as medium when evaluated by the Olsen's method. However, this is an aspect which requires further study.

A number of workers have repeatedly shown that the alkali extractable portion is dominated by iron phosphate. (Chi Moo Chu, (1959) Pratt and Garber, (1964).

Al-Abbas and Barber (1964) from a multiple regression analysis of different fractions of phosphorus of 24 soils as independant factors and the phosphorus taken up by plants in three Neubauer type experiments as dependant factors, have shown that it is the iron phosphate that is predominantly taken up by plants. The results of the present investigation thus indirectly support the above finding.

Correlation of the total phosphorus with the available phosphorus as determined by the four different extractants both for air dried soils and soils incubated at water holding capacity is significant only for the incubated soils with alkaline extractants via., Olsen (r = 0.414) Saunder (r = 0.437). The major fraction of the total phosphorus in soils is present as inorganic phosphorus both combined and occluded with aluminium, iron and calcium, and also as soluble and exchangeable phosphorus. (Hesse (1962) found that on addition of soluble phosphate to this phosphate pool it is immediately fixed as aluminium phosphate which later changed to iron phosphate on water logging the soil. This establishes the fact that alkali extractable phosphorus is the one which is related to a greater extent with total phosphorus.

Al-Abbas and Barber (1964) in their multiple regression analysis used important soil characteristics like organic matter and pH content as independant factors and could obtain only low multiple correlation coefficient on phosphorus uptake in three Neubauer type experiments. In the present investigation this was studied in greater detail by determining on 34 samples of soil a number of soil characteristics like pH, organic carbon, exchangeable iron, and exchangeable hydrogen that are known to have a relationship with phosphorus fixation and availability. Other soil properties which also influence phosphorus availability like conductivity of water extract, water soluble iron and water soluble aluminium were included along with the earlier mentioned ones, as independant variables in the multiple regression analysis with phosphorus uptake in Neubauer experiment. The multiple regression analysis gave the equation.

$$y_3 - 11.0235 = 1.3337\ (x_1 - 5.2294) - 0.0970\ (x_2 - 3.5118) - 0.2040\ (x_3 - 6.1800) + 0.0176\ (x_3 - 19.7412) - 0.3102\ (x_5 - 2.0824) + 0.0023\ (x_6 - 5.9382) + 0.2905\ (x_7 - 6.6853) - 0.5454\ (x_8 - 1.2559)$$

Where y_3 is the phosphorus uptake in mgs. in the Neubauer experiment.

x_1 = pH; x_2 = conductivity, x_3 = Organic carbon

x_4 = exchangeable iron x_5 = exchangeable aluminium

x_6 = exchangeable hydrogen x_7 = water soluble iron
x_8 = water soluble aluminium.

(See table I & table II for values for x_1 to x_8 and y_3 respectively)

It could be seen from the regression coefficients in the above equation that pH, and water soluble and exchangeable iron positively influence the uptake of phosphorus by plants. This positive influence, especially of soluble and exchangeable iron, when studied in the context of the findings of Al-Abbas and Barber (1964) and Blanchar and Caldwell (1964) shows that in these soils also iron phosphate is the predominant form of available phosphorus and is the one that is actually taken up by plants. The soils examined in the present study have a pH value lower than 6.0 and in some cases as low as 3.9. This would adversely affect phosphorus availability and normal crop growth. The multiple regression coefficients obtained in the present study show that phosphorus availability and uptake increase with higher pH values.

On the other hand, water soluble aluminium, exchangeable aluminium and organic carbon negatively influence the phosphorus uptake, in decreasing order. High water soluble aluminium has direct toxic effects on plants and is known to retard the uptake of phosphorus (Cate and Sukhai, 1964).

From the linear correlation coefficients for Olsen and Saunder (Table IX and fig. 1 and 2) the former is found to be superior provided, the soils are tested in the moist condition. A number of chemical processes takes place during extraction of available phosphorus with chemical reagents. These processes are in turn guided by varying soil chemical factors besides the nature of the extracting solution and soil to extractant ratio. These ultimately decide the phosphorus extracted. The effectiveness of an extracting solution is also affected by the buffering capacity of the soil and the readsorption of phosphorus from the solution by other ions especially iron and aluminium brought into solution. Thus, Cooke (1951) found that dissolution of iron and aluminium oxides during extraction causes readsorption. Generally, the effect of soil buffering action is obviated by increasing the extractant concentration or increasing extractant to soil ratio. Again, readsorption is minimised either by addition of compounds complexing the ions responsible for readsorption or by using short extracting periods. Pratt and Garber (1964) have discussed the ineffectiveness of the Bray and Olsen reagents for clayey soils attributing it to secondary reactions after dissolution or from the exhaustion of the reagent by minerals other than phosphates. Fractionation of the soils after extraction with the respective reagents in clayey and sandy soils gave results to show that clay content decreases the effectiveness of Olsen's reagent to extract phosphorus from soils by exhaustion of the reagent and secondary precipitation. Po Ho Hsu (1964) studying fixation in acid soils recognises two reactions operating at different rates. Of these the one which proceeds more rapidly is believed to be due to surface adsorption of phosphate on amorphous aluminium hydroxide and iron oxides already present in the soil. The other, a much slower reaction, is due to surface adsorption on similar hydroxides and oxides formed during the experiment. There are possibilities for such new hydroxides and oxides to be formed especially on extraction with alkaline reagents so that a readsorption of extracted phosphate on these newly formed oxides and hydroxide cannot be ruled out.

In the present study only two methods were significantly correlated with the actual phosphorus uptake in Neubauer experiment. From linear correlation coefficients alone the superiority of one over the other cannot be conclusively established. Besides, for the aforementioned reasons, a number of soil factors affects the extent of extraction and readsorption of phosphorus.

For this reason, a partial correlation analysis was conducted to nullify the effect of these independant variables in the linear correlation coefficient already obtained for the two methods on one hand and the Neubauer technique on the other. It was also expected that this would reveal the more suitable method for soils with widely differing chemical characteristics. The partial correlation coefficients and the linear correlation coefficients are given below:

Method	Linear correlation coefficient	Partial correlation coefficient
Olsen	0.75	0.70
Saunder	0.66	0.78

It couls be seen that there is greater degree of closeness between the linear correlation coefficient and partial correlation coefficient for the Olsen's method. In the case of Saunder's reagent there is considerable increase in the partial correlation coefficient indicating that soil factors adversely or erratically affect the extraction of phosphorus. From this it can be safely concluded that the soil chemical characteristics do not much influence the extraction of phosphorus by Olsen as it does for Saunder's. Thus the Olsen's method is found to be more tolerant of soil factors and can be widely adapted to varying soil conditions. The universality of the Olsen's reagent has been reported by other workers as well though by different reasonings (Patel and Mehta, 1961).

The multiple regression analysis to study the comparative effects of various soil chemical factors on the extraction of phosphorus by Olsen's and Saunders method gave the following equations.

$$y_1 - 214.0885 = 30.2642\ (x_1 - 5.2294) + 19.1090\ (x_2 - 3.5118) - 4.3474\ (x_3 - 6.1800) - 1.5019\ (x_4 - 19.7412) + 0.8169\ (x_5 - 2.0824) - 1.1115\ (x_6 - 5.9382) + 5.6288\ (x_7 - 6.6853)$$

Where y_1 is the phosphorus extracted by the Olsen's reagent.

$$y_2 - 452.3829 = 211.6058\ (x_1 - 5.2294) + 60.5077\ (x_2 - 3.5118) - 12.9701\ (x_3 - 6.1800) + 2.9344\ (x_4 - 19.7412) + 3.5333\ (x_5 - 2.0824) + 1.7930\ (x_6 - 5.9382) + 7.9160\ (x_7 - 6.6853) - 31.5044\ (x_8 - 1.2559).$$

Where y_2 is the phosphorus extracted by the Saunder's reagent.

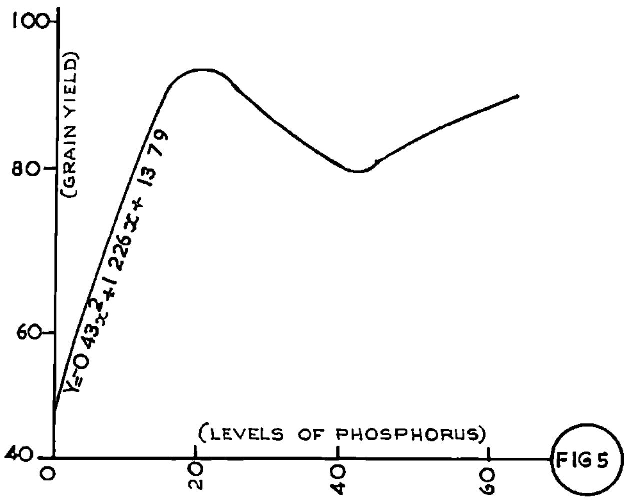
A study of the regression coefficients shows that the amount of available phosphorus extracted by Olsen's method is positively influenced by pH, conductivity and water soluble iron in the decreasing order. The lower the pH, the greater is the exhaustion of the alkaline bicarbonate solution and hence lesser the extraction. This is emphasised again by the fact that exchangeable hydrogen and exchangeable aluminium negatively influence the amounts of available phosphorus extracted. Organic carbon and water soluble aluminium also negatively affect the extraction. These results show that they probably play a significant role in exhausting the reagent by secondary reactions with the alkali. These secondary reactions provide conditions for readsorption of the extracted phosphorus (Po Ho Hsu, 1964).

From the regression coefficients of equation relating the phosphorus extracted by Saunder's reagent with soil characteristics, it can be seen that the amount extracted is affected in a positive manner by pH, conductivity and water soluble iron. Water soluble aluminium and organic carbon negatively influence the extraction. The reasonings given for Olsen's method with regard to this aspect also holds good for the Saunder's method.

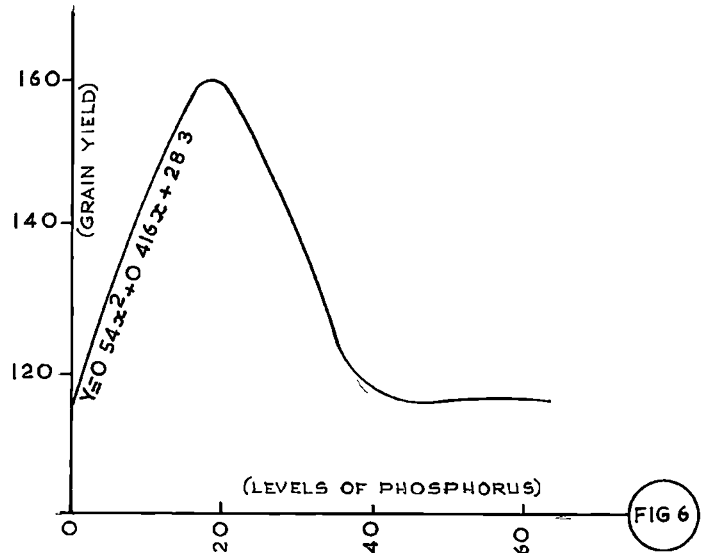
Though, in the multiple regression analysis both the alkaline extractants follow the same trend, Olsen extractant is less affected by soil chemical factors as revealed by the partial correlation coefficients and so can be safely recommended for soils of widely varying chemical characteristics.

Keresztenyi and Perjamosi (1961) determined the available phosphorus by Egner-Riehm method on 44 soils after incubation with known amounts of phosphorus for three weeks. A multiple regression analysis was worked out on the difference in the availables in the treated and untreated soils. It was found that the amounts of phosphorus not fixed by soil is significantly and positively correlated with pH and log of organic matter. This study was however, carried out with acid extractants on temperate calcareous soils. The present investigation using alkaline extractants with acid soils revealed the same trend.

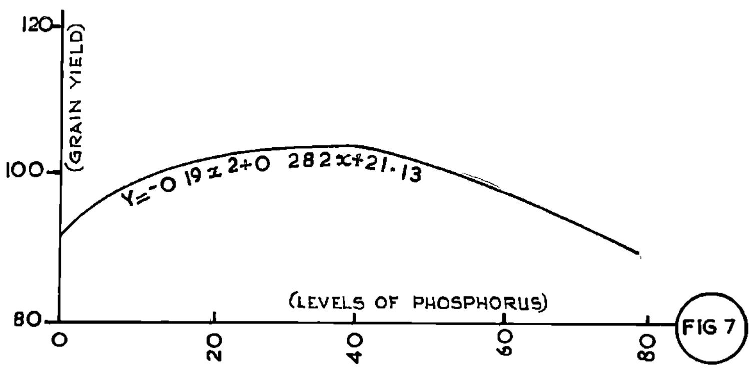
Response curves were fitted for the yield of grain and total dry matter production in rice plants in four soils with graded doses of phosphate (0.20, 40 and 60 lbs./acre). The quadratic model $y = ax^2 + bx + c$ was found to be the best fit. The model was fitted to the yield of grains and total dry matter. The equations and the calculated optimum phosphorus for maximum yield are given in the Table X.



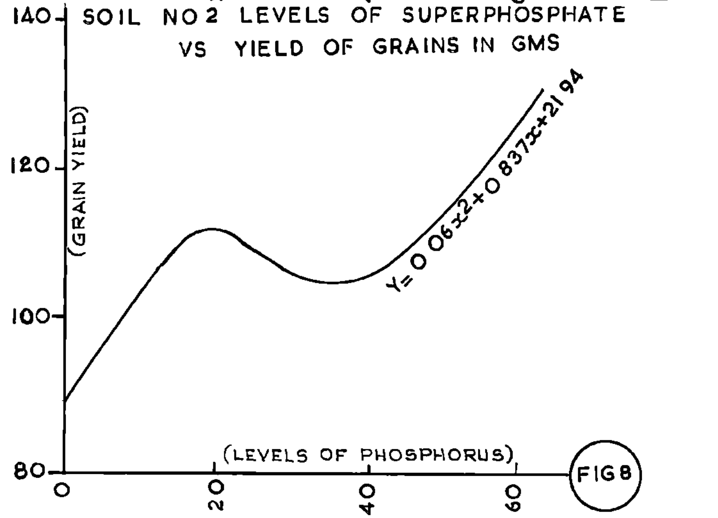
RESPONSE CURVE – LEVELS OF SUPERPHOSPHATE ADDED BY YIELD OF GRAINS IN SOIL NO1



SOIL NO 2 LEVELS OF SUPERPHOSPHATE VS YIELD OF GRAINS IN GMS



SOIL NO3 THE LEVELS OF SUPERPHOSPHATE VS YIELD OF GRAINS



SOIL NO 4 THE LEVELS OF SUPERPHOSPHATE VS YIELD OF GRAINS

TABLE X

	Soil	Calculated value of phosphorus	Equations
	Grain Yield		
1.	Mundar kari	44	$y= -0.43x^2+1.226x+13.79$
2.	Thakazhi soil	26.2	$y= -0.54x^2+0.416x+28.3$
3.	Vellarkonam soil	45	$y= -0.19x^2+0.282x+21.13$
4.	Pulakudukka	99.8	$y= 0.06x^2+0.837x+21.94$
	Drymatter		
1	Mundar kari	35.3	$y= -0.875x^2+0.932x+33.6$
2	Thakazhi soil	30.3	$y= -1.25x^2+0.09x+52.31$
3	Vellarkonam	40.1	$y= -0.39x^2+0.793x+41.73$
4	Pulakudukka	65.1	$y= -04x^2+0.701x+21.94$

The response curves are given in figures 5 to 12.

Phosphate application usually enhances the yield of grains. But the magnitude of response is generally much lower than that for other nutrients. Besides, the complex soil chemical characteristics affect the uptake of phosphorus and yield. This has already been discussed. So, any generalisation about phosphate response could be made only on the basis of a very large number of experiments, be they, field experiments or green-house experiments. Sethi *et al* (1952), Benigno and Talamison (1939), Bal (1950)

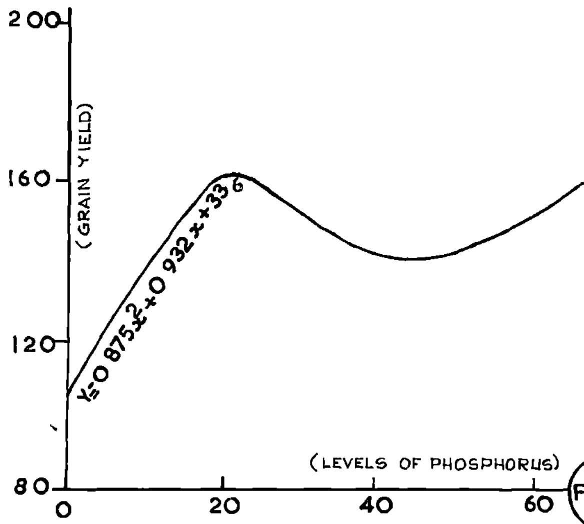


FIG 9

LEVELS OF SUPERPHOSPHATE VS TOTAL DRY MATTER IN SOIL NO I

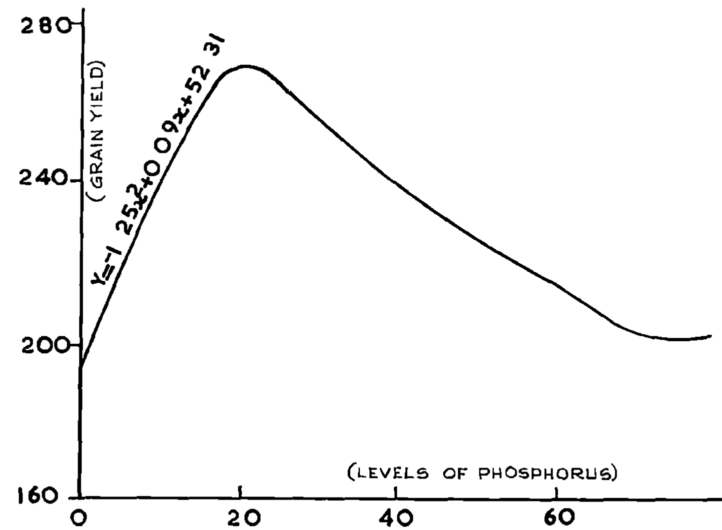


FIG 10

SOIL NO.2 LEVELS OF SUPERPHOSPHATE VS YIELD OF TOTAL DRY MATTER

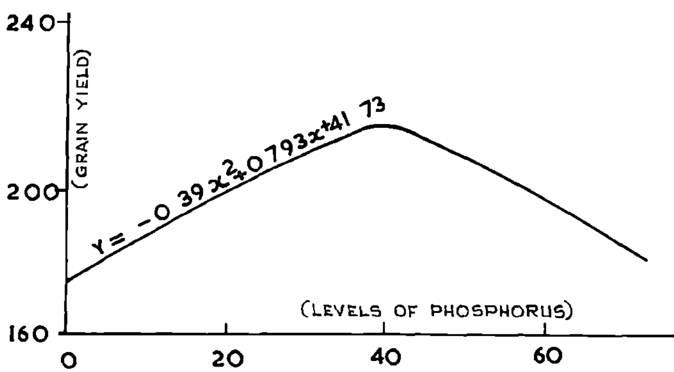


FIG 11

SOIL NO 3 LEVELS OF SUPERPHOSPHATE VS YIELD OF TOTAL DRY MATTER

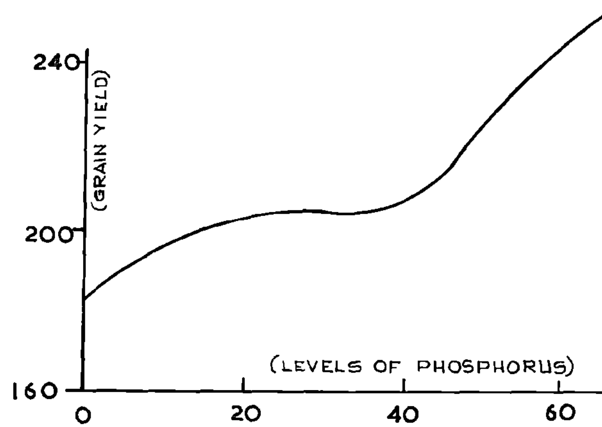


FIG 12

SOIL NO 4 LEVELS OF SUPERPHOSPHATE VS YIELD OF TOTAL DRY MATTER

Beacher (1962), Chang and Tsong (1953) and Scarpensel *et al* (1956) report a little or no response to phosphatic fertilisers under differing soil conditions. With the above back ground, examining the equations obtained give the following conclusions.

1. Very low quadratic coefficient in the equations, in general suggests that the optimum dose is reached even at a relatively low level of phosphorus. Indirectly this suggests that the soils are rich in available phosphorus. Low response could be attributed to the regeneration and mobilisation of phosphorus during the growth period of the rice crop (Basak and Bhattacharya, 1962).

2. From the equations, the optimum doses for maximum yield of both grain and total dry matter, for four different soils was found to range between 26-99 lbs. per acre.

The correlations between percentage yield response with available phosphorus determined after drying soil or after incubation was not attempted as only 4 pairs of values were available. More number of pot culture experiments have to be conducted before any general conclusions can be drawn.

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSION

The phosphorus extracted by four different chemical extractants from 34 samples of paddy soils was studied in relation to the phosphorus uptake by plants as well as eight of the important chemical characteristics of the soils that subtly control the fixation and availability of phosphorus in them. The soil chemical characteristics were also studied in relation to the uptake of phosphorus by plants. Since rice soils are generally waterlogged during the cropping period, its effect on readily extractable phosphorus was also studied in experiments under simulated conditions in the laboratory. Besides, on four typical soils graded doses of phosphorus was applied, rice plants grown and the yield response studied. The salient features of the results and the conclusions made are detailed below.

1. The available phosphorus extracted by the four different reagents on samples preconditioned in the usual manner, viz., after air drying in the laboratory gave no significant correlation with the actual phosphorus taken up plants in Neubauer experiments. However Olsen and Bray No. 1 showed a trend towards ~~significant~~ correlation.

2. When the soils were incubated at water holding capacity for 15 days in an experiment to simulate the reducing conditions, considerable increase in readily extractable phosphorus was noticed. This increase was marked in the case of Olsen and Saunder's reagents.

3. The readily extractable phosphorus determined after incubation with respect to Olsen and Saunder's reagents, significantly correlated with the plant uptake in Neubauer experiments.

4. Total phosphorus was found to be correlated with the available determined by Olsen's and Saunder's after incubation.

5. A number of soil characteristics like pH, conductivity, Organic carbon, exchangeable iron, aluminium and hydrogen, water soluble iron and aluminium were studied. The results show that there is considerable variation in these properties in the 34 samples of soils

6. The effect of these soil characteristics on the efficiency of extraction by the two highly correlated methods viz., Olsen and Saunder was studied by partial correlation and multiple regression. The efficiency of extraction of available phosphorus by Olsen's method, was

found to be less affected by the soil characteristics. The soil characteristics that improve this efficiency in both the methods are high pH, high exchangeable iron low organic carbon, and low soluble and exchangeable aluminium.

7. The effect of soil characteristics on the uptake of phosphorus by plants as studied by multiple regression analysis, revealed, that phosphorus uptake is favourably influenced by higher pH values, moderate amounts of exchangeable and water soluble iron, and high conductivity of the soil solution. High amounts of water soluble and exchangeable aluminium considerably decrease the phosphorus uptake.

8. Application of phosphorus gave varied response to grain yield and total dry matter production in rice plants in four pot culture experiments conducted with typical soils of Kuttanad.

9. The response was best fitted on a quadratic model and the optimum doses varied between 25 pounds to 100 pounds of phosphoric acid.

The present study reveals that there is a need to take up further studies, on the preconditioning to be given to soils prior to testing them in the laboratory for available phosphorus. Olsen's reagent appears to be a better one for the acid rice soils of Kerala. Studies based on the influence of soil chemical characteristics on the amounts extracted by Olsen's reagent shows that it is the only reagent, with potentialities for being adopted as a universal reagent for determining available phosphorus. All the experiments directly and indirectly show that iron phosphate is the predominant form of phosphate in the soils studied and it is this form that is plant available. It is noteworthy that the optimum dose for Kuttanad soils vary between 25 to 100 pounds. This only reveals the need for further work on the factors controlling the availability and fixation of phosphorus in these soils.

No attempt has been made in the present investigation to work out a rating chart for soil test data on available phosphorus, since this is an aspect which requires the results of a very large number of pot culture correlation experiments and field experiments.

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APPENDIX

A P P E N D I X I

Soil No: 31 Yield of grain

Analysis of variance Table

Source	Sum of squares	Degrees of freedom	F
Total	282.64	19	$F_{3, 16}$ **
Treatment	275.41	3	203.1
Error	7.23	16	

** F ratio highly significant

T_2 T_4 T_3 T_1

T_1 = 0 lbs. per acre phosphorus

T_2 = 20 "

T_3 = 40 "

T_4 = 60 "

Soil No: 32 Yield of grain

Analysis of variance Table

Source	Sum of squares	Degrees of freedom	F
Total	324.14	19	
Treatment	279.09	3	$F_{3, 16}$
Error	45.04	16	33.01**

C. D = 2.25

T_2 T_4 T_3 T_1

Soil No: 33 Yield of grain

Analysis of variance table

Source	Sum of squares	Degrees of freedom	F
Total	32.31	19	$F_{3, 16}$
Treatment	21.14	3	10.1**
Error	11.17	16	

C. D 1.11

T_3 T_2 T_4 T_1

Soil No: 34 Yield of grain

<u>Analysis of variance table</u>

Source	Sum of squares	Degrees of Freedom	F
Total	113.67	19	
Treatment	100.54	3	$F_{3, 16}$**
Error	13.13	6	40.84

C.D at 5 percent level = 1.213

T_4 T_2 T_3 T_1

Soil No: 31 Total dry matter

<u>Analysis of variance table</u>

Soirce	Sum of squares	Degrees of freedom	F
Total	593.43	19	
Treatment	590.89	3	$F_{3, 16}$
Error	2.54	16	3.21

C.D = 5.37

Not significant.

Soil No: 32 Total dry matter

Analysis of variance table

Source	Sum of squares	Degrees of freedom	F
Total	823.95	19	
Treatment	671.82	3	$F_{3,\ 16}$
Error	152.13	16	3.21

C.D = 2.3

$T_2\ T_3\ T_4\ T_1$

Soil No: 33 Total dry matter

Analysis of variance table

Source	Sum of squares	Degrees of freedom	F
Total	139.87	19	
Treatment	124.98	3	$F_{3,\ 16}$
Error	14.89	16	3.21

C. D = 0.4089

$T_3\ T_4\ T_2\ T_1$

Soil No: 34 Total dry matter

Analysis of variance table

Source	Sum of squares	Degrees of freedom	F
Total	1920.4	19	$F_{3, 16}$
Treatment	1904.17	3	3.2
Error	14.26	16	

C. D = 1.265

$T_4\ T_3\ T_2\ T_1$