EVALUATION OF AVAILABLE PHOSPHORUS AND POTASSIUM IN SOIL USING A COMMON EXTRACTANT

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Evaluation of available phosphorus and potassium in soil using a common extractant" is a bonafide record of research work done by me during the course of research and 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 University or Society.

Vellanikkara,
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CERTIFICATE

Certified that this thesis entitled "Evaluation of available phosphorus and potassium in soil using a common extractant" is a record of research work done by Smt. Durga Devi, K.M. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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CERTIFICATE

We, the undersigned members of the Advisory Committee of Smt. Durga Devi, K. M., a candidate for the degree of Master of Science in Agriculture with major in Soil Science and Agrl. Chemistry, agree that the thesis entitled "Evaluation of available phosphorus and potassium in soil using a common extractant" may be submitted by Smt. Durga Devi, K. M., in partial fulfilment of the requirement for the degree.

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The importance of an adequate supply of plant nutrients to ensure efficient crop production is being recognised now, more than ever. The need for phosphorus and potassium in soil is being increasingly realised by the cultivators and these elements have received the sufficient attention in soil testing laboratories and research institutions. Chemical soil tests are needed to determine the nutrient supplying power of the soil and hence the quantity of fertilizer to be applied to overcome any shortcomings.

Phosphorus is considered to be the most critical nutrient anion in the growth of plants, with the possible exception of nitrogen. Owing to its complex reactions and transformations in soil, and because of small total amount present in soil, the phosphorus problem has become very serious. In terms of quantities taken up by plants and the total amount in many soils, potassium is a very important nutrient cation. Therefore phosphorus and potassium are the two important plant nutrients determined by soil testing.

Attempts have been made to find some chemical means to remove those portions of the soil P and soil K that are available to plants. There are many soil testing methods and a great deal of work has been done in the search for the 'best' method.

Estimation of P and K available to plants is often carried out by chemical methods based on the principle that the amount of plant nutrients solubilised or extracted by a chemical extractant may be correlated with the amount of nutrients taken up by plants i.e., to simulate plant feeding.

A large number of extractants involving water, alkalies, strongly ionised to weakly ionised acids, buffered solutions, neutral salt solutions etc. have been suggested by various scientists for extracting available P and available K. At present the soil testing laboratories of Kerala employ Bray No.1 ($0.03\ \underline{N}\ NH_4F + 0.025\ \underline{N}\ HCl$) for extracting available P and neutral normal NH_4OAc for extracting available K, although numerous others have been used and are under investigation.

In the development of any extracting solution, two criteria should be considered. First, the extraction of nutrients must be from the labile pool that supplies those nutrients to plant roots. Second, the soil test procedure should be rapid, reproducible and economical.

The large number of extractant solutions which have been employed in trying to measure the availability of individual nutrients put forth practical difficulties in routine soil testing. Different extractants removed different fractions and different proportions of the total amount of an element present in the soil. These difficulties most commonly arise due to the fact that the nutrient availability to plants depends on the conditions under which the plant is grown and nutrient requirement of the crop. Very often, the most commonly used Bray No.1

and NH_4OAc methods could not perform very well in all situations. Because of the great variations that usually occur from place to place it is necessary to test considerable number of samples from a field. Since the number of soil samples tested annually in Kerala has been steadily increasing, extraction of individual nutrients with separate extractants has become laborious and time consuming. Moreover, recent advances in computor controlled data processing and sophisticated laboratory instruments that are capable of analysing a solution for many elements simultaneously, can be fully realised only if a single extracting solution can provide information on several soil nutrients.

A few tests generally known as rapid tests have been devised, which employ a single extraction and subsequent testing the extract obtained for many elements. Morgan's 'universal extractant' which is sodium acetate-acetic acid combination buffered to pH 4.8 was given much importance for many years. Several modifications of this extractant were made by several workers but none could give results which would correlate closely with the uptake of phosphorus and potassium in a wide range of soils. Unlike nitrogen, secondary nutrients and micro-nutrients, phosphorus and potassium follow certain unique pattern of soil reactions. So it has become necessary to find out an extractant suitable for extracting phosphorus and potassium simultaneously. Eventhough many extractants have been used and are tried for extracting most of the important plant nutrients using a single extracting solution, not enough work has been carried out to decide whether a common extractant can be employed for estimating available P and K alone.

Among the different types of chemical extractants, mineral acids in chelated system can be preferred to other extractants, since the acid conditions under which extraction takes place can be considered somewhat comparable to that of the field conditions under which P and K are taken up by plants from the acid laterite soils of Kerala.

Once an extractant is found suitable both for P and K, the analysis must be extended to other properties of the soil, a demand which has been made more frequently in recent years. In addition to the chemical calibration and determination of the relationship between test value and crop response, the fertilizer recommendation must be made in the light of a practical knowledge of the crop to be grown, characteristics of the soil under study and other environmental conditions. The relationship between the available nutrients obtained by chemical analysis and physico-chemical characteristics of the soil such as pH, organic carbon content, nutrient fixation, etc. will enable a better interpretation of the values of conventional analysis.

In view of the above facts, the present study is therefore undertaken with the objective of evolving a single extractant suitable for extracting both available P and available K so as to simplify the process of extracting these available plant nutrients in soil testing work.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

1 Estimation of available P in soil by chemical methods

The chemical technique that has received and is still receiving the most attention for estimating available P in soil is that of extraction with one or more solutions. Different extractants that have been suggested during the last century are legion and cover the whole gamut between concentrated sulphuric acid and boiling caustic alkali. The publications in which these solutions and their applications are discussed probably are the most voluminous. Some of the workers involved are Anderson (1960), Hanna and Flannery (1960), Hester (1960), Kamprath and Fitts (1960), Nelson *et al*. (1960), Schrader (1960), Wolf (1960), Hesse (1971), Bingham (1975) and Chopra and Kanwar (1976).

The principle involved in the extraction is that the extractant is capable of dissolving that fraction of soil P that is considered available to plants.

Eventhough a large number of extractants have been evaluated extensively, it must be admitted that no one method is useful for all types of soils. For example, the National Soil and Fertilizer Research Committee on Soil Testing (1956) compared a number of chemical soil tests, using soils of known P requirement. In all, 74 widely varying soils were involved, the committee noted that the chemical tests agreed better with greenhouse 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).

1.1 Chemical extractants used so far

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

The extractants proposed so far are listed in Table 1.

Table 1

List of extractants for available P

Sl. No.	Extractant	Proposed by
1	Water	Blenkinsop (1938), Burd and Murphy (1939), Burd (1948), Bingham (1949), Hashad *et al*. (1957) Thompson *et al*. (1960), Van Diest (1963a), Paauw and Sissingh (1968), Paauw (1971), Sissingh (1971), Gibson (1976)
2	CO_2 saturated water	Puri and Asghar (1936)
3	Carbonic acid	Mc George (1939), Stanberry (1949), Sen Gupta and Cornfield (1963), Abbott (1978)
4	1% citric acid	Dyer (1894)

(Table 1 Contd....)

Sl. No.	Extractant	Proposed by
5	0.5 *N* acetic acid	Suetov (1968)
6	Oxalic acid	Gachon (1966)
7	0.314 *N* HCl	Baver and Bruner (1939)
8	0.7 *N* HCl	Olsen (1946)
9	0.2 *N* HNO_3	Fraps (1909)
10	0.01 *N* HNO_3	Von Sigmond (1929)
11	0.01 *N* H_2SO_4	Kerr and Von Steightz (1938)
12	0.05 *N* H_2SO_4	Beater (1949)
13	0.2 *N* H_2SO_4	Bandroff (1952)
14	0.5 *N* H_2SO_4	Bittencourt *et al*. (1978)
15	0.05 *N* HCl + 0.025 *N* H_2SO_4	Nelson *et al*. (1953), Fitts (1956), Pritchett (1976)
16	0.1 *N* HCl + 0.025 *N* H_2SO_4	Mehlich (1955)
17	0.06 *N* H_2SO_4 + 0.06 *N* HCl + 0.05 *N* oxalic acid	Mathew (1979)
18	0.002 *N* H_2SO_4 buffered to pH 3 with$(NH_4)_2SO_4$	Truog (1930)
19	Acetic acid at varying strengths	Brown (1940), Ghani (1943), Peech and English (1944)
20	Sodium acetate-acetic acid	Morgan (1937)
21	0.02 *N* calcium lactage in 0.01 *N* HCl (pH 3.5)	Egner (1941)

(Table 1 Contd.....)

Sl. No.	Extractant	Proposed by
22	0.1 M ammonium lactate in 0.4 M acetic acid	Egner *et al*. (1960)
23	2.5% acetic acid containing 8-hydroxy quinoline	Williams (1950)
24	0.1 M calcium lactate and 0.1 M calcium acetate in 0.3 M acetic acid	Schuller (1969)
25	Boric acid and borax buffered to pH 7.6	Sik (1964)
26	0.07 N EDTA and 0.005 N oxalic acid	Borlan and Bordeiasu (1968)
27	EDTA	Kanwar (1953), Viro (1955a, 1955b), Wallace *et al*. (1955), Alexander and Robertson (1972), Nnadi (1975), Sahrawat (1977)
28	0.2 M ammonium oxalate	Joret and Herbert (1955), Owens (1977)
29	Calcium chloride	Aslyng (1954), Aslyng (1964), Gachon (1966), Baker and Hall (1967), Wainwright and Sowden (1977)
30	Normal HCl	Puri and Swarnakar (1969)
31	0.5% K_2SO_4 + 0.5% ammonium molybdate	Ginzburg and Artamonava (1966)
32	Ammonium acetate	Breland and Nesmith (1968), Quddus (1968), Ogot (1970)

(Table 1 Contd....)

Sl. No.	Extractant	Proposed by
33	Sodium acetate	Breland and Nesmith (1968)
34	Dilute stannous chloride solution	Wendt and Corey (1974)
35	0.5 M NH_4F and 0.1 N HCl	Bray and Kurtz (1945)
36	0.03 M NH_4F and 0.025 N HCl	Dupuis (1950)
37	NH_4F	Uriyo and Kesseba (1972)
38	NH_4F and H_2SO_4	Miller and Alexy (1956), Robertson (1962), Kacer *et al.* (1967)
39	NH_4F + HF	Agboola and John (1980)
40	0.03 M NH_4F and 1% EDTA	Datta and Kamath (1959)
41	1% K_2CO_3 at pH 8.5	Das (1930)
42	0.5 M $NaHCO_3$ adjusted to pH 8.5	Olsen *et al.* (1954), Webber and Mattingly (1970), Walmsley and Cornfoth (1973), Matar and Samman (1975), Barrow and Shaw (1976a, 1976b) Bowman and Cole (1978)
43	Ammonium bicarbonate	Dirks and Scheffer (1928)
44	1% ammonium carbonate	Bobrus and Kim (1969)
45	0.5 N sodium hydroxide	Jones (1949)
46	Hot 0.1 N sodium hydroxide	Saunder (1956)
47	Calcium bicarbonate	Warren and Cooke (1962)
48	0.3 N NaOH and 0.5 N sodium oxalate	Al-Abbas and Barber (1964)

1.2 Evaluation of the methods

The different extractants suggested by so many workers have often been compared to see their performance in estimating available P. Their relative efficiency was judged by the degree of correlation obtained with P uptake by plants in either greenhouse or field trials. The literature on the 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 analysis 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 fertilizer are limiting or lacking (Pack and Gomez, 1956).

Smith and Cook (1953) correlated the growth response of wheat with chemically measured available P in soil, utilizing 8 chemical methods of extracting available P. The use of any of the methods of Bray provided a considerably clear picture of the P availability, since inclusion of fluoride in the extracting solution enabled the adsorbed P in the soil to be removed.

Catani and Nakamura (1971) found that soil solution ratio had a marked influence on the P 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.

Jose (1972) compared several methods of measuring available P in soils of South India and reported that anion exchange resin and isotopic dilution techniques gave values highly correlated with P uptake by ragi plants. Among the chemical extractants, Bray No.1, Al-Abbas and Barber and Olsen's methods were most satisfactory and the P extracted by these methods were highly correlated with P uptake by plants. Water and anion exchange resin extracted comparatively lower amounts of P from soils, while acid extractants dissolved large amount of P especially from soils of high pH. Bray No.1 extractant though contained acid proved efficient due to its ability to dissolve Al-phosphate, the form of P most closely correlated with P uptake by plants in the soils studied. Walmsley and Cornfoth (1973) showed that Olsen's P (0.5 M $NaHCO_3$) method gave the best estimates of available P and was also least sensitive to changes in soil properties (texture, pH, CEC and percentage base saturation). Amer's resin method was almost as good except that it was unsuccessful with soils of low base saturation.

Kothandraman (1975) in his studies on the evaluation of different methods for estimating available P showed that Olsen, Bray No.1, Bray No.2, Truog, Williams, Mehlich and Fraps were most satisfactory and equally effective in extracting the plant available P, when all the soils were considered together. The results of the statistical analysis had shown that most of the variations in the P uptake by plants and Bray No.1 test values were accounted for by Al-P. The Fe-P fraction was the prime source of Olsen's P and isotopically exchangeable P. The greatest contribution in the variation of Bray No.2 and Truog soil test values was mainly from Ca-P followed by Fe-P and Al-P.

Rudd and French (1976) compared 9 methods of measuring available soil P in soils of South Australia, many of which contained large amounts of free lime. For all soils, 0.5 M $NaHCO_3$ extractant was found to be the best, HCl in NH_4F was good for noncalcareous soils.

Olsen and Bray No.1 solutions were equally precise in predicting percentage of yields (Enzewar, 1977).

Maida (1978) found that the amounts of soil P extracted by the methods of Olsen, Bray, Williams and Stewart, Morgan, Aslyng, anion exchange resin, Saunder, Dyer and North Corolina were significantly inter-related. The extraction of Al-P by chemical soil tests was in the decreasing order of Dyer > North Coroline > 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 NaOH extractable P, Olsen P, North Carolina P, resin extractable P and Dyer P values.

Mathew (1979) revealed that Bray No.1 could not estimate 'Ra-value' of the soil i.e., total available phosphate reserve of soil. He found that resorption of P from the solution can be effectively prevented by employing organic acids and thus the amount of P extracted by the mineral acid could be increased by the presence of organic acids, notably oxalic acid. He recommended an extractant consisting of 0.06 N H_2SO_4, 0.06 N HCl and 0.05 N oxalic acid, with an equilibration period of 30 min and a soil solution of 1:10 for estimating the 'Ra-value' of the soils of Kerala.

Onken *et al*. (1980) found that EDTA procedure resulted in better predictability of P fertilizer needs than either the NH_4OAC or $NaHCO_3$ extraction procedures.

Holford (1980) showed that in a successful soil test, increasing buffer capacity could depress the extraction of labile P in the same way as it depressed P uptake by plants. He observed that extraction of labile P was depressed by increasing buffer capacity most in the Bray test, followed by the Olsen test and least in the Colwell test. The Olsen test appeared to be correctly sensitive to buffering.

Olsen's extractant was capable of extracting the inorganic forms of P which were considered to be readily available to rice crop under flooded soil conditions and this method was promised to be a reliable soil test method for the evaluation of P requirement of rice crop in flooded soils (Biddappa and Sarkuman, 1981).

Debnath and Mandal (1982) related the different inorganic P fractions to available P determined by various chemical and biological methods. It was indicated that Al-P was the major source of labile P determined by Bray No.1 and Troug's methods whereas Fe-P was the main source as secured by Olsen and Neubauer procedures. From the stand point of similarity with Neubauer method in extracting P dominantly from a common fraction of phosphate, Olsen's P appeared to be the best for soils under study especially for rice crop. The wider range applicability of Olsen's method in Indian soils especially for low land rice has been established by Datta and Kamath (1958), Layesse and

Tilo (1970), Muruiki and Barber (1983).

Tripathi and Verma (1982) determined the phosphate availability indices and inorganic P fractions in 12 Alfisols of Himachal Pradesh on air dry and waterlogged soil samples. The stepwise regression analysis indicated that Fe-P was the most important variable contributing to the total variation in the regression of Olsen, Bray P1, Bray P2, Peech and Morgan's extractants and Ca-P in the regression of North Carolina extractants both in air dry and waterlogged soils. Al-P was the second important variable contributing to the variation in the regression of Olsen, Bray P1, Bray P2, and North Carolina extractants and Ca-P in the regression of Peech and Morgan's extractants. With the exception of Trueg's extractant, six other extractants extracted P from the same inorganic phosphate fractions under both air dry and waterlogged situations indicating their similarity under the two situations. The same workers in the same year found that Fe-P was the most important inorganic P fraction contributing to P nutrition of rice and that Al-P was next in importance. The Bray P2 soil extractant was the most effective in extracting P from Fe and Al-P fractions of soil P in both air dry and waterlogged soils. This method correlated well with all the growth parameters of plants grown under waterlogged condition.

Sibbeson (1983) evaluated the suitability of some soil P testS to assess the P status of contrasting soils and the evaluation rankedthe P tests into three groups, viz., best group -

anion exchange resin method; intermediate group - water and sodium bicarbonate method; worst group - all acid methods, acetate buffer, lactate buffer, citric acid, Bray 1, Truog and Bandroff's methods.

The relationship between extractable phosphate and mobile phosphate was more complex than might be assumed and depends on the sorption characteristics of the soil. It was therefore not possible to accurately estimate labile phosphate simply from Bray P1 extractable phosphate. No simple way conventional methods could replace the need for isotopic exchange measurements (Probert and Willett, 1983).

Holford (1983) reported that phosphate sorptivity had no effect on the critical levels of any soil tests on the very acid soils and sodium bicarbonate tests were the most effective and Mehlich test was the least effective, on all soils regardless of sorptivity or pH. The results suggested that major source of plant available P in moderately acid to alkaline soils is exchangeable P whereas in very acid soils it is non-exchangeable mineral P associated with Fe and Al.

Mackay *et al.* (1984) reported that Bray procedure appeared to be the most effective soil testing procedure in situations where unreacted phosphate rock contributed significantly to plant available P in soil. The better predictive ability of the Bray test resulted from the ability of this procedure to extract unreacted phosphate rock which is likely to dissolve in the short term and sorbed.

Dalal (1985) correlated the P desorbed from 18 South Australian soils by anion exchange resin (AER) and cation anion exchange resin (CAER) K at different periods with yield response and P uptake by wheat. The relationship between the quantity of P desorbed by both resin systems and P uptake and grain yield was found to improve significantly as the period of desorption increased upto about 10 hours, after that improved only slightly. The CAER-P was better correlated with P uptake and grain yield and predicted yield response more closely than AER-P. CAER desorbed more P from soil than AER due to its capacity to take up cations as well as P from the soil solution, thus better simulating cation and P uptake by plants.

Wolf and Baker (1985) had undertaken a study to evaluate the agreement among different University laboratories performing the Olsen, Bray P1, Mehlich I and Mehlich III tests for P on a diverse group of non-calcareous agricultural soils. The Bray P1 and Mehlich III were highly correlated and similar quantities of P were extracted by the two tests.

2. Extractants used for the estimation of available K

Available K in soil is consisted of immediately available which is the water soluble and exchangeable, and potentially available or 'fixed' K. It has been firmly established that plants are able to take up more K from a soil than is present in water soluble and exchangeable form. The release of non-exchangeable K from nonexchangeable sources may be appreciable.

However, the release rate is universally too slow to provide a K supply that is adequate for high yields (Grimme, 1974).

The main trend for the determination of available K was for rapid methods, and the search went on for extractants which would dissolve the plant available fraction with the least possible expenditure of time and labour (Ahmed *et al.*, 1973). A great number of different extraction procedures have been used with varying success, still there is lack of a satisfactory extractant which can be postulated universally for determining available K.

The different extractants suggested by various workers for estimating available K are given in the table below:

Table 2

List of extractants for available K

Sl. No.	Name of extractant	Proposed by
1	Water	Nelson (1959), Swami and Lal (1970)
2	HCl (dilute)	Garman (1957), Harada and Sinohara (1968), Mishra *et al.* (1970)
3	0.7 *N* HCl	Baumgardner and Barbier (1956)
4	HCl under reflux	Singh *et al.* (1983)
5	1.38 *N* H_2SO_4	Hunter and Pratt (1957)
6	6 *N* H_2SO_4	Hunter and Pratt (1957)
7	0.05 *N* HCl + 0.025 *N* H_2SO_4	Wang and Tseng (1962)

(Table 2 Contd.....)

Sl.No.	Name of extractant	Proposed by
8	0.5 N nitric acid (boiling)	Oommen and Iswaran (1962), Mirchaev (1966)
9	0.5 N nitric acid (shaking)	Oommen and Iswaran (1962), Weber and Caldwell (1965) Eagle (1967)
10	Boiling normal nitric acid	Nelson (1959), Boyd and Fracter (1967)
11	Normal nitric acid	Wood and De Turk (1941)
12	1% citric acid	Dyer (1894), Sen *et al.* (1949)
13	0.5 N acetic acid	Sen *et al.* (1949), Russell (1967)
14	Neutral normal NH_4OAc	Hanway and Heidal (1962), Van Diest (1963b), Datta and Kalbande (1967), Mishra *et al.* (1970), Chiriac (1964)
15	1 N sodium acetate (pH 7.5)	Singh and Ghosh (1982)
16	10% sodium acetate added to 3% acetic acid	Morgan (1941), Swami and Lal (1970)
17	Ammonium lactate and acetic acid	Van Diest (1963b)
18	NH_4Cl 10%	Wheeting (1930)
19	0.5 N NH_4Cl and 0.025 N HCl	Nelson (1959)
20	Sodium acetate + acetic acid + hydrochloric acid	Carpenter (1953)
21	43.65% sodium acetate and 15% HNO_3	Bray (1932)
22	6% NH_3 solution and 7% acetic acid (pH 4.8)	Datta and Kalbande (1967)
23	1 N MgOAc (pH 7.5)	Conyers and Mc Lean (1969)

(Table 2 Contd....)

Sl.No.	Name of extractant	Proposed by
24	0.01 M $CaCl_2$	Hagin and Feigenbaum (1962), Feigenbaum and Hagin (1967), Russell (1967)
25	0.025 M $CaCl_2$	Schachtschabel and Heineman (1974), Grimme and Nemeth (1976a, 1976b)
26	Olsen's bicarbonate solution	Mc Conaghy and Mc Allister (1967), Singh and Ghosh (1982)

2.2 Evaluation of the extractants

Considerable amount of work have been carried out in the laboratory and greenhouse to determine the relative efficiency of various soil test procedures for K.

Wheeting (1930) indicated that Neubauer test evidently detected quite accurately the K deficiencies of soils. Of the several solvents used NH_4Cl solution most closely simulated plant activity in removing available K.

Replaceable K was generally considered to be a source of K for the soil solution and therefore to be more or less available for plant growth (Bray, 1932).

Water soluble K has given a better measure of K supplying power of a soil than the initial exchangeable level of K as reported by Hood *et al.* (1956)

Hunter and Pratt (1957) suggested that sulphuric acid would be a much simpler method than 1 N NH_4OAc and boiling 1 N HNO_3 since an exact quantity of heat energy was furnished to the soil extraction system which theoretically furnished a means of releasing a constant amount of non-exchangeable K due to breakdown of primary and secondary minerals as well as exchangeable K from a particular soil.

Six methods of extraction viz., Morgan, Peech and English, Maine, North Corolina, Amberlite I.R.20, boiling normal HNO_3 and normal NH_4OAc have been compared by Salomon and Smith (1957). He reported that the use of exchange resin although too lengthy for rapid soil testing appeared more effective in estimating crop response than did the buffered acetate solution.

As pointed out by Sutton and Seay (1958) K extracted by 0.1 N H_2SO_4 and 1 N NH_4OAc from air dry soil samples and the K extracted by 1.38 N H_2SO_4 from moist samples have given the best indices for evaluating the K supplying power of soils.

Nelson (1959) compared the total K removed by sunflower plant to removal by 6 chemical extractants using 17 soils. The best correlations were obtained with those methods measuring exchangeable K. He found that uptake of K by sunflower correlated equally well with K extracted by normal NH_4OAc or boiling normal nitric acid.

Oommen (1962) correlated soil test values for K and crop response to K fertiliser by paddy and wheat in Indian soils. Semi-normal nitric acids (30 min shaking and 1 h heating) appeared to be suitable extractants for determining K fertilizer needs in the red loam Rameswar Block (Bihar) soils, and coastal alluvial Mangalore soils respectively for paddy. Similarly Morgan's extractant appeared to be suitable for predicting K fertilizer needs for wheat crop. For Simla (H.P) submontane forest soils, Dyer's 1% citric acid appeared to be a suitable extractant for predicting the K fertilizer needs for wheat crop. Any single extractant was not found suitable for judging the needs of K fertilizer for all types of Indian soils studied.

Stanton and Orchard (1963) confirmed that exchangeable K would be the immediate source on which plants draw ~~from~~ their requirements and that depletion was followed by replenishment from other categories of soil K, the so called step K, was found to be the main secondary source. He suggested that for a better prediction of the K supplying power of a soil both the exchangeable and step K must be determined.

Datta and Kalbande (1967) reported that Hunter-Pratt method using 6 N H_2SO_4 appeared to be the best extractant under present set of conditions. In the soils having illite as the dominant clay mineral and the soils containing less than 20% clay, determination of exchangeable K by Barbier and Morgan as well as Hanway and Heidal method gave promising results. Barbier and Morgan's method was found suitable in soils containing exchangeable K less than 0.2 me/100 g of soil whereas the method developed by Hanway and Heidal was better in soils having more than this level of exchangeable K.

Swami and Lal (1970) compared 6 extractants on the basis of 'r' values and he arranged the methods in the following order in terms of K extraction ability i.e., 1 N HNO_3 soluble > non-exchangeable > exchangeable > 1.38 N H_2SO_4 soluble > 2.5% acetic acid soluble > Morgan's > water soluble.

Nambiar (1972) noted the following decreasing order of extraction efficiency of extractants and methods when he measured the available K by estimating the uptake of K by ragi seedlings grown according to a modified Neubauer technique. Normal HNO_3 (Wood and De Turk), 6 N H_2SO_4 (Hunter and Pratt No.2), 0.5 N HNO_3 with heating (Oommen and Iswaran), 1.38 N H_2SO_4 (Hunter and Pratt No.1), neutral normal NH_4OAc (Hanway and Heidal), 0.5 N HNO_3 with shaking (Oommen and Iswaran), 1% citric acid (Dyer), 1% ammonium carbonate, 43.65% sodium acetate and 15% HNO_3 (Bray), 0.05 N HCl + 0.025 N H_2SO_4 (North Carolina), Neubauer method (modified), 0.1 N EDTA, 10% sodium acetate and 3% acetic acid (Morgan), 0.5 N NaCl, 0.05 N EDTA and water. Correlation was obtained between available K extracted by the common used NH_4OAc or Neubauer value and each of the extractants used.

NH_4OAc (exchangeable K) and cold H_2SO_4 have been found to be the most successful methods and least sensitive to changes in soil properties. The acetic acid extract in general was the least effective (Ahmed _et al._, 1973).

Grimme and Nemeth (1976a, 1976b) reported that extraction with 0.025 N $CaCl_2$ appeared to be a promising method. This method took into account the clay content of soils and extracted a decreasing proportion of the exchangeable K with increasing clay content. The results were closely correlated with K concentration and K diffusion.

Halevy (1977) was of opinion that extraction with $CaCl_2$ solution (0.01 M) would be a better method for estimation of available K. Since it reflected changes in free energy and was easy to operate.

Normal nitric acid has been found to be the most suitable extractant for predicting the K uptake by plants from the soil groups of South India (Ramanathan, 1978). The correlation coefficients obtained between laboratory estimates of K and K uptake by Neubauer crops were in the following order:

$N\ HNO_3 >$ non-exchangeable K (by difference) $> N\ NH_4OAc >$ $0.5\ N\ HCl > 6\ N\ H_2SO_4 > 0.01\ M\ CaCl_2 >$ water soluble.

Grewal and Sharma (1980) reported that soil K extracted with neutral N NH_4OAc or Morgan's extractant was highly correlated with yield and K uptake of potato in acidic brown hill soils of Simla region.

Singh and Ghosh (1982) evaluated the efficiency of 19 soil test procedures for measuring the K availability through correlation with dry matter yield, total K uptake, the percentage of K concentration in maize, cowpea and wheat crops grown in greenhouse using 10 soils of alluvial origin having widely different physico-chemical characteristics. They revealed the extractable K in the soils as released with various soil tests in the following decreasing order. Boiling NHO_3 > non-exchangeable K > Hunter and Pratt's method 2 > Hunter and Pratt's method 1 > ammonium acetate-acetic acid > Mehlich new reagent > sodium acetate > ammonium acetate > Olsen's reagent > ammonium bicarbonate + DTPA > exchangeable K > Mehlich's diacid > Morgan's reagent > $CaCl_2$ > Mg acetate > water. The amount of K extracted by 1 N MgOAc solution (pH 7.5) was closely correlated with plant utilizable K. Olsen's reagent, modified Olsen's reagent and Mehlich's diacid extractants proved quite reliable in majority of cases. However, the tests measuring the non-exchangeable K did not give high correlation with crop response behaviour. No single soil test was found to be ideally suited for all the three crops in respect of the plant growth parameters and levels of K applied during both years of cropping.

Singh et al. (1983) reported that HNO_3 extractions of Haylock and Mac Lean, electro ultrafiltration (Nemeth, 1976) and a new procedure using extraction by HCl under reflux gave significant correlations with K balance of soils, and the yield and/or K uptake of winter wheat grown on the plots. The new HCl reflux suggested by them gave the closest correlations. The amount and rate of release of fixed K (available but non-exchangeable) estimated by HCl reflux was also correlated with yield and uptake.

Ross and Cline (1984) indicated that amounts of exchangeable K extracted with NaCl or NH_4Cl were relatively high, but were not correlated with K uptake by grapes.

3 Estimation of available P and K using a common extractant

Rapid soil tests which employ a common extractant for estimating several nutrient elements, as aids in determining fertility requirements of plants have aroused considerable interest in recent years. Unfortunately, only very few of the inorganic or organic reagents employed in analytical chemistry possess a sufficient degree of specificity to permit their use in the presence of diverse ions (Peech and English, 1944). In comparison with the number of extractants evolved for determining individual nutrients, relatively fewer number of extractants have been evolved as common extractants. Most of these extractants were able to determine several of the important plant nutrients. Only a very few extractants have been suggested for estimating both available P and K.

The following table shows the common extractants proposed by various scientists.

Table 3

List of extractants for available P and K

Sl. No.	Name of extractant	Proposed by
1	0.028 N acetic acid	Spurway (1933)
2	Sodium hydroxide and acetic acid, pH 5.0 (0.25 N for sodium and 0.33 N for acetate ion)	Merkle (1934)

(Table 3. contd....)

Sl. No.	Name of extractants	Proposed by
3	Sodium acetate and acetic acid, pH 4.8 (percolation)	Morgan (1937)
4	0.135 N HCl	Spurway (1935)
5	Sodium hydroxide and acetic acid, pH 5 (0.125 N for Na and 0.167 N for acetate ion)	Hester (1934)
6	25% sodium perchlorate solution	Bray (1936)
7	Sodium acetate acetic acid (shaking with charcoal)	Peech and English (1944)
8	0.73 N sodium acetate and 0.52 N acetic acid	Wolf and Ichisaka (1947)
9	0.05 M EDTA	Viro (1955a, 1955b)
10	0.3 N HCl	Warren and Cooke (1962)
11	1% citric acid	Warren and Cooke (1962)
12	Water	Warren and Cooke (1962)
13	Ammonium lactate acetic acid	Fried and Broeshart (1967)
14	1 M NH_4HCO_3 and 0.005 M DTPA (pH 7.6)	Soltanpour and Schwab (1977)
15	Olsen's extractant (0.5 M $NaHCO_3$ adjusted to pH 8.5)	Bar and Akiri (1978)
16	Mehlich II 0.2 N NH_4Cl + 0.015 N NH_4F + 0.2 N acetic acid + 0.012 N HCl	Mehlich (1978)
17	Bray No.2 (0.03 N NH_4F + 0.1 N Cl)	Ballard (1978)

(Table 3 contd....)

Sl. No.	Name of extractant	Proposed by
18	0.5 M NH_4F + 0.005 M DTPA	Rao and Ghosh (1981)
19	Sodium acetate acetic acid of pH 4.8 and 0.0001 M DTPA	Wolf (1982)
20	Bray and Kurtz No.1 (0.03 M NH_4F + 0.025 N HCl)	Ram and Prasad (1983)
21	Mehlich III (0.2 N acetic acid + 0.025 N NH_4NO_3 + 1 M NH_4HCO_3 + 0.005 M DTPA) pH 7.6	Mehlich (1984)

3.1 Evaluation of the extractants

Only a few attempts have been made to measure quantitatively, the differences between various methods of soil tests employing a single extraction for the estimation of readily soluble soil constituents.

Through the action of a large number of rye seedlings, grown on a small amount of soil, the Neubauer method made possible the simultaneous extraction of both available P and K (Thornton 1935).

Morgan (1935) noted a close correlation between his method and that of Hester eventhough the quantity extracted varied considerably. He noted further that the results of his method correlated closer to the plant response than any of the other methods studied.

Bray (1936) reported the relative efficiency of various procedures for extracting K, concluding that, of the many salt and acid combinations used, a 25% solution of sodium perchlorate was the most efficient to extract exchangeable K.

Goss and Owens (1937) employed Morgan, Bray, Hester, Merkle and Spurway methods in order to find out the relative efficiencies of the soil test extracting reagents to release soil constituents. It was found that the acid leaching solution proposed by Bray removed larger quantities of P and K than that of the other proposed procedures. It was also observed that considerable organic materials were removed by this solution which interfered with the estimation of P, Mg, and Mn. The percolation procedure of extraction as adopted by Morgan failed to give results which would correlate closely in all cases with application of fertilizers and liming materials. The shaking procedure of extracting soil samples, on the other hand liberated quantities of soil constituents which correlated quite closely with the soil pH value, the fertilizer and liming material application and crop yield.

The amounts of nutrients liberated by the solution proposed by Hester correlated very closely with that of the modified Morgan's procedure (Shaking 15 min). The Hester solution failed to release P in comparable amounts to that modified Morgan's procedure particularly in acid soils. The "universal extracting solution" released more Fe, Al and Mn phosphates than that of the Hester reagent. The Morgan's procedure as modified was more reliable for diagnosing soil fertility problems for a wider range of crops, since some plants have the power of utilising considerable quantities of phosphate when applied as Fe, Al and Mn phosphates. The quantities of soil constituents removed by dilute acid extraction of Spurway limited the use of this testing procedure as a criterion of making fertilizer and liming material recommendations for field crops in New Jersey.

Miles (1937) reported that the use of the buffered perchloric acid solution in the rapid soil test gave a good picture of the fertilizer needs of southern soils of Mississippi of the four extractants used, viz., Morgan, Spurway, Bray and Truog.

Correlation of soil test for available P and K with crop yield response to fertilization as worked out by Long and Seatz (1953) using 22% sodium perchlorate in N/10 perchloric acid and shown that correlation coefficient (r) was not significant, with respect to P on any crop viz., corn, cotton, small grains, legume hays and permanent pastures. It was significant with respect to K only on corn.

EDTA would be a more effective extractant for the adsorbed ions than NH_4OAc and it could be recommended for determining the content of exchangeable nutrients in acid soil. On the other hand, this method was hardly suitable for calcareous soils, since EDTA dissolve water insoluble carbonates that are not part of the exchange complex (Viro, 1955a)

Warren and Cooke (1962) made a comparison between methods of measuring soluble P and K in soils used for fertilizer experiments on sugar beet. The best method used a rapid extraction with dilute HCl, but extracting with water ($CaHCO_3$ was used for calcereous soils) or with citric acid was nearly as effective. These three methods were more useful than methods using larger volumes of dilute H_2SO_4, dilute acetic acid and a lactate solution.

Subramanyan (1968) worked out the correlation coefficients between the various methods for K determination and concluded that Bray and Kurtz No.2 and Olsen's methods might be used for the determination of available K and both the extractants were suitable for P and K. Both nutrients could be estimated in a single extraction thus saving considerable time spent on extraction.

Baker (1973) developed a new approach to soil testing in which the equilibrating or testing a solution contained each element for which the soil was being tested. In 1973, he reported that although the adsorption equilibria soil test could be used successfully to test for several elements and to indicate soil differences, additional calibration data would be required prior to routine use of the method.

Soil organic carbon as a common index of availability of both P and K to potatoes in acidic brown hill soils of Simla has been reported by Sharma et al. (1981).

Hanlon and Johnson (1984) compared Mehlich III, and NH_4HCO_3

DTPA multi-element extraction solutions with the more conventional Bray and Kurtz for P determination and with 1 N neutral NH_4OAc for K and Mg determinations. All solutions were highly correlated to Bray and Kurtz and 1 N NH_4OAc extractant for Oklahama soils. He showed that NH_4HCO_3 + DTPA (AB/D) could extract nutrients from neutral and acid soils also although it was originally developed for basic soils. When considering the speed of analysis Bray and Kurtz No.1, Mehlich III and 1 N neutral NH_4OAc procedures were found to be superior to AB/D procedure. AB/D was relatively unstable with respect to pH and the mixture tended to have stronger NH_3 odour.

The AB/D test procedure with analysis by an inductively coupled plasma spectrometer for simultaneous determination of elements, made soil and overburden testing very efficient (Soltanpour, 1985).

MATERIALS AND METHODS

MATERIALS AND METHODS

1. Collection of soil samples

Eighty seven surface soil samples (0-15 cm) were collected from all over the State, covering all the districts for assuring wide variation in the content of available P, K and physicochemical characteristics of the soil.

Samples were collected to a depth of 15 cm from the surface of the soil with the help of a spade, making a 'V' shaped cut, with one side perpendicular to the surface. About 2 kg of well mixed soil (composited) was collected out of 4 to 6 pits from a plot representing a soil type.

The samples were dried in shade, powdered using a mortar and pestle and sieved through a 2 mm sieve. Approximately 1 kg of the sieved sample was kept for the pot culture experiment. One kg of the sample was further processed to pass through a 0.5 mm sieve and used for chemical analysis. Details of the location of the soils selected for the study are given in Appendix I.

2. Analytical procedures

The soils were analysed for moisture, pH, EC, organic carbon, CEC, total P, total K, available P, available K and P fixing capacity.

2.1. Moisture

Five g of soil was weighed into a sqat form bottle and then dried to constant weight in an electric oven at 105-110°C.

After cooling in a desiccator, the loss in weight was determined and the result was expressed on dry basis.

2.2. pH and electrical conductivity

pH of the soil was determined with an Elico combined electrode, type CL-51 pH meter using a soil water ratio of 1:2.5. The electrical conductivity of the supernatant liquid was measured in a direct reading conductivity meter.

2.3. Organic carbon

The chromic acid method of Walkley and Black as described by Jackson (1958) based on spontaneous heat of dilution of H_2SO_4 was used for the determination of organic carbon. The soil was digested with standard potassium dichromate and concentrated sulphuric acid. The excess chromic acid was back titrated against standard ferrous sulphate using ferroin as the indicator (Jackson, 1958).

2.4. Cation exchange capacity

The CEC was determined by saturating the exchange site with K. Five g of soil was weighed out into a 15 ml centrifuge tube. Potassium saturation was obtained by 5 washings with 1 N KCl solution, 10 ml at a time. Removal of excess salt was done by washing once with distilled water and twice with 95% ethanol 10 ml each and once with 10 ml acetone. To the sample, 10 ml of 1 N NH_4Cl solution was added and the suspension was centrifuged. This was done 5 times and each time supernatant liquid was quantitatively transferred to 100 ml volumetric flask. The volume was diluted to the mark with 0.5 N NH_4Cl and K was estimated in the solution using a flame photometer (Jackson, 1969).

2.5. Total P and total K

2.5.1. Digestion with perchloric-nitric acids

About 1 g of air dry 0.5 mm soil was weighed into a beaker, 20 ml of concentrated nitric acid was added, covered the beaker and cautiously heated to oxidise organic matter. Added 10 ml of 60 per cent perchloric acid, and digested the mixture until the content in the beaker was white and clear. The digested content was filtered and made upto 100 ml (Hesse, 1971).

2.5.2. Total phosphorus

An aliquot of the soil digest was taken and phosphorus was determined colorimetrically by the vanadomolybdophosphoric yellow colour method in nitric acid system (Jackson, 1958).

2.5.3. Total potassium

Potassium in the soil digest was determined flame photometrically (Jackson, 1958).

2.6. Available phosphorus

For the determination of available P, the soil was extracted with Bray No.1 extractant (0.03 N NH_4F + 0.025 N HCl, using 1:10 soil solution ratio and an equilibration period of 5 min) and phosphorus in the extract was determined by the chlorostannous blue colour method in hydrochloric acid system using spectronic 20 spectrophotometer (Jackson, 1958).

2.7. Available potassium

The soil was extracted with normal neutral ammonium acetate (using a soil solution ratio 1:5 and an equilibration period of 5 min) and potassium in solution was determined using an EEL flame photometer.

2.8. Phosphate fixing capacity

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

3. Estimation of P and K uptake from soils using rice as the test crop

The total uptake of P and K from the soils was determined by growing rice crop in soils taken in small plastic containers following the Neubauer seedling technique (Kanwar, 1976) with some modifications. This experiment was so planned that maximum removal of phosphorus from soils was effected in a short period of time by growing a large number of plants in a small quantity of soil.

One hundred g of soil was taken in small plastic container of 12 cm diameter and 5 cm depth and mixed with

50 g of sand. A control pot was maintained in which no soil was taken. The short duration high yielding variety of rice viz., Annapoorna was used as the test crop. Germinated seeds were used as the seed material and 100 seedlings were grown in the pots for a period of 30 days. The plants along with roots were harvested and the adhering soil particles were completely removed. The harvested plant material was dried in an electric oven at 80°C till a constant weight was obtained.

3.1 P and K uptake by plants

The whole plant material was powdered, dried and 0.5 g was transferred into a 100 ml volumetric flask. The content was digested in triple acid mixture consisting of nitric, sulphuric and perchloric acids in the ratio of 10:1:4 till the content turned colourless. The digest was diluted with water, the volume made up, kept aside for one day and filtered when the whole silica was settled down. Phosphorus in the digest was determined by vanadomolybdophosphoric yellow colour method in nitric acid system using spectronic 20 spectrophotometer and K was estimated using an EEL flame photometer.

The percentages of P and K in plant material were calculated and P and K uptakes by plants were then computed from total dry weights.

4. Screening of chemical extractants as indices of available P and K content of soil

To evolve a common extractant both for available P and available K, the following extractants were tried.

4.1 Initial screening of chemical extractants

To fix up extractants for preliminary screening an initial study was taken up, using 1 soil, 18 extractants and 2 equilibration periods. The extractants were:

1 0.1 M NH_4F + 0.001 M DTPA

2 0.1 M NH_4F + 0.005 M DTPA

3 0.1 M NH_4F + 0.05 M DTPA

4 0.5 M NH_4F + 0.001 M DTPA

5 0.5 M NH_4F + 0.005 M DTPA

6 0.5 M NH_4F + 0.05 M DTPA

7 1.00 M NH_4F + 0.001 M DTPA

8 1.00 M NH_4F + 0.005 M DTPA

9 1.00 M NH_4F + 0.05 M DTPA

10 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid

11 0.03 M NH_4F + 0.025 N HCl (Bray No.1)

12 0.03 M NH_4F + 0.05 M NH_4OAc + 0.025 N HCl

13 0.05 M NH_4F + 0.05 M NH_4OAc + 0.025 N HCl

14 0.05 M NH_4F + 0.05 M acetic acid

15 0.03 M NH_4F + 0.05 M acetic acid

16 0.03 M NH_4F + 0.025 N HCl + 0.001 M DTPA

17 0.03 M NH_4F + 0.025 N HCl + 0.005 M DTPA

18 1 N neutral NH_4OAc

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 (30 and 60 min) in a mechanical shaker.

Immediately after shaking, the content was filtered through Whatman No.1 filter paper. Phosphorus in the filtrate was determined colorimetrically by the chlorostannous reduced molybdophosphoric blue colour method in hydrochloric acid system, and K was determined using an EEL flame photometer (Jackson, 1958).

On the basis of workable concentration ranges of NH_4F and DTPA combinations and rate of release of P and K into the soil solution , some extractants were eliminated and 9 combinations of NH_4F + DTPA were tried for the next phase of the study, viz., preliminary screening of the extractants.

4.2 Preliminary screening of extractants

In the preliminary screening, nine NH_4F + DTPA combinations were tried at different concentrations within the workable limits. In addition, Olsen's extractant was also introduced. Thus preliminary screening consisted of 15 extractants at 5 periods of equilibration viz., 5, 10, 15, 30 and 60 min with 9 soils, and a single soil solution ratio of 1:10. Selected extractants for preliminary screening are listed below:

1 0.1 M NH_4F + 0.001 M DTPA
2 0.1 M NH_4F + 0.003 M DTPA
3 0.1 M NH_4F + 0.005 M DTPA
4 0.3 M NH_4F + 0.001 M DTPA
5 0.3 M NH_4F + 0.003 M DTPA
6 0.3 M NH_4F + 0.005 M DTPA

7 0.5 M NH_4F + 0.001 M DTPA
8 0.5 M NH_4F + 0.003 M DTPA
9 0.5 M NH_4F + 0.005 M DTPA
10 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid
11 0.03 M NH_4F + 0.025 N HCl (Bray No.1)
12 0.03 M NH_4F + 0.025 M HCl + 0.005 M DTPA
13 0.05 M NH_4F + 0.05 M acetic acid
14 0.5 M $NaHCO_3$, pH 8.5 (Olsen)
15 Normal neutral NH_4OAc (std)

Graphs were plotted taking period of equilibration on the X axis and P values on the Y axis for each extractant solution. From the nature of the curves obtained a few extractants with suitable equilibration periods were selected for studying their performance in all the 87 soils for the final selection.

Thus the selected 10 extractants and their equilibration periods are given below:

Sl.No.	Name of extractant	Equilibration period
1	0.1 M NH_4F + 0.001 M DTPA	5 min
2	0.1 M NH_4F + 0.003 M DTPA	5 min
3	0.3 M NH_4F + 0.001 M DTPA	10 min
4	0.5 M NH_4F + 0.005 M DTPA	5 min
5	0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid	30 min
6	0.03 M NH_4F + 0.025 N HCl (Bray No.1)	5 min
7	0.03 M NH_4F + 0.025 M HCl + 0.005 M DTPA	10 min

Sl.No.	Name of extractant	Equilibration period
8	0.05 M NH_4F + 0.05 M acetic acid	5 min
9	0.5 M $NaHCO_3$, pH 8.5 (Olsen)	30 min
10	Normal neutral NH_4OAc (std)	30 min

4.3 Final selection of common extractant

The performance of the ten extractants selected from the preliminary screening was studied using the 87 soils with the selected equilibration period for each extractant. Phosphorus in solution was estimated colorimetrically by the chlorostannous reduced molybdophosphoric blue colour method in hydrochloric acid system and potassium was determined flame photometrically.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Any soil test that measures the available quantity of phosphorus and potassium will provide enough information to support atleast an approximation of the quantity of these nutrients to be supplied to soil for correcting the deficiency. However, all soil tests so far used could not predict the corrective treatment for a wide range of soils and environmental conditions. Very often the amount of nutrient extracted by the widely accepted and presently using common methods viz., Bray No.1 for available P and neutral normal NH_4OAc for available K vary in their correlation with the plant responses when different soils and varying climatic conditions were considered.

For practical routine soil testing the use of separate soil extractants for each nutrient would be cumbersome and cost prohibitive, especially when the number of soil samples to be handled in a soil testing laboratory is very large. In this respect, the use of a common extractant both for P and K receives greater attention than the classical conventional methods. Unlike the classical methods of involving individual extractants for P and K, the extraction using a common extractant will make the process simpler and rapid and the individual soil tests can be carried out on separate aliquots of a single extract by means of colorimetric method and flame photometric method for P and K, respectively. The use of sophisticated laboratory instruments that are capable of analysing a solution for many elements simultaneously in soil testing laboratories is becoming widespread. The advantages of such modern equipment can be fully realised only if a single soil extracting solution can provide information on several soil nutrients.

On the choice of the extracting solution best suited for the determination of P and K simultaneously, many restrictions must be imposed necessarily. The extracting solution must remove a portion of the element under consideration that can be related to plant uptake in the field and the results of the test must necessarily correlate with known crop responses to fertilizers.

A satisfactory extracting solution should effect complete or proportional removal of the portion of plant nutrients that will be really available to the crop under field conditions. The extractant should yield a clear filterate with minimum interference due to organic matter. The extractant solution should not contain ions that will interfere with the proper execution of the individual tests. The concentration of the reagents must be within limits of acceptable sensitivity of the respective tests (Peech and English, 1944)

Unfortunately, only very few of the chemicals used in soil analysis possess a sufficient degree of specificity to permit their direct use in the presence of diverse ions. In addition to the chemical interference, there are so many biological and environmental factors involved in the interpretation and in the practical use of the soil tests.

Because of the above reasons, the results of a chemical soil test involving a common extractant have provided only a part of the information necessary for an intelligent fertilizer recommendation. Nevertheless, these chemical soil tests when properly correlated with plant uptake on different soils, can furnish valuable information that can serve a very useful purpose in fertilizer recommendation provided that the tests can be relied upon to give a consistently accurate and reliable analytical results. Thus, the adoption of a common extractant must be based on successful statewide soil test calibrations.

During the early years of the present century, Morgan's extractant (sodium acetate-acetic acid, pH 4.8) was used as an universal extractant solution. As pointed out by Morgan (1935) it is well buffered at a pH value that is closely approximated by that of the soil solution in equilibrium with the partial pressure of carbon dioxide normally found in the soil air and its solvent action is relatively unchanged even upon prolonged contact with a soil containing moderate amounts of $CaCO_3$. This solution has been found capable of replacing a fairly high proportion of the exchangeable bases in most soils by a single extraction using 1:5 soil solution ratio. Despite its acidity, Morgan's solution was found to bring sufficient organic matter into solution to interfere seriously, with P tests. The possibility of removing dissolved organic matter by means of activated carbon was then investigated by Peech and English (1944). In the removal of organic matter from soil solutions using carbon, appreciable reduction in the concentration of many ions was found out by Reitemeir (1941). Interference with organic matter is possible in the Olsen's extractant (Olsen et al. 1954), NH_4HCO_3- DTPA (Soltanpour and Schwab, 1977) and Mehlich III (Mehlich, 1984) because of their alkaline nature, although these extractants were considered to be suitable for estimating both P and K. Therefore, evolving a common extractant which can estimate both P and K without any analytical difficulty is highly warranted.

The present study was therefore planned to evolve an extractant which will extract both P and K simultaneously, which will be correlated with plant uptake. The investigation was oriented to estimate P and K using a common extractant without any analytical difficulties.

The investigation for a common extractant was carried out through three stages of evaluation. The first stage was an initial study, in order to fix up approximate range in concentration of reagents. The second stage was a preliminary screening of extractants using 9 soils, 15 extractants and 5 equilibration periods viz., 5 min, 10 min, 15 min, 30 min and 60 min. The optimum equilibration period for each extractant was finalised in this stage, by conducting an plant uptake study using Neubauer seedling technique and correlating the nutrient uptake with the amount of nutrients extracted by various extractants at different equilibration periods. The selected extractants from this preliminary screening with suitable equilibration periods were then used for the final stage which consisted of a large number of soils (87) and the ultimate selection of the extractant was made.

The availability of nutrients to plants in soils is decided upon by a number of factors which are influenced by soil physical and chemical characteristics. Therefore, estimation of general characteristics of the soil related to P and K availability was made prior to the evaluation of extractants.

Eighty seven soil samples were collected from all over the State and the general properties of the soil viz., texture, moisture, organic carbon, pH, EC, CEC, total P, P fixing capacity, Bray No.1 P (available P), total K and neutral normal NH_4OAc K (available K) were estimated. Considerable variations in soil properties relating to the available P and available K were obtained between the soils.

The general properties of the soils selected for the study are presented in the Table 4 and 5. The location of soils is given in Appendix I.

Table 4

General chemical properties of the soils

Soil sample No.	Moisture %	Organic carbon %	pH in water	EC (mmho/cm^3)	CEC (me/100 g soil)	Textural class
1	1.11	0.07	5.10	0.11	3.12	clay
2	0.81	0.98	5.40	0.39	1.56	loamy sand
3	2.04	0.23	4.70	0.09	4.68	loam
4	1.83	0.11	4.65	0.08	6.76	loam
5	2.25	0.35	4.50	0.15	3.64	loam
6	0.40	0.05	5.00	0.12	1.04	sandy loam
7	1.32	0.34	6.10	0.07	1.82	loamy sand
8	2.46	0.32	4.20	0.12	5.98	loam
9	3.73	2.34	6.00	0.33	10.66	sandy loam
10	1.84	0.38	4.50	0.10	2.86	sandy loam
11	3.52	0.29	4.10	0.28	3.64	clay loam
12	1.63	0.46	5.90	0.13	3.12	clay loam
13	3.09	0.86	5.25	0.24	7.02	clay loam

Table 4 Contd......

Soil sample No.	Moisture %	Organic carbon %	pH in water	EC (mmho/cm^3)	CEC (me/100 g soil)	Textural Class
14	3.95	0.51	5.80	0.07	9.10	clay
15	4.17	1.88	6.50	0.15	6.50	clay loam
16	1.42	0.12	5.60	0.13	0.78	loamy sand
17	1.21	0.20	6.90	0.07	0.78	loamy sand
18	1.01	0.12	8.80	0.17	1.04	loamy sand
19	5.37	2.17	5.30	0.14	5.06	clay loam
20	0.20	0.12	5.10	0.47	0.52	loamy sand
21	2.35	0.29	8.60	0.69	5.46	loam
22	4.38	0.51	4.80	0.07	5.98	clay loam
23	0.20	0.001	6.80	0.11	0.26	loamy sand
24	1.94	1.33	5.60	0.10	1.04	loamy sand
25	0.91	0.14	6.00	0.90	0.52	loamy sand
26	5.49	0.02	4.90	0.14	13.26	clay
27	9.17	0.40	6.80	0.12	15.34	clay

Table 4 Contd.......

Soil sample No.	Moisture %	Organic carbon %	pH in water	EC (mmho/cm^3)	CEC (me/100 g soil)	Textural class
28	10.62	0.98	7.40	0.53	21.06	clay
29	2.46	1.50	4.20	0.09	9.88	clay loam
30	2.88	0.41	6.40	0.10	6.24	loam
31	5.37	1.65	5.40	0.10	3.12	loam
32	2.56	0.40	7.20	0.13	2.60	loam
33	2.46	0.38	6.30	0.09	1.04	sandy loam
34	11.48	0.47	9.20	0.20	13.00	clay
35	3.84	0.83	8.80	0.34	3.12	loam
36	3.09	0.24	7.55	0.18	1.56	loam
37	4.95	0.85	4.20	0.18	0.52	loamy sand
38	13.64	0.18	4.70	0.07	1.30	clay loam
39	3.09	0.85	4.30	0.05	2.08	sandy loam
40	0.81	0.30	6.60	0.07	0.52	loamy sand
41	0.81	0.30	6.60	0.07	0.52	loamy sand

Table 4 Contd.....

Soil sample No.	Moisture %	Organic carbon %	pH in water	EC (mmho/cm^3)	CEC (me/100 g soil)	Textural class
42	4.82	0.53	6.00	0.07	2.08	clay loam
43	0.60	0.22	6.60	0.07	1.04	sandy loam
44	2.67	1.25	5.90	0.75	1.82	sandy loam
45	4.71	0.07	6.70	0.10	0.26	sand
46	0.40	0.19	6.00	0.09	0.26	sand
47	0.10	0.31	5.70	0.08	0.26	sand
48	5.49	0.61	5.40	0.10	1.82	clay loam
49	2.04	0.26	4.60	0.05	0.78	sandy loam
50	3.20	0.72	5.70	0.05	2.08	clay loam
51	2.04	0.69	5.20	0.06	1.04	loamy sand
52	2.03	0.40	5.10	0.12	1.04	loamy sand
53	1.21	0.94	5.40	0.03	0.52	loamy sand
54	7.30	0.15	6.10	0.29	3.12	clay loam
55	3.73	0.78	5.20	0.11	1.04	loam

Table 4 Contd.......

Soil sample No.	Moisture %	Organic carbon %	pH in water	EC (mmho/cm^3)	CEC (me/100 g soil)	Textural class
56	1.01	0.74	5.60	0.09	0.52	loamy sand
57	2.77	0.47	5.80	0.09	1.56	sandy loam
58	16.55	1.09	4.60	0.45	2.08	loam
59	1.32	0.59	5.25	0.09	0.52	loamy sand
60	3.20	0.48	5.50	0.08	1.30	sandy loam
61	4.17	1.57	5.70	0.11	1.56	sandy loam
62	5.49	0.96	5.10	0.06	1.04	sandy loam
63	5.49	0.57	4.70	0.14	1.56	loam
64	4.60	0.88	4.70	0.09	1.82	sandy loam
65	1.21	0.47	5.50	0.93	0.62	loamy sand
66	3.41	1.31	6.70	0.31	2.34	sandy loam
67	2.04	0.63	7.60	0.31	1.56	sandy loam
68	4.82	1.00	6.60	0.20	2.60	sandy loam
69	0.81	0.90	6.15	0.14	0.52	loamy sand

Table 4 Contd.......

Soil sample No.	Moisture %	Organic carbon %	pH in water	EC (mmho/cm^3)	CEC (me/100 g soil	Textural class
70	3.73	1.09	4.60	0.07	1.30	loamy sand
71	4.28	1.44	4.95	0.09	2.08	sandy loam
72	4.82	1.56	4.75	0.14	1.30	loamy sand
73	0.70	1.11	7.80	0.18	1.04	loamy sand
74	4.71	1.80	7.40	0.06	0.78	loamy sand
75	5.04	1.89	4.75	0.10	2.60	sandy loam
76	0.60	0.38	5.15	0.08	0.52	loamy sand
77	1.21	0.30	4.40	0.05	0.26	loamy sand
78	1.42	0.75	7.50	0.16	1.56	loamy sand
79	4.82	1.78	6.00	0.10	1.30	loamy sand
80	4.93	1.19	6.25	0.08	2.08	loam

Table 4 Contd.......

Soil sample No.	Moisture %	Organic carbon %	pH in water	EC (mmho/cm^3)	CEC (me/100 g soil)	Textural class
81	4.60	1.42	6.10	0.06	2.08	loam
82	0.81	0.24	7.90	0.09	1.04	sandy loam
83	2.67	0.38	5.30	0.04	0.52	loamy sand
84	2.25	0.44	4.35	0.05	0.78	loamy sand
85	2.46	0.78	8.85	0.14	2.60	sandy loam
86	2.04	0.24	5.60	0.05	1.04	sandy loam
87	1.42	0.22	5.70	0.04	0.78	sandy loam

Table 5

Properties relating to the behaviour of phosphorus and potassium in soils

Soil sample No.	Total P fixing capacity (mg/100g soil)	Total P, ppm	Available P, ppm	Total K, ppm	Available K, ppm
1	153.81	220.00	22.60	100.0	32.50
2	78.10	220.00	21.91	500.0	107.50
3	125.50	332.50	6.54	1500.0	14.00
4	103.60	440.00	19.15	2000.0	550.00
5	103.60	110.00	4.24	1500.0	15.00
6	51.20	55.00	16.10	500.0	20.50
7	119.50	220.00	85.27	1000.0	42.50
8	79.20	220.00	22.60	1250.0	10.50
9	71.60	795.00	38.91	3250.0	165.00
10	131.30	447.50	17.64	1000.0	20.00
11	59.60	276.25	66.78	1000.0	10.00
12	97.00	562.50	38.91	1000.0	45.00
13	106.90	110.00	17.33	1250.0	45.00
14	71.60	1095.00	18.90	2500.0	220.00
15	103.60	562.50	15.29	1500.0	82.50
16	86.50	332.50	30.79	1000.0	20.00
17	71.60	562.50	49.10	750.0	17.50
18	90.00	562.50	100.97	750.0	60.00

Table 5 Contd.......

Soil sample No.	Total P fixing capacity (mg/100g soil)	Total P, ppm	Available P, ppm	Total K, ppm	Available K, ppm
19	106.90	332.50	4.24	3000.0	90.00
20	71.60	55.00	30.36	250.0	15.00
21	71.60	447.50	13.77	2250.0	72.50
22	93.50	915.00	2.33	1500.0	15.00
23	97.00	110.00	13.21	250.0	5.00
24	86.50	1095.00	58.25	1500.0	320.00
25	55.50	890.00	54.96	500.0	45.00
26	86.50	1155.00	4.24	3500.0	125.00
27	79.20	220.00	5.60	4000.0	107.50
28	42.50	795.00	52.65	5500.0	1000.00
29	51.20	332.50	13.21	250.0	70.00
30	28.60	795.00	25.15	3000.0	142.50
31	33.40	115.00	2.92	1000.0	70.00
32	38.00	2798.75	198.31	7000.0	200.00
33	97.00	1527.50	32.56	4250.0	200.00
34	18.80	55.00	4.24	5000.0	187.50
35	5.12	2177.50	338.74	4000.0	1300.00
36	75.40	110.00	2.92	1000.0	65.00
37	93.50	276.25	13.49	1000.0	65.00
38	131.30	677.50	5.60	3500.0	17.50
39	51.20	110.00	8.47	1000.0	25.00

Table 5 Contd.......

Soil sample No.	Total P fixing capacity (mg/100g soil)	Total P, ppm	Available P, ppm	Total K, ppm	Available K, ppm
40	128.40	210.00	64.73	3250.0	110.00
41	93.50	110.00	48.42	500.0	35.00
42	86.50	55.00	24.41	225.0	13.50
43	103.60	55.00	11.57	250.0	12.50
44	90.00	1035.00	26.69	500.0	12.50
45	59.60	55.00	6.30	250.0	15.00
46	110.10	55.00	45.20	500.0	15.00
47	42.50	55.00	31.67	500.0	27.50
48	110.10	55.00	10.35	1000.0	17.50
49	113.30	55.00	15.29	1000.0	20.00
50	75.40	2831.25	51.19	2500.0	147.50
51	59.80	390.00	6.54	1000.0	30.00
52	79.20	390.00	14.93	1000.0	62.50
53	23.80	10.00	14.96	500.0	40.00
54	79.20	55.00	14.04	2000.0	82.50
55	103.60	276.25	13.77	2500.0	250.00
56	103.60	447.50	43.58	500.0	20.00
57	131.30	620.00	31.22	1500.0	55.00
58	59.60	562.50	11.57	3500.0	82.50
59	125.50	620.00	35.85	500.0	35.00

Table 5 Contd..........

Soil sample No.	Total P fixing capacity (mg/100g soil)	Total P, ppm	Available P, ppm	Total K, ppm	Available K, ppm
60	55.50	505.00	36.20	2750.0	210.00
61	100.40	276.25	13.21	750.0	175.00
62	97.00	620.00	17.64	1750.0	20.00
63	82.50	505.00	23.32	2500.0	145.00
64	110.10	447.50	5.37	3250.0	30.00
65	119.50	110.00	42.22	750.0	385.00
66	147.50	795.00	35.85	2250.0	185.00
67	55.50	447.50	58.25	750.0	165.00
68	38.00	915.00	36.85	2500.0	90.00
69	71.60	55.00	23.32	250.0	42.50
70	134.20	915.00	6.07	4000.0	110.00
71	106.90	447.50	5.83	3500.0	232.50
72	119.50	505.00	4.46	2000.0	130.00
73	90.00	332.50	70.11	500.0	50.00
74	28.60	110.00	21.56	500.0	25.00
75	128.40	677.50	15.81	2250.0	120.00
76	97.00	55.00	13.21	250.0	20.00
77	38.00	110.00	19.88	500.0	10.00
78	79.20	332.50	80.56	250.0	60.00
79	116.40	220.00	6.07	2750.0	52.50
80	67.70	915.00	36.85	1500.0	45.00

Table 5 Contd...........

Soil sample No.	Total P fixing capacity (mg/100g soil)	Total P, ppm	Available P, ppm	Total K, ppm	Available K, ppm
81	93.50	447.50	7.25	2500.0	170.00
82	59.60	110.00	28.69	250.0	20.00
83	23.80	55.00	6.07	500.0	10.00
84	38.00	110.00	2.92	750.0	25.00
85	46.90	330.00	38.91	1250.0	340.00
86	137.00	550.00	5.60	500.0	25.00
87	38.00	110.00	6.07	500.0	15.00

The soils varied in their texture from sand to clay. But majority of the soils were sandy loam or loamy sand in texture.

The pH of the soils selected for the study showed that they are mainly acidic to neutral in character though there were a few alkaline soils. Therefore, the extractant that would be selected must be suited to mostly acidic to neutral soils. The EC of the soils was in the range of 0.03 to 0.93 mmho/cm^3 indicating that all the soils were non-saline.

Soil No.9 registered the highest organic carbon content (2.34%) and soil No.23 registered the lowest value (0.001%) which showed that the organic carbon content of the soils under study was extremely varying. The CEC of the soils was varying, the range being 0.26 to 21.06 me/100 g of soil. The phosphorus fixing capacity ranged from 5.12 (soil No.35) to 147.5 mg P per 100 g of soil (Soil No.66).

Maximum variation was obtained in the case of total P and total K content of the soil. Total P content of the soil No.50 was the highest (2831.25 ppm) and the lowest value was observed in soil Nos.6, 20, 42, 43, 45, 46, 47, 48, 49, 54, 69, 76 and 83 (55 ppm). Total K content varied from 100 ppm (soil No.1) to 7000 ppm (soil No.32). Similarly soils varied very much in their status of available P estimated by Bray No.1 and available K estimated by neutral normal NH_4OAc. Variations from 2.33 ppm (Soil No.22) to 338.74 ppm (soil No.35) in available P were recorded by the soils.

According to Mathew (1979) the sorption of P into the soil from the solution can be effectively prevented by employing organic acids and the amount of P extracted by the mineral acids can be increased by the presence of organic acid notably oxalic acid.

Chelating agents such as DTPA, EDTA, NTA etc. have been found to be effective as reported by many scientists. Wolf (1982) observed a far better relationship between the nutrients extracted by Morgan's solution + 0.0001 M DTPA and leaf cations than did the Morgan's solution with either NaEDTA or NTA.

Since EDTA dissolves water insoluble carbonates that are not part of the exchange complex, and it is hardly suitable for calcareous soils, DTPA is found more effective than EDTA (Viro, 1955a).

The chemical extractants employed in this study were mainly NH_4F and DTPA combinations. These extractants were employed based on the following assumptions.

(i) NH_4F will specifically release Al and Fe phosphates which are the more predominant sources of P in acid soils of Kerala. DTPA when added to NH_4F, can prevent the resorption of P into the soil.

(ii) the NH_4^+ ion is the most suitable for releasing exchangeable K, since NH_4^+ holds highly charged layers together just as K^+, the release of non-exchangeable K to exchangeable form can be retarded.

The extractant suggested by Mathew (1979) was included in the present study. The theoretical basis for the selection of extractant by Mathew (1979) was as follows.

Very often, poor correlation between Bray No.1 P and uptake of P by plants has been observed. This can be attributed to (i) low acid strength of the extractant which does not extract major portion from plant available P (ii) the formation of CaF and immobilisation of P as reported by Smillie and Syers (1972).

According to Mathew (1979) increasing concentration of HCl could not extract higher concentration of P from the soil when employed individually. But increasing concentration of HCl in the presence of H_2SO_4 increased the amount of P extracted from the soil and when the pattern of release was examined as a function of period of equilibration, the degree of fluctuation was considerably smaller as compared to the pattern of release observed when the acids were employed independently. This was mainly because of the total amount of P brought into solution by the combination of mineral acids was much larger than that extracted by the individual acids. As a result, the degree of fluctuation due to the desorption of P into the soil became smaller, when expressed in relation to the total P extracted. It was felt necessary that unless the resorption of extracted P is effectively checked, the reproducibility of the result obtained would be very much affected. If resorption of the extracted P takes place then the amount of P finally remaining in the solution, may become a function of the period of shaking, time taken for centrifuging or filtering and also time taken for the associated dispensing procedure 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 P 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 extracting solution so that soil P once brought into the solution will not be resorbed by the soil. Acetate, citrate, and oxalate are well known chelating organic anions which can be employed to prevent the resorption of P from the solution.. The amount of P 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.

The drastic effect of oxalic acid in releasing P into the solution can be assigned to (i) the chelating effect of oxalate anion on the P release into the soil thereby avoiding the possible resorption of P on the soil surface (ii) oxalic acid itself is an extractant for soil P which when in combination with a mineral acid extracts considerably higher amount of P from the soil as compared to the mineral acids alone. The extractant 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid which is suggested by Mathew (1979) appeared to be very promising for the determination of available P in soils. However, the effect of this extractant on K release has not yet been found out. It is possible that this extractant can estimate available K in soil becasuse, ample hydrogen ions provided by this solution can effectively exchange with K^+ ions occupying on the exchange complex of the soil.

It is observed that the amount of P and K extracted by Bray No.1 and NH_4OAc respectively in soils containing relatively small amount of P and K is so small that the error involved in the analytical procedure is relatively high. The Bray's sodium perchlorate perchloric acid extracting solution used in some studies differentiated the low from the high phosphate soils. However, the reliability of prediction of response at the low levels of P was far from satisfactory. The correlation of soil test for available K and crop response to K fertilization also was unsatisfactory over a wide range of K levels in the soil (Long and Seatz, 1953).

The correct evaluation of the K status of soils and the correct adjustment of K fertilization appear to be rather complicated. Because of the correlation between K concentration and K saturation, it will be quite acceptable in routine advisory works to use exchangeable K content and clay content when assessing the K status (Grimme, 1980). With these two parameters it is possible to make an estimate of the degree of availability and the required K application.

Bray No.1 was also indluded in the study since it has been found to be promising for estimating P and K simultaneously as shown by Ram and Prasad (1983). The main reaction mechanism of Bray No.1 is the formation of stable coordination complexes of the F^- ion with Fe^{3+} and Al^{3+} and the formation of insoluble CaF_2 and Ca^{2+}. The F^- ion being very effective in complexing Al^{3+} ions will release P from Al-P and with the precipitation of Ca^{2+} as CaF_2 extracts P present as Ca HPO_4. The HCl provides sufficient hydrogen ion activity to dissolve Ca-P and to a lesser Al-P and Fe-P. Both hydrogen ions and ammonium ions are suitable for releasing the exchangeable potassium from the exchange complex of the soil.

Hanlon and Johnson (1984) suggested that ammonium bicarbonate - DTPA procedure introduced by Soltanpour and Schwab in 1977, could be used for acid soils also although originally it was developed for alkaline soils. But this extractant was unstable with respect to pH.

Olsen's extractant (Olsen *et al.*, 1954) might be used for estimating available P and available K as reported by Subramanyam (1968). This extractant was buffered to pH 8.5. The primary purpose of including HCO_3^- in the extracting solution is to extract phosphorus. As CO_2 gas evolves during extraction with $NaHCO_3$, $CaCO_3$ precipitates which lowers Ca^{2+} activity and allows the labile phases of calcium phosphates to dissolve resulting in an increase in solution P. The extraction of P by Olsen's method can be considered to be a two way process. i.e., one involving competitive desorption of P from the soil particles by OH^- and HCO_3^- and the other involving inhibition of secondary resorption of P by OH^- and HCO_3^- on soil particles. The sodium ions of the $NaHCO_3$ serves to release K into the solution. Based on these assumptions Olsen's extractant was employed in this evaluation study.

Carbon black used in the AB-DTPA test should be eliminated not only because of its staining and sometimes contaminative properties but mainly because it adsorbs metal chelates and will introduce rather large errors if its particle size is not kept constant (Soltanpour, 1985). This fact holds good for Olsen's extractant also. Therefore, it was decided not to use carbon black with any extractant except for Olsen. With Olsen, carbon black was used since it was the standard procedure proposed by Olsen *et al.* (1954)

While considering the relative efficiency of various extractants for determining available K, neutral normal NH_4 OAc was found to be superior to others in releasing the exchangeable K. To see whether NH_4OAc can release P, this was also included in the investigation.

The fact that an extracting solution fails to remove all the available P or available K, is however, relatively unimportant. The values obtained by any chemical method, should be considered as indices of the relative soil supplying power rather than absolute amounts. The different extractants involved in the present study was so determined that they should invariably extract a fraction of soil P as well as soil K which will be always higher than that extracted by Bray No.1 and NH_4OAc.

The results of the initial study, preliminary screening and the final selection are discussed below.

1. Initial study

The initial study was conducted mainly to fix an approximate range in concentration of reagents. NH_4F was tried at 0.1 *M*, 0.5 *M* and 1 *M* concentrations in combination with 0.001 *M*, 0.005 *M* and 0.05 *M* concentrations of DTPA. The extractant proposed by Mathew, Bray No.1, Bray No.1 + ammonium acetate at different concentrations, Bray No.1 + DTPA at varying concentrations and varying concentrations of NH_4F and acetic acid were also included in the initial study. While studying the pattern of P release, Jose (1972) observed that during the initial period of equilibration the release of P into solution would be at a rapid rate, the rate of release being logarithmic in nature. After this initial release of P at a faster rate, the rate of release 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 P released during the initial period of equilibration which represented the curved region of the graphs, when P values were plotted on Y axis and period of equilibration on X axis, need be considered in estimating the P availability of the soil. Since the release of P after this initial period will be at a constant rate with a linear function and will continue for a longer period of time, this part of the graph does not decisively affect the estimate of available P in soil. For most of the soils, the major part of the P that can be extracted by a solution will be released within the initial period of equilibration. According to Mathew (1979) for the mineral and organic acid combination a period of equilibration not less than 30 min at a soil solution ratio of 1:10 was considered critical and optimum for P. For K not much work has been done on fixing optimum equilibration period. Equilibration periods more than 60 min may not be suited for analytical procedures oriented to advisory works. In the initial study equilibration periods of 30 min and 60 min were employed in order to confirm that whether 60 min must be included in the preliminary screening. A soil solution ratio of 1:10 was employed.

The results of the initial study is presented in Table 6.

Ammonium fluoride was employed at 0.1 *M*, 0.5 *M* and 1 *M* concentrations in combination with 0.001 *M*, 0.005 *M* and 0.05 *M* DTPA. It was found that increasing concentrations of NH_4F decreased the P release. Maximum P and K release was obtained at 0.1 *M* at both equilibration periods. With 0.1 *M* concentration of NH_4F and 0.001 *M* DTPA largest amount of K was extracted and it was maximum at 60 min. In the case of P also the same trend was noticed but the amount of P extracted was maximum at 60 min only when the higher concentration of DTPA was employed. With 0.5 *M* NH_4F more K was extracted by 0.001 *M* DTPA but P concentration in the soil solution was improved when the concentration of DTPA was increased from 0.001 *M* to 0.005 *M*. The result suggests that DTPA is a strong chelating agent. The amount of K extracted was more at 60 min than at 30 min, but in the case of P the reverse happened.

The action of DTPA is as follows. Chelates such as DTPA when added to the soil solution, form stable soluble complexes with the various metal cations. The binding strength of a chelate for a metal cation depends upon the stability constant of the metal chelate complex. The higher the stability constant, the stronger is the metal chelate complex. As free metal cations are removed from solution through this complexation, labile

Table 6

Phosphorus and potassium extracted (ppm) by the various extractants used at different periods (min) of equilibration in the initial study

Sl.No.	Name of extractant	P, ppm		K, ppm	
		Period		Period	
		30	60	30	60
1.	0.1 $\underline{M}$ NH_4F + 0.001 $\underline{M}$ DTPA	1.51	1.27	280.0	290.0
2	0.1 $\underline{M}$ NH_4F + 0.005 $\underline{M}$ DTPA	1.51	2.56	210.0	290.0
3	0.5 $\underline{M}$ NH_4F + 0.001 $\underline{M}$ DTPA	0.56	0.44	240.0	260.0
4	0.5 $\underline{M}$ NH_4F + 0.005 $\underline{M}$ DTPA	0.79	0.44	160.0	230.0
5	1.0 $\underline{M}$ NH_4F + 0.001 $\underline{M}$ DTPA	0.11	0.22	170.0	160.0
6	1.0 $\underline{M}$ NH_4F + 0.005 $\underline{M}$ DTPA	0.17	0.33	100.0	60.0
7	0.06 $\underline{N}$ H_2SO_4 + 0.06 $\underline{N}$ HCl + 0.05 $\underline{M}$ oxalic acid	4.19	2.29	230.0	310.0

Table 6 Contd....

Sl.No.	Name of extractant	P, ppm		K, ppm	
		Period		Period	
		30	60	30	60
8	0.03 M NH_4F + 0.025 M HCl (Bray No.1)	3.27	2.02	270.0	240.0
9	0.03 M NH_4F + 0.05 M NH_4OAc + 0.025M HCl	0.44	0.11	230.0	260.0
10	0.05 M NH_4F + 0.05 M NH_4OAc + 0.025 M HCl	0.11	0.44	220.0	230.0
11	0.05 M NH_4F + 0.05 M acetic acid	1.45	3.12	250.0	260.0
12	0.03 M NH_4F + 0.05 M acetic acid	1.27	0.67	220.0	230.0
13	0.03 M NH_4F + 0.025 M HCl + 0.001 M DTPA	0.67	0.98	150.0	180.0
14	0.03 M NH_4F + 0.025 M HCl + 0.005 M DTPA	0.67	0.67	170.0	180.0
15	Bray No.1 (std) P 1.30 ppm				
16	Neutral Normal NH_4OAc (std) K 230.0 ppm				

solid phase dissolves or surface cations desorb to replenish the solution.

It is seen that 0.001 M DTPA is enough to complex the various cations and therefore to release P into the solution at 0.1 M concentration of NH_4F. It is also observed that DTPA had no effect in complexing K. To prevent the resorption of P, 0.005 M DTPA is required in combination with 0.1 M NH_4F. A higher amount of P was extracted when the equilibration period was increased to 60 min while the concentration of DTPA was increased to 0.005 M. Similarly with higher concentration of NH_4F, a high concentration of DTPA was required. Since NH_4F releases large quantity of P, in order to prevent the resorption greater quantity of DTPA would be required.

With 0.1 M concentration of NH_4F and 0.001 M DTPA, the amount of P extracted at 30 min was 1.51 ppm while at 1 M concentration of NH_4F the amount of P extracted was only 0.11 ppm. This shows that increasing strength of NH_4F employed has no effect on the amount of P extracted from the soil. Similar results were obtained in the case of K also. The primary purpose of including NH_4F in the extracting solution was to extract Al-P since it is established by several workers that this is a selective extractant for Al-P. Fluoride ion complexes with Al and Fe (to a lesser extent) which are the foremost agents in the fixation of phosphate in acid soils where Al and Fe are highly mobilised at low pH. NH_4^+ ion can exchange with the K of the soil colloids.

It was obvious from the initial study that NH_4F at higher concentrations will retard the extraction of phosphorus as well as potassium and they extracted much smaller quantities of P and K as compared to that of Bray No.1 and NH_4OAc. DTPA is soluble in water only upto a concentration of 0.005 M. Hence it is visualised that DTPA should be tried only upto a concentration of 0.005 M.

When Bray No.1 was used as the extractant for P it was observed that increasing the equilibration period had considerable effects in the extraction of P. But due to the absence of a chelating agent the efficiency of extraction was decreased when the period of equilibration was increased from 30 to 60 min. The amount of K extracted by Bray No.1 was higher than that of neutral normal NH_4OAc (std). This result indicates that both NH_4F and HCl are good agents of K extraction. Both NH_4^+ and H^+ have the power of replacing exchangeable K. But the amount of K extracted was less than that of 0.1 M NH_4F + 0.001 M DTPA combination. It may be due to the lower concentration of NH_4^+ in Bray No.1.

Use of neutral normal ammonium acetate along with Bray No.1 inhibited the release of P drastically, eventhough it has not retarded the amount of K release. Bray No.1 P (Std) value was 1.30 ppm while the combination of Bray No.1 and ammonium acetate registered a value of 0.44 ppm. Increasing the concentration of NH_4F from 0.03 M to 0.05 M had not much effect on the P extraction pattern.

Mathew's extractant viz., 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid released large amounts of P and K. It is a good extractant for K either because of its ability to solubilise K containing minerals or due to the replacing power of hydrogen ions. This extractant extracted large amounts of P due to the fact that it is a combination of mineral acids and organic acid. Combination of mineral acids extracted larger quantities of P from soil than the individual acids and the resorption of P from solution is effectively prevented by employing organic acids and the amount of P extracted by the mineral acid could be increased by the presence of organic acid as reported by Mathew (1979). Maximum quantity of P was released when the equilibration period was 30 min, but the amount of P extracted even at 60 min (2.29 ppm) was greater than the amount extracted by Bray No.1 at 1:10 soil solution ratio and 5 min equilibration period (1.30 ppm). The amount of K extracted was considerably increased when the period of equilibration was increased from 30 to 60 min. While considering the relative efficiency of extraction, Bray No.1 + DTPA was not a good combination. With Bray No.1 the two concentrations of DTPA, viz., 0.001 M and 0.005 M were on par in their efficiency of releasing P as well as K.

The NH_4F + acetic acid was a good extractant for P and K. The combination, 0.05 M NH_4F + 0.05 M acetic acid extracted more P and K than 0.03 M NH_4F + 0.05 M acetic acid. More quantity of P was extracted by 0.05 M NH_4F + 0.05 M acetic acid even at 60 min (3.12 ppm) than Bray No.1 (std) (1.30 ppm). This result shows the chelating action of acetic acid. The amounts of K extracted at 30 and 60 min were 250.0 ppm and 260.0 ppm respectively, while it was 230.0 ppm for NH_4OAc (std).

In most of the extractants employed in the initial study, the amounts of both P and K extracted at 30 min and 60 min were not on par. The K extraction efficiency was higher at 60 min that at 30 min for the extractants, viz., 0.1 M NH_4F in combination with 0.001 M and 0.005 M DTPA, 0.5 M NH_4F in combination with 0.001 M and 0.005 M DTPA, Mathew's triacid, the two combinations of Bray No.1 + NH_4OAc, the two combinations of NH_4F and acetic acid, and the two combinations of Bray No.1 and DTPA. But P extraction by higher concentrations of NH_4F viz., 0.5 M and 1.0 M showed varying patterns. In the case of 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid, the amount of P extracted was decreased when the period of equilibration was increased. But the amount of K extracted was much more at 60 min (310.0 ppm) that at 30 min (230.0 ppm). Bray No.1 extracted more P and K when the period of equilibration was 30 min than at 60 min.

It was seen that the amount of K extracted by neutral normal ammonium acetate in the initial study was higher when the soil solution ratio was 1: 10 as compared to 1:5. Two hundred and thirty ppm K was extracted by 1:5 soil solution ratio while 280.0 ppm was extracted by 1:10 soil solution ratio at both equilibration periods. The following are the highlights of the initial study:

1. In NH_4F and DTPA combinations, increasing concentration of NH_4F decreased the P and K release. DTPA at 0.001 *M* strength released maximum amount of phosphorus and potassium with NH_4F.
2. DTPA is not soluble in water at concentrations higher than 0.005 *M*.
3. A larger amount of P was extracted when the equilibration period was increased to 60 min and when the concentration of DTPA was increased to 0.005 *M*.
4. Increasing equilibration period had considerable effects on the extraction of P by Bray No.1. The efficiency of extraction was decreased when the period of equilibration was increased from 30 to 60 min, possibly due to the absence of a chelating agent in order to prevent resorption of phosphorus on to the soil.
5. The amount of K extracted by Bray No.1 was higher than that of neutral normal ammonium acetate (std).
6. Use of neutral normal ammonium acetate along with Bray No.1 inhibited the release of P drastically, though this effect was not noticed on K extraction.
7. Mathew's triacid extractant released large amounts of P and K.
8. In combination with Bray No.1, DTPA at the strength of

0.001 M was as good as 0.005 M in its effects on P and K extraction.

9. The NH_4F + acetic acid was found to be a good combination in estimating available P and available K. More quantity of P was extracted by 0.05 M NH_4F + 0.05 M acetic acid even at 60 min than Bray No.1 showing the chelating action of acetic acid.

10. The amount of K extracted by neutral normal ammonium acetate was higher when the soil solution ratio was 1:10 as compared to 1:5.

2. Preliminary screening of extractants

For the preliminary screening, only 9 soils were chosen. The main criteria for selecting these soils were the nutrient status (available P and available K) and texture of the soil. Based on the observations from the initial study, NH_4F at concentrations 0.1, 0.3 and 0.5 M were employed along with 0.001 M, 0.003 M and 0.005 M DTPA. Mathew's extractant (0.06 N HCl + 0.06 N H_2SO_4 + 0.05 M oxalic acid), Bray No.1 Bray No.1 + 0.005 M DTPA, 0.05 M NH_4F + 0.005 M acetic acid, neutral normal NH_4OAc and Olsen's extractant (0.5 M $NaHCO_3$, pH 8.5) were also included in the preliminary screening. Five equilibration periods were selected viz., 5, 10, 15, 30 and 60 min and only a single soil solution ratio of 1:10 was employed.

The relationship between P and K extracted by these extractants and the uptake of these nutrients by rice crop in the soils were studied. Mean percentage and uptake of P and K of rice grown in the soils are presented in Appendix II. The coefficients of correlation (r) between the nutrients extracted by the extractants at different equilibration periods and nutrient uptake by rice are given in Table 37 and Table 38.

2.1 Combinations of NH_4F and DTPA

NH_4F at 0.1 M, 0.3 M and 0.5 M were combined with 0.001 M, 0.003 M and 0.005 M concentrations of DTPA. The amounts of P and K extracted by the different combinations of NH_4F and DTPA are presented in Table 7 to Table 24. As regards the efficiency of these combinations in extracting soil P, it was seen that 0.3 M NH_4F + 0.003 M DTPA at 60 min extracted the highest quantity of P when the effects of soils were pooled. An amount of 115.74 ppm P was extracted by this extractant within a period of 60 min when the effects of soils were pooled. Maximum quantity of P was extracted from soil No.35 (502.92 ppm) which recorded a value of 338.74 ppm for Bray No.1 and when considering the K extraction it would be seen that 0.5 M + 0.001 M combination extracted maximum quantity of K when the effects of soils were pooled, the available K extracted within a period of 5 min being 261.7 ppm. Soil No.35 registered the maximum value which was 1645 ppm. When individual soils were considered separately 0.5 M + 0.005 M combination registered the maximum P value (527.52 ppm) while 0.5 M + 0.001 M combination extracted maximum amount of K from soil No.35.

The pattern of P and K release into the solution when examined together as a function of period of equilibration

Table 7

P extracted by 0.1 M NH_4F + 0.001 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	11.76	11.76	11.76	11.76	4.55
2	48	10.52	9.31	11.76	11.14	9.31
3	22	1.69	2.26	2.26	5.71	4.54
4	54	26.48	25.05	26.48	23.64	19.52
5	15	5.95	105.60	79.76	107.15	89.69
6	4	27.91	14.29	43.62	29.38	9.31
7	60	38.64	33.91	48.84	40.29	37.05
8	35	195.81	204.48	169.81	188.67	195.81
9	32	127.88	110.31	95.31	84.69	68.41
Mean		49.63	57.33	67.15	55.83	48.69

Table 8

K extracted by 0.1 M NH_4F + 0.001 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	15	15	15	15	15
2	48	5	10	15	15	15
3	22	5	10	15	15	15
4	54	55	55	55	60	45
5	15	25	45	45	45	45
6	4	45	50	50	55	45
7	60	165	175	175	185	155
8	35	1070	1070	1070	1045	1045
9	32	155	185	185	185	175
Mean		171.1	189.4	180.6	180.0	172.8

Table 9

P extracted by 0.1 M NH_4F + 0.003 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	8.00	5.65	9.19	9.19	14.12
2	48	14.12	13.49	16.67	16.67	19.30
3	22	1.67	2.23	1.12	1.12	2.79
4	54	36.65	36.65	33.56	38.26	38.26
5	15	53.81	27.60	55.70	29.07	30.54
6	4	16.67	15.40	14.12	14.12	23.37
7	60	39.86	36.65	38.26	39.86	38.26
8	35	224.14	193.90	246.51	234.61	234.61
9	32	190.16	183.19	186.70	170.56	156.72
Mean		65.00	57.20	66.86	61.50	62.00

Table 10

K extracted by 0.1 M NH_4F + 0.003 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	10	15	35	20	15
2	48	15	15	15	10	10
3	22	5	10	10	10	10
4	54	50	45	50	45	45
5	15	45	50	50	50	50
6	4	55	50	50	60	80
7	60	155	160	160	160	160
8	35	980	955	980	980	1005
9	32	155	160	180	180	180
Mean		163.3	163.3	170.0	169.4	172.8

Table 11

P extracted by 0.1 *M* NH_4F + 0.005 *M* DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	15.79	14.39	13.00	11.63	14.39
2	48	13.00	21.58	21.58	26.13	26.13
3	22	3.76	3.76	3.76	5.03	5.03
4	54	52.00	62.13	37.47	34.97	34.97
5	15	64.26	64.26	52.00	44.53	40.95
6	4	34.13	37.47	29.26	18.66	26.13
7	60	57.97	40.95	57.97	66.45	60.03
8	35	280.40	280.40	249.42	313.16	293.11
9	32	137.19	187.69	280.40	295.63	359.48
Mean		73.17	79.18	82.76	90.69	106.58

Table 12

K extracted by 0.1 M NH_4F + 0.005 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	15	20	15	15	15
2	48	15	15	15	20	15
3	22	10	15	15	15	15
4	54	55	60	60	60	60
5	15	65	55	55	55	45
6	4	55	55	55	25	30
7	60	185	190	180	170	140
8	35	1045	1045	1070	1070	1045
9	32	190	200	170	180	185
Mean		181.7	183.7	181.7	178.9	172.2

Table 13

P extracted by 0.3 *M* NH_4F + 0.001 *M* DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	6.26	9.03	9.03	10.59	12.17
2	48	7.47	18.74	25.65	18.74	31.09
3	22	9.03	2.21	2.94	5.94	4.44
4	54	34.82	32.94	42.71	38.71	32.94
5	15	57.74	48.91	60.03	72.21	64.77
6	4	14.65	18.74	15.41	27.41	23.88
7	60	40.68	53.27	48.91	64.77	64.77
8	35	344.12	429.41	366.18	394.71	483.24
9	32	171.41	217.77	277.80	234.83	323.24
Mean		84.69	92.34	94.30	96.43	115.62

Table 14

K extracted by 0.3 M NH_4F + 0.001 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	15	15	10	10	10
2	48	10	10	10	10	10
3	22	5	5	10	5	0
4	54	70	70	45	70	50
5	15	30	30	35	25	10
6	4	45	50	50	35	30
7	60	135	135	125	115	100
8	35	1095	1220	1245	1145	1120
9	32	205	205	215	200	225
Mean		178.9	193.3	193.9	179.4	172.8

Table 15

P extracted by 0.3 M NH_4F + 0.003 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	3.85	7.70	5.10	5.10	5.10
2	48	7.70	21.20	25.20	27.10	15.70
3	22	2.55	3.85	5.10	5.10	5.10
4	54	28.30	29.70	29.70	25.20	38.60
5	15	71.05	57.50	57.50	57.50	64.15
6	4	15.70	13.00	18.45	5.10	18.45
7	60	41.60	41.60	41.60	47.85	85.55
8	35	365.20	316.75	277.15	490.15	502.92
9	32	177.35	189.10	177.35	189.10	306.15
Mean		72.26	75.60	70.79	95.80	115.74

Table 16

K extracted by 0.3 M NH_4F + 0.003 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	10	0	0	0	0
2	48	10	0	0	0	0
3	22	5	0	0	0	0
4	54	70	60	50	25	25
5	15	10	5	0	0	5
6	4	40	25	5	5	15
7	60	145	95	65	40	35
8	35	1085	1010	1035	1035	1010
9	32	195	185	195	175	175
Mean		174.4	153.3	150.0	142.2	140.6

Table 17

P extracted by 0.3 M NH_4F + 0.005 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	12.31	9.19	9.19	6.06	18.69
2	48	21.94	21.94	15.50	35.38	15.50
3	22	3.00	12.31	3.00	6.06	3.00
4	54	88.31	49.44	42.31	42.31	60.56
5	15	92.50	53.13	76.06	84.19	88.31
6	4	15.50	21.94	6.06	18.69	21.94
7	60	56.81	92.50	53.13	64.31	64.31
8	35	452.38	505.06	436.81	468.81	436.81
9	32	289.25	358.75	382.38	370.31	248.69
Mean		114.67	124.92	113.83	121.79	106.42

Table 18

K extracted by 0.3 M NH_4F + 0.005 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	0	0	0	0	0
2	48	0	0	0	0	0
3	22	0	0	0	0	0
4	54	25	20	20	10	20
5	15	5	10	5	5	5
6	4	25	15	5	5	5
7	60	105	85	30	35	30
8	35	1060	1035	1035	1085	1035
9	32	195	190	190	110	90
Mean		157.2	150.6	142.8	138.9	131.7

Table 19

P extracted by 0.5 M NH_4F + 0.001 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	3.81	3.81	3.81	3.81	9.49
2	48	10.94	10.94	12.42	12.78	16.96
3	22	6.62	9.49	10.94	8.04	12.42
4	54	67.76	67.76	67.76	72.50	80.06
5	15	70.06	46.45	74.95	72.50	72.50
6	4	37.02	74.95	44.55	54.52	65.46
7	60	63.18	70.06	74.95	54.52	80.06
8	35	301.06	386.57	386.57	386.57	386.57
9	32	176.26	201.00	165.57	194.32	160.37
Mean		81.86	96.78	93.50	95.51	98.21

Table 20

K extracted by 0.5 *M* NH_4F + 0.001 *M* DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	10	10	10	10	10
2	48	25	15	10	10	0
3	22	15	10	10	0	0
4	54	75	95	90	60	55
5	15	10	25	10	20	0
6	4	50	40	30	40	20
7	60	170	145	80	70	95
8	35	1045	1645	1620	1570	1520
9	32	355	300	265	260	250
Mean		261.7	253.9	236.1	226.7	215.6

Table 21

P extracted by 0.5 M NH_4F + 0.003 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	10.42	10.42	11.99	11.99	11.99
2	48	16.77	20.05	15.14	16.77	21.74
3	22	21.74	23.42	20.05	30.44	20.05
4	54	67.54	72.38	66.37	67.54	74.86
5	15	77.41	82.62	82.62	82.62	82.62
6	4	32.25	41.69	45.68	28.63	58.34
7	60	74.86	68.17	82.62	58.34	67.54
8	35	310.93	310.93	310.93	326.61	326.61
9	32	191.94	191.94	191.94	191.94	204.75
Mean		89.32	91.29	91.93	90.54	96.50

Table 22

K extracted by 0.5 M NH_4F + 0.003 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	0	0	0	0	0
2	48	0	0	0	0	0
3	22	0	0	0	0	0
4	54	10	10	20	20	50
5	15	0	0	0	0	0
6	4	0	5	10	20	20
7	60	55	60	50	90	50
8	35	1645	1445	1445	1545	1545
9	32	195	170	145	115	225
Mean		211.7	187.8	185.6	198.9	210.0

Table 23

P extracted by 0.5 $\underline{M}$ NH_4F + 0.005 $\underline{M}$ DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	8.86	7.04	8.86	1.71	3.46
2	48	18.25	28.25	32.46	20.21	10.68
3	22	26.21	22.18	22.18	20.21	1.71
4	54	52.86	52.86	48.11	45.75	52.86
5	15	60.32	52.86	50.46	50.46	57.79
6	4	16.32	16.32	7.04	14.43	18.25
7	60	43.46	18.25	20.21	22.18	43.46
8	35	448.29	375.39	326.00	288.60	527.52
9	32	192.57	198.68	218.50	186.71	218.50
Mean		96.35	85.76	81.54	72.25	103.80

Table 24

K extracted by 0.5 M NH_4F + 0.005 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	0	0	0	0	0
2	48	0	0	0	0	0
3	22	25	0	0	0	0
4	54	55	20	20	20	10
5	15	0	0	0	0	0
6	4	20	10	10	0	10
7	60	85	60	50	50	35
8	35	1120	1120	1120	1145	1145
9	32	210	170	130	130	130
Mean		168.3	153.3	147.8	149.4	147.8

revealed that the rate of release was varying at different equilibration periods for different extractants. The optimum equilibration period will be the one by which the release of P and K into the extractant solution will be almost complete and after which further release of these nutrients will take place at a constant rate with a linear function. When the period of equilibration was plotted against P and K concentration, it was seen that 0.1 M NH_4F + 0.005 M DTPA, 0.3 M NH_4F + 0.003 M DTPA, 0.3 M NH_4F + 0.005 M DTPA, 0.5 M NH_4F + 0.001 M DTPA and 0.5 M NH_4F + 0.003 M DTPA could not release both P and K in similar patterns. For the combination of 0.1 M + 0.001 M an equilibration period of 5 min was found to be suitable for bringing a reasonable quantity of both P and K into the soil solution. The mean values of P extracted by 0.1 M NH_4F + 0.001 M DTPA combination at 5, 10, 15, 30 and 60 min were 49.63, 57.33, 67.15, 55.83 and 48.69 ppm. For K, the values were 171.1, 189.4, 180.6, 180.0 and 172.8 ppm respectively. The mean values of P extracted by 0.1 M NH_4F + 0.003 M DTPA was in the order of 65.00, 57.20, 66.86, 61.50, 62.00 ppm and extraction of K followed the order of 163.3, 163.3, 170.0, 169.4 and 172.8 ppm for 5, 10, 15, 30 and 60 min respectively. In the case of 0.3 M NH_4F + 0.001 M DTPA combination, the phosphorus and potassium values were 84.7, 92.3, 94.3, 96.4 and 115.6 ppm and 178.9, 193.3, 193.9, 179.4 and 172.8 ppm respectively.

The combination 0.5 M NH_4F + 0.005 M DTPA extracted phosphorus in the order 96.35, 85.76, 81.94, 72.25 and 103.80 ppm and potassium was extracted in the order 168.3, 153.3, 147.8, 149.4 and 147.8 ppm. It was revealed that NH_4F + DTPA combinations of 0.1 $\underline{M}$ + 0.001 $\underline{M}$, 0.1 $\underline{M}$ + 0.003 $\underline{M}$ and 0.5 $\underline{M}$ + 0.005 $\underline{M}$ require only 5 min for releasing P and K in reasonable amounts. But, for the combination of 0.3 $\underline{M}$ + 0.001 $\underline{M}$ a period of 10 min would be required for attaining an equilibration value. The extraction of P and K by 0.1 $\underline{M}$ + 0.001 $\underline{M}$ combination slightly increased from 5 min to 15 min and thereafter both decreased. The combination of 0.1 $\underline{M}$ + 0.003 $\underline{M}$ showed a small increase in K value and varying patterns of P value after 5 min. For 0.5 $\underline{M}$ + 0.005 $\underline{M}$ combination, both P and K extractions were highly retarded, within a period of 5 to 15 min in the case of K and upto 30 min in the case of P, then increased the K value slightly and rapidly in the case of P.

The coefficients of correlation worked out between P extracted by different combinations of NH_4F and DTPA and P uptake by rice were significant for all the extractants at all the equilibration periods. Highest correlation was obtained with 0.1 $\underline{M}$ + 0.001 $\underline{M}$ combination of NH_4F and DTPA at an equilibration period of 10 min (0.9572^{**}, Table 37).

In the case of K also all the values at all the periods of equilibration were significantly correlated with plant uptake of K. The highest correlation was obtained for 0.1 N NH_4F + 0.005 N DTPA at an equilibration period of 10 min (r = 0.9584^{**})

2.2 Combination of H_2SO_4 + HCl + oxalic acid

The performance of this extractant on the extraction of P and K are given in Table 25 and 26 respectively. This extractant extracted very large amount of P from all the soils. The amount of K extracted was comparatively smaller but extraction pattern was almost uniform at all the equilibration periods. The composition of the extractant is 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid. The amounts of P extracted by this extractant at different periods (5, 10, 15, 30 and 60 min) were 130.75, 139.90, 140.93, 133.90 and 174.01 ppm respectively. Therefore, an equilibration period of 15 min was found to be adequate for estimating P. But for K an equilibration period of 30 min would be required for extracting a reasonable amount of K. During this period P extraction was also found to be reasonable. The data furnished show that this extractant is promising for estimating P and K simultaneously, though originally developed by Mathew (1979) for P. The pattern of release when examined as a function of period of equilibration, the equilibrium P and K values were not seen established even after 60 min due to the expected release and resorption of P and K taking place during equilibration. It gave highly significant correlation with P and K concentration for all the periods. The highest correlation was obtained at 15 min (Table 37) in the case of P (0.9016^{**}) and at 30 min (Table 38) in the case of K (0.9567^{**}). The relationship between the amounts of nutrients (P and K) extracted by this extractant and the nutrient uptake by rice crop are represented by Fig 1 and Fig 2.

Table 25

P extracted by 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid, ppm

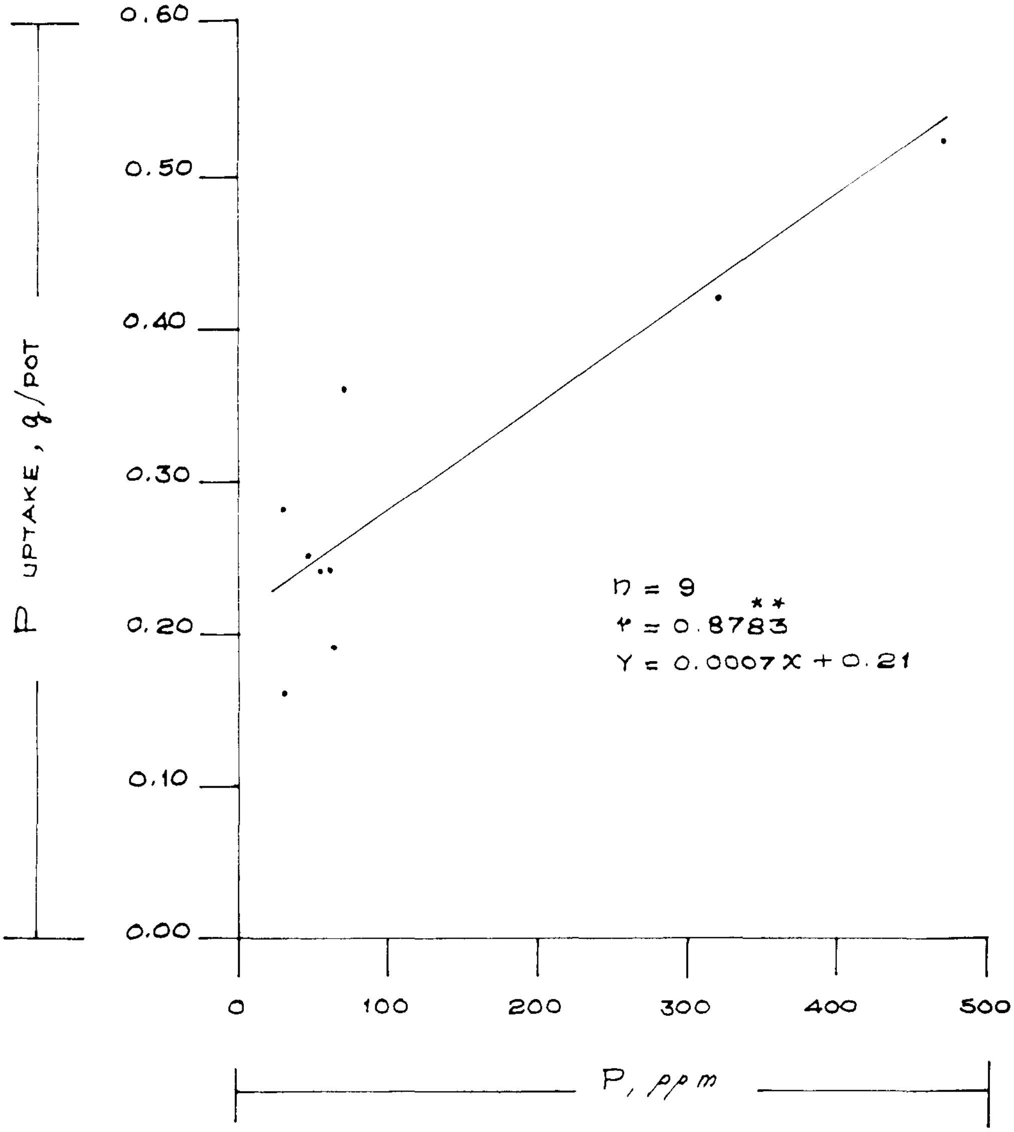
Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	22.47	22.47	22.47	28.44	28.45
2	48	46.53	104.67	57.66	64.89	101.81
3	22	28.45	26.92	25.42	28.44	34.69
4	54	93.67	110.53	91.08	59.64	101.81
5	15	80.06	86.06	99.03	67.81	107.56
6	4	41.31	41.31	48.31	46.53	59.64
7	60	101.81	104.67	91.08	116.72	153.56
8	35	471.94	471.94	471.94	471.94	555.56
9	32	290.49	290.49	361.40	320.81	423.03
Mean		130.75	139.90	140.93	133.90	174.01

Table 26

K extracted by 0.06 N NH_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	10	10	10	10	10
2	48	15	25	20	10	15
3	22	10	10	10	10	10
4	54	75	70	70	70	65
5	15	55	55	50	50	55
6	4	40	40	45	45	40
7	60	175	180	185	205	220
8	35	1200	1200	1225	1250	1350
9	32	190	160	210	230	245
Mean		194.4	195.0	202.8	208.9	223.3

FIG: 1 RELATIONSHIP BETWEEN P EXTRACTED BY 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N OXALIC ACID (TRIACID) AND P UPTAKE



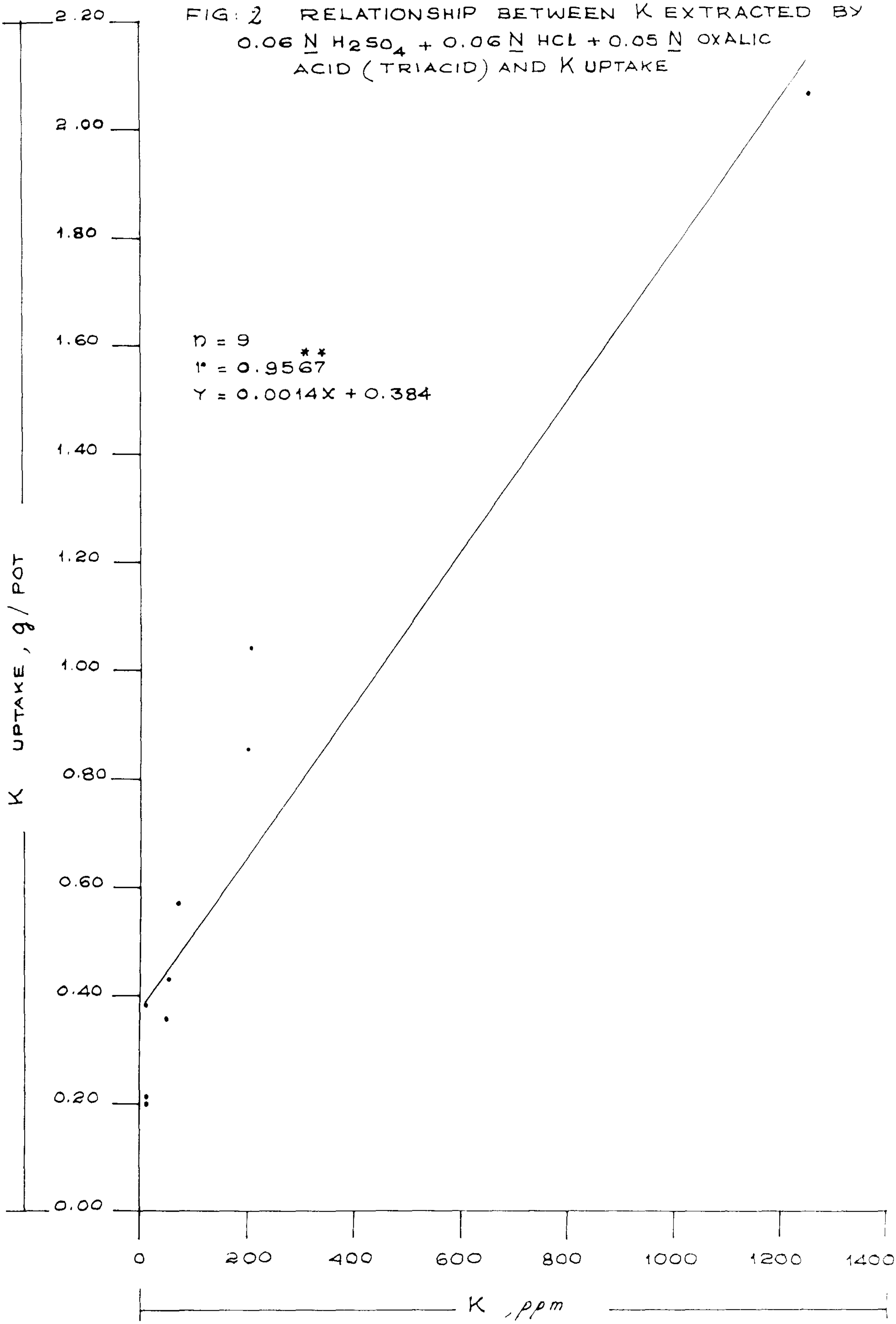


FIG: 2 RELATIONSHIP BETWEEN K EXTRACTED BY $0.06\,\underline{N}\ H_2SO_4 + 0.06\,\underline{N}\ HCL + 0.05\,\underline{N}$ OXALIC ACID (TRIACID) AND K UPTAKE

2.3 Bray No.1 ($0.03\ N\ NH_4F + 0.025\ N\ HCl$)

Bray No.1 was considered to be suitable for extracting both P and K from soil as reported by several workers (Ram and Prasad, 1983; Singh and Ghosh, 1982). The effects of this extractant on P and K release are presented in Table 27 and 28. The pattern of release of soil P and K during varying periods of equilibration showed that the values of P and K were fluctuating probably due to the similar release and resorption taking place during extraction. Maximum P and K released within 15 min but the release was retarded thereafter and attained an equilibrium value at 30 min.

The P was released during varying periods in the order 72.18, 69.30, 73.55, 72.34 and 73.19 ppm at 5, 10, 15, 30 and 60 min respectively. The amounts of K released were 189.4, 192.8, 201.1, 192.2 and 196.7 ppm during the respective equilibration periods. The values obtained at 30 min and 5 min were similar. Thus it was obvious that an equilibration period of 5 min is sufficient to bring available forms of these nutrients into solution. The correlation coefficients between P and K uptake and the amount of P and K extracted at all the equilibration periods (Table 37 and 38) were highly significant. Highest correlation was obtained with an equilibration period of 5 min for K (0.9535^{**}, Table 38) and 10 min for P (0.8976^{**}, Table 37)

Table 27

P extracted by 0.03 *N* NH_4F + 0.025 *N* HCl (Bray No.1), ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	15.29	16.56	16.56	16.56	16.56
2	48	10.35	11.57	12.79	4.48	6.80
3	22	2.23	2.23	3.35	1.10	2.23
4	54	14.04	14.04	16.56	11.57	16.56
5	15	15.29	25.93	17.86	15.29	21.82
6	4	19.15	25.93	25.93	33.15	23.17
7	60	36.20	34.66	24.54	24.54	28.77
8	35	338.74	279.28	338.74	338.74	338.74
9	32	198.31	213.53	205.65	205.65	204.02
Mean		72.18	69.30	73.55	72.34	73.19

Table 28

K extracted by 0.03 N NH_4F + 0.025 N HCl (Bray No.1), ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	30	30	30	30	30
2	48	25	30	30	30	30
3	22	25	25	30	25	20
4	54	80	70	70	75	75
5	15	60	65	65	70	60
6	4	65	65	70	60	65
7	60	180	185	200	175	190
8	35	1050	1070	1125	1125	1125
9	32	190	190	190	140	175
Mean		189.4	192.8	201.1	192.2	196.7

2.4 Combination of Bray No.1 and DTPA

As observed by Mathew (1979) the pattern of P release over varying periods of equilibration was consistently increased with increasing periods of equilibration showing that resorption of P once brought into solution on to a solid phase has to be effectively controlled in the presence of chelating agents like acetic, citric or oxalic acids. DTPA was found to be a good chelating agent for P as well as cations (Wolf, 1982). In the present study, Bray No.1 was combined with DTPA at varying equilibration periods. The P and K extractions have attained an equilibrium level within a period of 30 min according to the results presented in Table 29 and 30. But the values were similar in magnitude at 10 min also, eventhough there was a slight decrease at 10 min in the case of P.

The P values for the various equilibration periods were 55.77, 47.88, 55.28, 51.59 and 53.25 ppm and K values were 173.9, 193.3, 198.3, 189.4 and 192.2 ppm at 5, 10, 15, 30 and 60 min respectively. The correlation between P and K uptake and P and K concentration (Table 37 and 38) at varying equilibration periods were all highly significant. Sixty min for K (0.9608^{**}) and 10 min for P (0.8880^{**}) gave the highest coefficient of correlation.

2.5 NH_4F + Acetic acid

The chelating agent acetic acid and NH_4F were used in

Table 29

P extracted by 0.03 M NH_4F + 0.025 M HCl + 0.005 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	12.00	12.00	12.00	10.61	7.86
2	48	12.00	7.86	13.42	5.19	6.53
3	22	6.53	1.28	2.56	1.28	1.28
4	54	38.58	36.83	31.78	30.14	33.44
5	15	26.92	19.22	20.72	10.61	9.22
6	4	20.72	28.50	27.72	14.83	31.78
7	60	42.11	40.33	47.55	45.78	26.92
8	35	222.66	171.11	200.66	194.13	231.00
9	32	120.44	113.75	141.11	151.75	131.25
Mean		55.77	47.88	55.28	51.59	53.25

Table 30

K extracted by 0.03 M NH_4F + 0.025 N HCl + 0.005 M DTPA, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	10	40	20	15	15
2	48	5	10	25	15	15
3	22	5	10	15	15	15
4	54	55	75	65	65	65
5	15	45	55	45	65	60
6	4	45	60	50	60	60
7	60	155	185	200	185	205
8	35	1060	1110	1175	1085	1085
9	32	185	195	190	200	210
Mean		173.9	193.3	198.3	189.4	192.2

combination (0.05 M NH_4F + 0.05 M acetic acid). The amounts of phosphorus extracted at 5, 10, 15, 30 and 60 min were 65.38, 68.05, 65.93, 64.65 and 64.41 ppm respectively (Table 31). The values of K corresponding to these periods were 173.3, 174.4, 179.4, 169.4 and 170.0 ppm (Table 32). This combination did not show much fluctuation in the extraction of P and K at different periods which indicates that acetic acid is a good chelating agent both for P and K. Significant correlations were obtained between K uptake and K extracted by the extractant at all equilibration periods (Table 38). Maximum correlation was observed at 5 min (0.9499^{**}). Phosphorus extracted by this extractant also showed significant positive correlation with P uptake at all the periods of equilibration. Maximum correlation was obtained at 10 min ($r = 0.8896^{**}$). The coefficients of correlation for 30 min (0.8879^{**}) was also highly significant and P extracted at 5 min was almost equal to that of 30 min. Therefore equilibration period of 5 min is considered satisfactory to extract both P and K simultaneously.

2.6 <u>Olsen's extractant</u> (0.5 M $NaHCO_3$)

There are reports showing that Olsen's extractant could be used for estimating P and K simultaneously (Mc Conaghy and Mc Allister, 1967; Bar and Akiri, 1978). This extractant showed almost static P values at different equilibration periods i.e., 52.87, 57.42, 57.03, 59.80 and 61.28 ppm of P at 5, 10, 15, 30 and 60 min equilibration periods respectively (Table 33) and 163.9, 155.0, 156.1, 158.3 and 161.7 ppm of K for the

Table 31

P extracted by 0.05 *M* NH_4F + 0.05 *M* acetic acid, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	14.20	15.39	15.39	14.20	14.20
2	48	16.60	17.80	19.02	11.89	17.80
3	22	7.41	7.41	7.41	5.23	7.40
4	54	21.52	21.52	21.52	19.02	19.02
5	15	24.09	25.39	25.39	25.39	25.39
6	4	28.07	32.20	32.20	32.20	32.20
7	60	39.52	42.60	39.52	41.04	41.04
8	35	259.09	259.09	234.54	234.54	224.27
9	32	177.88	191.07	198.38	198.38	198.38
Mean		65.38	68.05	65.93	64.65	64.41

Table 32

K extracted by 0.05 M NH_4F + 0.05 M acetic acid, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	30	35	40	20	25
2	48	25	25	25	10	10
3	22	15	15	20	10	5
4	54	55	45	40	45	35
5	15	40	55	50	50	45
6	4	85	85	75	55	60
7	60	180	160	180	135	155
8	35	995	995	1020	1045	1045
9	32	135	155	165	155	150
Mean		173.3	174.4	179.4	169.4	170.0

Table 33

P extracted by 0.5 M $NaHCO_3$ (Olsen, pH 8.5), ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	14.06	10.06	12.72	11.39	11.39
2	48	16.81	18.20	19.61	23.95	21.03
3	22	8.75	6.20	14.06	8.75	6.20
4	54	25.42	29.77	31.53	29.77	31.53
5	15	28.45	31.53	29.77	29.77	29.77
6	4	11.39	15.42	12.72	14.06	14.06
7	60	31.53	31.53	18.20	29.77	34.69
8	35	194.17	228.86	221.09	237.20	233.03
9	32	145.25	145.25	153.56	153.56	169.71
Mean		52.87	57.42	57.93	59.80	61.28

corresponding equilibration periods (Table 34). These values were obtained when the effects of soils were pooled. Zero values were obtained in soils of low K status (Table 34). Since this extractant could not predict the K availability in soils containing low amount of K, it was obvious that it may not be suited to all soils. The available K values using neutral normal ammonium acetate (std) in soil No.49, 48 and 22 were 20, 17.5 and 15.0 ppm respectively which registered zero values when extracted with Olsen's extractant. Equilibration period of 30 min was the best suited to this extractant which has been already established by Olsen et al. (1954). The correlation coefficients between P and K extraction and P and K uptake were significant at all the equilibration periods.

2.7 Neutral normal NH_4OAc

The amounts of P and K extracted by this extractant are given in Table 35 and 36. Ammonium acetate extracted the largest amount of K in all the soils under study. With increasing period of equilibration K value increased almost linearly. Maximum was recorded at 60 min. The amounts of K extracted at varying equilibration periods (5, 10, 15, 30 and 60 min) were 233.9, 255.0, 263.9, 268.3 and 295.0 ppm respectively and the corresponding P values were 17.11, 32.23, 42.47, 46.71 and 55.02 ppm. When the effects of soils were pooled the amount of P extracted increased with increasing periods of equilibrium from 5 to 15 min steadily and thereafter comparatively smaller increase was observed. When the P and K extraction was considered together an equilibration period of 30 min was

Table 34

K extracted by 0.5 M $NaHCO_3$ (Olsen, pH 8.5), ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	0	0	0	0	0
2	48	0	0	5	5	5
3	22	0	0	0	0	0
4	54	50	50	50	55	60
5	15	20	30	35	45	45
6	4	20	30	30	25	35
7	60	165	165	165	165	165
8	35	1040	965	965	965	965
9	32	180	155	155	165	180
Mean		163.9	155.0	156.1	158.3	161.7

Table 35

P extracted by N neutral NH_4OAc, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	4.40	4.40	4.40	4.40	4.40
2	48	4.40	8.90	4.40	4.40	8.90
3	22	4.40	0	4.40	0	8.90
4	54	4.40	4.40	4.40	4.40	8.90
5	15	4.40	18.10	22.70	22.70	22.70
6	4	8.90	22.70	22.70	22.70	22.70
7	60	13.50	18.10	18.10	18.10	27.40
8	35	77.40	171.70	185.00	185.00	213.00
9	32	32.20	41.80	116.10	158.70	178.30
Mean		17.11	32.23	42.47	46.71	55.02

Table 36

K extracted by 1N neutral NH_4OAc, ppm

Sl. No.	Soil sample No.	Period of equilibration, min				
		5	10	15	30	60
1	49	15	15	15	30	40
2	48	35	25	20	45	45
3	22	25	25	25	30	35
4	54	95	115	90	85	115
5	15	55	65	55	80	95
6	4	45	65	65	75	80
7	60	255	215	225	250	265
8	35	1355	1575	1675	1615	1715
9	32	225	195	205	205	265
Mean		233.9	255.0	263.9	268.3	295.0

Table 37

Coefficients of correlation (r) between P extracted by the chemical extractants and P uptake by rice

Sl.No.	Name of extractant	Period of equilibration, min				
		5	10	15	30	60
1	0.1 M NH_4F + 0.001 M DTPA	0.8658^{**}	0.9572^{**}	0.9489^{**}	0.9341^{**}	0.9058^{**}
2	0.1 M NH_4F + 0.003 M DTPA	0.91802^{**}	0.8762^{**}	0.9248^{**}	0.8951^{**}	0.9005^{**}
3	0.1 M NH_4F + 0.005 M DTPA	0.9156^{**}	0.9253^{**}	0.8669^{**}	0.8760^{**}	0.8769^{**}
4	0.3 M NH_4F + 0.001 M DTPA	0.9085^{**}	0.8958^{**}	0.9073^{**}	0.9170^{**}	0.90480^{**}
5	0.3 M NH_4F + 0.003 M DTPA	0.8022^{**}	0.9155^{**}	0.9164^{**}	0.8703^{**}	0.9009^{**}
6	0.3 M NH_4F + 0.005 M DTPA	0.8898^{**}	0.8884^{**}	0.9034^{**}	0.9060^{**}	0.9252^{**}
7	0.5 M NH_4F + 0.001 M DTPA	0.8935^{**}	0.8778^{**}	0.8868^{**}	0.9030^{**}	0.9252^{**}
8	0.5 M NH_4F + 0.003 M DTPA	0.9053^{**}	0.9132^{**}	0.9140^{**}	0.9107^{**}	0.9155^{**}

Table 37 Contd.....

Sl.No.	Name of extractant	Period of equilibration, min				
		5	10	15	30	60
9	0.5 $\underline{M}$ NH_4F + 0.005 $\underline{M}$ DTPA	0.8764^{**}	0.8860^{**}	0.8891^{**}	0.8964^{**}	0.8847^{**}
10	0.06 $\underline{N}$ H_2SO_4 + 0.06 $\underline{N}$ HCl + 0.05 $\underline{N}$ oxalic acid	0.85767^{**}	0.8625^{**}	0.9016^{**}	0.8783^{**}	0.8764^{**}
11	Bray No.1	0.8758^{**}	0.8976^{**}	0.8894^{**}	0.8917^{**}	0.8968^{**}
12	Bray No.1 + 0.005 $\underline{M}$ DTPA	0.8800^{**}	0.8880^{**}	0.8850^{**}	0.8700^{**}	0.8738^{**}
13	0.05 $\underline{M}$ NH_4F + 0.05 $\underline{M}$ acetic acid	0.8759^{**}	0.8896^{**}	0.8830^{**}	0.8879^{**}	0.8792^{**}
14	Olsen's extractant	0.8828^{**}	0.9009^{**}	0.8929^{**}	0.8924^{**}	0.8940^{**}
15	Normal neutral NH_4OAc	0.7230^{*}	0.8319^{**}	0.9060^{**}	0.8982^{**}	0.8836^{**}

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 38

Coefficients of correlation (r) between K extracted by chemical extractants and K uptake

Sl. No.	Name of the extractant	Period of equilibration, min				
		5	10	15	30	60
1	0.1 M NH_4F + 0.001 M DTPA	0.9512**	0.9543**	0.9536**	0.9572**	0.9488**
2	0.1 M NH_4F + 0.003 M DTPA	0.9522**	0.9538**	0.9513**	0.9522**	0.9500**
3	0.1 M NH_4F + 0.005 M DTPA	0.9574**	0.9584**	0.9539**	0.9534**	0.9471**
4	0.3 M NH_4F + 0.001 M DTPA	0.9560**	0.9411**	0.9369**	0.9395**	0.9364**
5	0.3 M NH_4F + 0.003 M DTPA	0.9491**	0.9399**	0.9395**	0.9208**	0.9188**
6	0.3 M NH_4F + 0.005 M DTPA	0.9394**	0.9345**	0.9172**	0.9141**	0.9122**
7	0.5 M NH_4F + 0.001 M DTPA	0.9395**	0.9361**	0.9229**	0.9209**	0.9289**
8	0.5 M NH_4F + 0.003 M DTPA	0.9160**	0.9185**	0.9150**	0.9198**	0.9197**
9	0.5 M NH_4F + 0.005 M DTPA	0.93067**	0.9247**	0.9198**	0.9198**	0.9142**

** Significant at 1 per cent level

Table 38 Contd.........

Sl. No.	Name of the extractant	Period of equilibration, min				
		5	10	15	30	60
10	0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid	0.9500**	0.9501**	0.9527**	0.9567**	0.9562**
11	Bray No.1	0.9535**	0.9531**	0.9533**	0.9448**	0.9519**
12	Bray No.1 + 0.005 M DTPA	0.9513**	0.9549**	0.9489**	0.9558**	0.9608**
13	0.05 M NH_4F + 0.05 M acetic acid	0.9499**	0.9449**	0.9489**	0.9416**	0.9455**
14	Olsen's extractant	0.9573**	0.9594**	0.9593**	0.9602**	0.9607**
15	Normal neutral NH_4OAc	0.9608**	0.9445**	0.9434**	0.9464**	0.9487**
16	NH_4OAc (std)	0.9527**				

** Significant at 1 per cent level

found to be the best. Highly significant correlation with P and K uptake were observed at all the equilibration periods. In soil No.22 zero values of P were observed at 10 and 30 min which may be due to the very low available P status of the soil and the poor P extracting power of this extractant. The available P content in this soil is 2.33 ppm. Thus it is seen that NH_4OAc is not a good extractant for predicting available P in soils of low P status.

From the correlation coefficients established between the nutrients extracted by the extractants employed in the study and the nutrient uptake by rice it was obvious that the nutrients extracted by all the extractants were highly correlated with their uptake at selected periods of equilibration, most of them being on par. Thus it was very difficult to select an extractant based simply on the correlation coefficients. Then the main criterion was to find an extractant which will extract amounts of P and K which will show high correlation with P extracted by Bray No.1 and K extracted by neutral normal ammonium acetate respectively, since these methods are already being adopted in the soil testing laboratories of Kerala and rating and fertilizer recommendation procedures are already developed.

The preliminary study thus brought to light the following facts.

1. NH_4F + DTPA combinations viz., 0.1 M + 0.005 M, 0.3 M +

0.003 *M*, 0.3 *M* + 0.005 *M*, 0.5 *M* + 0.001 *M* and 0.5 *M* + 0.003 *M* were not suitable for the estimation of phosphorus and potassium simultaneously from soil. The combinations of NH_4F + DTPA i.e., 0.1 *M* + 0.001 *M*, 0.1 *M* + 0.003 *M*, 0.3 *M* + 0.001 *M*, and 0.5 *M* + 0.005 *M* were effective as common extractants.

2. The suitable equilibration period for 0.1 *M* NH_4F + 0.001 *M* DTPA, 0.1 *M* NH_4F + 0.003 *M* DTPA, 0.5 *M* NH_4F + 0.005 *M* DTPA, 0.05 *M* NH_4F + 0.05 *M* acetic acid and Bray No.1 was 5 min. For 0.3 *M* NH_4F + 0.001 *M* DTPA combination and Bray No.1 + 0.005 *M* DTPA, an equilibration period of 10 min was found to be the best. An equilibration period of 30 min was suitable for 0.06 *N* H_2SO_4 + 0.06 *N* HCl + 0.05 *N* oxalic acid, Olsen's extractant and neutral normal ammonium acetate.

3. *Final selection of a common extractant for available P and available K.*

For the last many years the soil testing laboratories of the State had adopted Bray No.1 for the extraction of available P and the neutral normal ammonium acetate extractant for the estimation of available K. Accordingly, soil test ratings and fertility classifications have already been developed and even soil fertility maps are under preparation. The initial and preliminary studies conducted now have established the suitability of Bray No.1 for available P and the neutral normal ammonium acetate for available K. Therefore, the final selection of a common extractant with 87 soils was oriented towards the highest correlation of the P and K values of the newly selected extractants with that of Bray No.1 phosphorus and NH_4OAc extractable potassium.

The extractants with appropriate equilibration periods selected from the preliminary screening viz., NH_4F + DTPA combinations of 0.1 M + 0.001 M (5 min), 0.1 M + 0.003 M (5 min), 0.3 M + 0.001 M (10 min), 0.5 M + 0.005 M (5 min), 0.06 M H_2SO_4 + 0.06 M HCl + 0.05 M oxalic acid (30 min), Bray No.1 (5 min), Bray No.1 + 0.005 M DTPA (10 min), 0.5 M NH_4F + 0.05 M acetic acid (5 min), Olsen's extractant (30 min), and NH_4OAc (30 min) were employed for determining their efficiency of extracting both P and K in all the 87 soils selected for the study using a single soil solution ratio of 1:10. Correlations were worked out between the P and K extracted by the selected extractants and Bray No.1 P and neutral normal NH_4OAc K. The P values obtained by various extractants from 87 soils are presented in Table 39.

When the mean values of P extracted by the different extractants were compared, it was found that 0.1 M + 0.003 M combination of NH_4F + DTPA extracted the maximum quantity of P (88.21 ppm), while Bray No.1 extracted much smaller amount of P (30.67 ppm) Neutral normal NH_4OAc was the least efficient in extracting P (7.16 ppm).

The extractable P in the 87 soils when considered altogether, the following order of decreasing efficiency was observed: 0.1 M NH_4F + 0.003 M DTPA (88.21 ppm) > 0.3 M NH_4F + 0.001 M DTPA (43.43 ppm) > 0.1 M NH_4F + 0.001 M DTPA

Table 39

P extracted by various extractants, ppm

Soil sample No.	0.1*M* NH_4F + 0.001*M* DTPA	0.1*M* NH_4F + 0.003*M* DTPA	0.3*M* NH_4F + 0.001*M* DTPA	0.5*M* NH_4F + 0.005*M* DTPA	0.06*N* H_2SO_4 + 0.06*N* HCl + 0.05*N* oxalic acid	0.03*M* NH_4F + 0.025*N* HCl (Bray No.1)	0.03*M* NH_4F + 0.025*N* HCl + 0.005*M* DTPA	0.05*M* NH_4F + 0.05*M* acetic acid	0.5*M* $NaHCO_3$ pH 8.5 (Olsen)	Neutral *N* NH_4OAc
1	37.45	20.78	34.80	12.66	10.75	22.6	4.64	5.19	12.34	0.00
2	38.70	23.50	54.50	30.78	14.15	21.91	14.58	16.23	0.83	6.15
3	9.35	10.17	15.90	9.63	3.81	6.54	5.63	10.71	30.93	0.26
4	27.91	16.67	18.74	16.32	46.53	19.15	28.50	28.07	14.06	22.70
5	6.90	7.61	11.30	6.63	2.51	4.24	2.72	6.02	3.87	0.26
6	19.13	31.89	11.30	15.78	8.58	16.10	4.15	10.40	2.97	0.00
7	50.90	132.56	44.50	51.72	28.60	55.27	46.76	27.00	32.26	7.50
8	43.87	58.89	54.50	18.97	14.54	22.60	13.66	31.99	5.71	1.06
9	62.07	40.56	49.50	41.78	11.49	38.91	7.70	13.88	3.64	1.88
10	30.45	40.56	20.50	18.97	4.47	17.64	1.57	15.54	5.24	0.00
11	96.77	68.61	30.00	36.19	20.29	66.78	15.21	15.54	29.23	2.43
12	53.92	89.28	20.50	22.25	13.00	38.91	19.18	31.04	9.92	2.15

Table 39 Contd......

Soil sample No.	0.1M NH_4F + 0.001M DTPA	0.1M NH_4F + 0.003M DTPA	0.3M NH_4F + 0.001M DTPA	0.5M NH_4F + 0.005M DTPA	0.06N H_2SO_4 + 0.06N HCl + 0.05N oxalic acid	0.03M NH_4F + 0.025N HCl (Bray No.1)	0.03M NH_4F + 0.025N HCl + 0.005M DTPA	0.05M NH_4F + 0.05M acetic acid	0.5M $NaHCO_3$ pH 8.5 (Olsen)	Neutral N NH_4OAc
13	16.33	34.72	44.50	32.56	3.81	17.33	6.40	14.21	11.25	0.26
14	24.05	89.28	30.00	15.78	16.13	18.90	26.80	29.66	8.13	0.52
15	5.95	53.81	48.91	60.32	67.81	15.29	19.22	24.09	29.77	22.70
16	25.08	92.95	34.80	23.91	16.94	30.79	17.82	37.56	12.62	0.52
17	30.45	52.61	39.60	22.25	11.12	49.10	22.07	38.09	12.34	1.61
18	18.18	185.34	49.50	36.19	43.06	100.97	27.64	25.73	15.21	4.12
19	22.05	141.34	59.60	29.03	3.81	4.24	67.20	7.43	5.24	0.26
20	17.25	46.50	30.00	11.13	13.76	30.36	20.60	16.23	7.14	1.06
21	19.13	55.72	25.20	15.78	32.16	13.77	15.85	15.54	15.80	2.70
22	1.69	1.67	2.21	26.21	28.44	2.33	1.28	7.41	8.75	0.00
23	11.03	26.28	25.20	12.66	24.76	13.21	23.84	18.71	4.55	1.06
24	28.25	150.45	44.50	53.78	24.76	58.25	11.00	44.46	125.49	6.75
25	25.08	66.61	85.90	49.66	30.09	54.96	42.30	19.44	23.75	4.40

Table 39 Contd.....

Soil sample No.	0.1M NH_4F + 0.001M DTPA	0.1M NH_4F + 0.003M DTPA	0.3M NH_4F + 0.001M DTPA	0.5M NH_4F + 0.005M DTPA	0.06N H_2SO_4 + 0.06N HCl + 0.05N oxalic acid	0.03M NH_4F + 0.025N HCl (Bray No.1)	0.03M NH_4F + 0.025N HCl + 0.005M DTPA	0.05M NH_4F + 0.05M acetic acid	0.5M $NaHCO_3$ pH 8.5 (Olsen)	Neutral N NH_4OAc
26	15.42	18.11	34.80	37.11	5.81	4.24	9.32	14.88	10.18	0.00
27	5.30	18.11	6.70	6.63	11.12	5.60	6.65	3.84	2.54	0.00
28	39.95	100.34	54.50	47.66	23.39	52.65	51.01	95.69	37.03	9.85
29	10.18	78.72	15.90	25.59	6.49	13.21	7.70	12.58	19.58	0.00
30	19.13	128.28	75.20	30.78	27.61	25.15	17.82	24.07	32.72	7.66
31	9.35	20.78	20.50	14.22	3.15	2.92	6.65	5.47	4.15	0.00
32	127.88	190.16	217.77	192.57	320.81	198.31	113.75	177.88	153.56	158.70
33	27.18	78.72	44.50	15.78	13.00	32.56	39.37	39.19	26.79	3.26
34	1.47	12.78	0.00	3.72	11.49	4.24	2.72	0.99	1.04	0.00
35	195.81	224.14	429.41	448.29	471.94	338.74	171.11	259.09	237.20	185.00
36	4.52	34.72	6.70	6.63	5.14	2.92	9.06	3.58	4.55	0.00
37	16.33	49.56	34.80	30.78	7.18	13.49	15.21	14.21	19.58	0.26
38	13.63	31.89	6.70	19.44	6.49	5.60	9.06	9.79	8.13	0.00

Table 39 Contd......

Soil sample No.	0.1M NH$_4$F + 0.001M DTPA	0.1M NH$_4$F + 0.003M DTPA	0.3M NH$_4$F + 0.001M DTPA	0.5M NH$_4$F + 0.005M DTPA	0.06N H$_2$SO$_4$+ 0.06N HCl + 0.05 N oxalic acid	0.03M NH$_4$F + 0.025N HCl (Bray No.1)	0.03M NH$_4$F + 0.025N HCl + 0.005M DTPA	0.05M NH$_4$F + 0.05N acetic acid	0.5M NaHCO$_3$ pH 8.5 (Olsen)	Neutral N NH$_4$OAc
39	11.01	34.72	15.90	18.97	5.14	8.47	14.27	9.49	3.42	0.00
40	182.09	82.22	44.50	38.03	22.93	64.73	49.55	47.66	40.74	1.06
41	35.05	75.28	25.20	30.78	22.93	48.42	17.15	33.44	19.92	13.48
42	31.57	49.56	49.50	22.25	12.24	24.41	31.20	38.63	19.34	0.00
43	15.42	245.95	54.50	17.34	11.49	11.57	11.58	8.01	8.13	1.88
44	22.05	111.95	59.60	25.59	16.94	26.69	14.58	47.00	26.79	2.15
45	6.17	29.06	34.80	25.59	7.88	6.30	6.14	8.60	2.97	0.26
46	26.13	174.84	30.00	34.34	22.04	45.20	23.59	49.68	23.03	4.40
47	8.18	85.72	39.60	22.25	26.17	31.67	25.57	24.48	13.18	2.79
48	10.52	14.12	18.74	18.25	64.89	10.35	7.86	16.60	23.95	4.40
49	11.76	8.00	9.03	8.86	28.44	15.29	12.00	14.20	11.39	4.40
50	35.05	337.01	39.60	17.34	2.04	51.19	34.09	56.30	27.19	2.70
51	5.30	68.61	11.30	14.22	.18	6.54	14.58	7.43	5.94	0.00

Table 39 Contd......

Soil sample No	0.1M NH_4F + 0.001M DTPA	0.1M NH_4F + 0.003M DTPA	0.3M NH_4F + 0.001M DTPA	0.5M NH_4F + 0.005M DTPA	0.06N H_2SO_4+ 0.06N HCl + 0.05 N oxalic acid	0.03M NH_4F + 0.025N HCl (Bray No.1)	0.03M NH_4F + 0.025N HCl + 0.005M DTPA	0.05M NH_4F + 0.05M acetic acid	0.5M $NaHCO_3$ pH 8.5 (Olsen)	Neutral N NH_4OAc
52	16.33	68.61	34.80	12.66	10.75	14.93	20.97	14.88	19.58	0.00
53	42.53	65.34	34.80	8.13	14.15	14.64	17.82	14.21	5.24	0.00
54	26.48	36.65	32.14	52.86	59.64	14.04	36.83	21.52	29.77	4.40
55	36.23	190.73	30.00	12.66	12.24	13.77	16.17	20.56	7.14	0.00
56	84.04	110.38	113.90	14.22	32.68	43.58	36.64	51.08	29.65	3.83
57	33.87	150.45	34.80	11.13	14.54	31.22	24.97	45.71	26.00	0.00
58	22.05	128.28	20.50	12.66	7.88	11.57	13.36	22.88	7.63	0.00
59	43.87	239.17	91.40	20.59	20.29	35.85	26.80	25.31	16.41	3.26
60	38.64	39.86	53.27	43.46	116.72	36.20	40.33	39.52	29.77	18.10
61	41.23	65.34	44.50	17.34	5.14	13.21	10.72	11.63	6.18	0.00
62	26.13	132.56	25.20	14.22	7.88	17.64	19.88	27.00	15.80	0.00
63	12.75	92.95	20.50	20.59	4.47	23.32	22.44	29.66	3.87	0.00
64	11.88	71.95	20.50	11.13	5.47	5.37	11.58	16.58	3.87	0.00

Table 39 Contd.......

Soil sample No.	0.1M NH_4F + 0.001M DTPA	0.1M NH_4F + 0.003M DTPA	0.3M NH_4F + 0.001M DTPA	0.5M NH_4F + 0.005M DTPA	0.06N H_2SO_4 + 0.06N HCl + 0.05 N oxalic acid	0.03M NH_4F + 0.025N HCl (Bray No.1)	0.03M NH_4F + 0.025N HCl + 0.005M DTPA	0.05M NH_4F + 0.05M acetic acid	0.5M $NaHCO_3$ pH 8.5 (Olsen)	Neutral N NH_4OAc
65	46.60	11.95	69.90	69.25	31.12	42.22	25.97	21.32	5.71	1.06
66	21.07	132.56	49.50	2.25	17.76	35.85	23.98	38.63	18.61	1.06
67	55.47	155.12	54.50	45.69	21.17	58.25	41.69	49.00	30.08	9.85
68	33.87	78.72	34.80	15.78	10.01	36.85	16.49	66.90	40.74	2.43
69	35.05	75.28	34.80	20.59	20.29	23.32	16.82	26.57	30.93	9.85
70	21.07	92.95	25.20	8.13	5.14	6.07	6.40	4.11	4.09	0.00
71	22.05	4.11	64.70	32.56	4.47	5.83	11.58	21.32	5.24	0.00
72	10.18	96.61	30.00	23.91	9.65	4.46	6.40	16.93	3.42	0.00
73	36.23	406.40	64.70	60.19	35.39	70.11	52.53	37.56	20.25	15.23
74	27.18	31.89	11.30	15.78	21.17	21.56	15.85	14.21	4.32	0.00
75	53.92	62.06	44.50	29.03	7.88	15.81	3.19	17.63	19.58	0.00
76	26.13	52.61	25.20	25.59	16.94	13.21	18.50	24.48	23.39	4.40

Table 39 Contd.......

Soil sample No.	0.1M NH_4F + 0.001M DTPA	0.1M NH_4F + 0.003M DTPA	0.3M NH_4F + 0.001M DTPA	0.5M NH_4F + 0.005M DTPA	0.06N H_2SO_4 + 0.06N HCl + 0.05N oxalic acid	0.03M NH_4F + 0.025N HCl (Bray No.1)	0.03M NH_4F + 0.025N HCl + 0.005M DTPA	0.05M NH_4F + 0.05M acetic acid	0.5M $NaHCO_3$ pH 8.5 (Olsen)	Neutral N NH_4OAc
77	27.05	56.89	25.20	18.97	12.24	19.88	23.98	25.31	9.14	0.00
78	65.58	164.78	49.50	92.13	54.81	80.56	61.08	73.21	38.58	43.81
79	22.05	96.61	15.90	20.59	6.49	6.07	12.15	19.08	5.19	0.52
80	53.92	145.84	91.40	30.78	18.60	36.85	34.59	49.66	12.90	0.52
81	29.35	71.95	39.60	29.03	15.73	7.25	10.43	5.19	4.77	0.00
82	21.07	96.61	39.60	34.34	35.94	28.69	30.28	7.72	10.71	7.05
83	18.18	31.89	0.00	6.63	3.81	6.07	6.14	12.27	1.46	0.00
84	3.75	7.61	0.00	3.72	0.61	2.92	5.38	1.50	0.83	0.00
85	42.53	174.84	133.80	23.91	16.53	38.91	46.76	25.31	6.18	6.15
86	8.52	26.28	0.00	5.16	4.81	5.60	7.97	7.43	3.87	0.52
87	10.18	43.50	6.70	6.63	4.14	6.07	6.65	6.30	2.97	0.52
Mean	31.56	88.21	43.43	31.45	27.31	30.67	22.67	28.56	19.75	7.16

(31.56 ppm) > 0.5 N NH_4F + 0.005 M DTPA (31.45 ppm) > Bray No.1 (30.67 ppm) > 0.05 N NH_4F + 0.05 N acetic acid (28.56 ppm) > 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid (27.31 ppm) > Bray No.1 + 0.005 M DTPA (22.67 ppm) > Olsen's extractant (19.75 ppm) > neutral normal NH_4OAc (7.16 ppm). The higher values obtained by NH_4F + DTPA may be attributed to the stronger chelating action of DTPA which prevents the resorption of P into the soil.

When the individual soils were considered it was found that 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid was more effective in releasing P into the solution in soil No.35 which registered highest available P value i.e., 471.94 ppm, while the corresponding value for Bray No.1 was only 338.74.

The comparison of mean values of K extracted by the different selected extractants is presented in Table 40. The different extractants extracted K in the following decreasing order.

NH_4OAc (119.1 ppm) > Bray No.1 + 0.005 M DTPA (111.0 ppm) > Mathew's triacid (110.7 ppm) > NH_4OAc std (107.4 ppm) > Bray No.1 (101.4 ppm) > Olsen (100.8 ppm) > 0.05 N NH_4F + 0.05 N acetic acid (94.1 ppm) > 0.1 N NH_4F + 0.003 M DTPA (88.4 ppm) > 0.1 N NH_4F + 0.001 M DTPA (88.1 ppm) > 0.3 N NH_4F + 0.001 M DTPA (83.6 ppm) > 0.5 N NH_4F + 0.005 M DTPA (62.0 ppm). Combinations of NH_4F and DTPA could not release large amounts of K eventhough it could release large amounts of P.

Table 40

K extracted by various extractants, ppm

Soil sample No.	0.1M NH_4F + 0.001M DTPA	0.1M NH_4F + 0.003M DTPA	0.3M NH_4F + 0.001M DTPA	0.5M NH_4F + 0.005M DTPA	0.06N H_2SO_4 + 0.06N HCl + 0.05N oxalic acid	0.03M NH_4F + 0.025N HCl (Bray No.1)	0.03M NH_4F + 0.025N HCl + 0.005M DTPA	0.05M NH_4F + 0.05M acetic acid	0.5M $NaHCO_3$ pH 8.5 (Olsen)	N neutral NH_4OAc	N neutral NH_4OAc (std)
1	45.00	60.00	15.00	40.00	40.00	60.00	60.00	55.00	45.00	45.00	32.50
2	65.00	90.00	85.00	30.00	40.00	90.00	105.00	85.00	15.00	80.00	107.50
3	25.00	30.00	25.00	25.00	15.00	15.00	20.00	80.00	95.00	15.00	14.00
4	45.00	55.00	50.00	20.00	45.00	65.00	65.00	85.00	25.00	75.00	55.00
5	25.00	30.00	25.00	15.00	15.00	27.00	20.00	35.00	5.00	15.00	15.00
6	20.00	25.00	10.00	15.00	20.00	50.00	20.00	25.00	20.00	20.00	20.50
7	55.00	50.00	25.00	20.00	50.00	65.00	65.00	60.00	55.00	50.00	42.50
8	35.00	30.00	10.00	10.00	15.00	10.00	20.00	30.00	15.00	15.00	10.50
9	110.00	110.00	45.00	55.00	195.00	160.00	190.00	150.00	175.00	190.00	165.00
10	35.00	50.00	20.00	15.00	30.00	30.00	40.00	50.00	55.00	40.00	20.00
11	25.00	35.00	15.00	20.00	20.00	20.00	25.00	25.00	25.00	25.00	10.00
12	50.00	50.00	20.00	20.00	50.00	40.00	75.00	50.00	55.00	60.00	45.00
13	50.00	55.00	15.00	20.00	55.00	45.00	60.00	55.00	60.00	60.00	45.00

Table 40 Contd.....

Soil sample No.	0.1M NH_4F + 0.001M DTPA	0.1M NH_4F + 0.003M DTPA	0.3M NH_4F + 0.001M DTPA	0.5M NH_4F + 0.005M DTPA	0.06M H_2SO_4 + 0.06M HCl + 0.05M oxalic acid	0.03M NH_4F + 0.025M HCl (Bray No.1)	0.03M NH_4F + 0.025M HCl + 0.005M DTPA	0.05M NH_4F + 0.05M acetic acid	0.5M $NaHCO_3$ pH 8.5 (Olsen)	N neutral NH_4OAc	N neutral NHOAc (std)
14	40.00	160.00	195.00	40.00	18.00	175.00	180.00	165.00	195.00	235.00	220.00
15	25.00	45.00	30.00	0.00	50.00	60.00	55.00	40.00	45.00	80.00	82.50
16	50.00	60.00	20.00	20.00	11.00	45.00	50.00	60.00	45.00	40.00	20.00
17	25.00	30.00	55.00	10.00	25.00	25.00	30.00	30.00	30.00	25.00	17.50
18	55.00	35.00	15.00	10.00	30.00	30.00	35.00	30.00	40.00	30.00	60.00
19	65.00	80.00	95.00	15.00	80.00	75.00	80.00	75.00	75.00	100.00	90.00
20	20.00	30.00	45.00	25.00	15.00	15.00	20.00	25.00	25.00	15.00	15.00
21	55.00	55.00	75.00	35.00	100.00	60.00	80.00	65.00	85.00	85.00	72.50
22	5.00	5.00	5.00	25.00	10.00	25.00	10.00	15.00	0.00	30.00	15.00
23	20.00	20.00	10.00	10.00	10.00	30.00	135.00	30.00	15.00	10.00	5.00
24	270.00	275.00	135.00	125.00	340.00	325.00	345.00	295.00	295.00	320.00	320.00
25	55.00	60.00	30.00	35.00	45.00	50.00	50.00	55.00	60.00	45.00	45.00
26	95.00	100.00	120.00	35.00	120.00	110.00	110.00	90.00	105.00	140.00	125.00

Table 40 Contd.....

Soil sample No.	0.1$\underline{M}$ NH_4F + 0.001$\underline{M}$ DTPA	0.1$\underline{M}$ NH_4F + 0.003$\underline{M}$ DTPA	0.3$\underline{M}$ NH_4F + 0.001$\underline{M}$ DTPA	0.5$\underline{M}$ NH_4F + 0.005$\underline{M}$ DTPA	0.06$\underline{N}$ H_2SO_4 + 0.06$\underline{N}$ HCl + 0.05$\underline{N}$ oxalic acid	0.03$\underline{M}$ NH_4F + 0.025$\underline{N}$ HCl + (Bray No.1)	0.03$\underline{M}$ NH_4F + 0.025$\underline{N}$ HCl + 0.005$\underline{M}$ DTPA	0.05$\underline{M}$ NH_4F + 0.05$\underline{M}$ acetic acid	0.5$\underline{M}$ $NaHCO_3$ pH 8.5 (Olsen)	$\underline{N}$ neutral NH_4OAc	$\underline{N}$ neutral NH_4OAc (std)
27	55.00	60.00	115.00	135.00	90.00	80.00	85.00	55.00	55.00	135.00	107.50
28	590.00	600.00	780.00	755.00	850.00	700.00	710.00	580.00	625.00	1000.00	1000.00
29	65.00	70.00	60.00	145.00	90.00	70.00	80.00	75.00	75.00	80.00	70.00
30	125.00	115.00	95.00	125.00	145.00	155.00	160.00	125.00	145.00	160.00	142.50
31	55.00	50.00	75.00	15.00	65.00	60.00	70.00	65.00	70.00	75.00	70.00
32	155.00	155.00	205.00	210.00	230.00	190.00	195.00	135.00	165.00	205.00	200.00
33	185.00	175.00	150.00	115.00	200.00	200.00	210.00	180.00	230.00	205.00	200.00
34	80.00	85.00	110.00	190.00	150.00	105.00	115.00	85.00	85.00	215.00	187.50
35	1070.00	980.00	1220.00	1120.00	1250.00	1050.00	1110.00	995.00	965.00	1615.00	1300.00
36	50.00	50.00	35.00	40.00	55.00	50.00	65.00	50.00	60.00	55.00	65.00
37	60.00	65.00	30.00	20.00	65.00	65.00	65.00	65.00	75.00	70.00	65.00
38	15.00	20.00	15.00	20.00	25.00	20.00	25.00	20.00	25.00	25.00	17.50
39	25.00	30.00	20.00	15.00	25.00	25.00	30.00	35.00	35.00	30.00	25.00

Table 40 Contd......

Soil sample No.	0.1M NH$_4$F + 0.001M DTPA	0.1M NH$_4$F + 0.003M DTPA	0.3M NH$_4$F + 0.001M DTPA	0.5M NH$_4$F + 0.005M DTPA	0.06M H$_2$SO$_4$ + 0.06M HCl + 0.05N oxalic acid	0.03M NH$_4$F + 0.025M HCl + (Bray No.1)	0.03M NH$_4$F + 0.025M HCl + 0.005M DTPA	0.05M NH$_4$F + 0.05M acetic acid	0.5M NaHCO$_3$ pH 8.5 (Olsen)	N neutral NH$_4$OAc	N neutral NH$_4$OAc (std)
40	80.00	80.00	50.00	30.00	110.00	100.00	110.00	90.00	105.00	120.00	120.00
41	45.00	45.00	20.00	20.00	40.00	35.00	210.00	40.00	45.00	35.00	35.00
42	115.00	110.00	150.00	125.00	130.00	125.00	120.00	115.00	120.00	150.00	13.50
43	30.00	35.00	20.00	15.00	20.00	20.00	25.00	40.00	25.00	15.00	12.50
44	100.00	105.00	165.00	80.00	125.00	130.00	125.00	110.00	125.00	130.00	12.50
45	25.00	30.00	65.00	10.00	25.00	15.00	20.00	35.00	25.00	15.00	15.00
46	35.00	40.00	25.00	15.00	25.00	20.00	30.00	30.00	25.00	20.00	15.00
47	40.00	45.00	25.00	15.00	35.00	35.00	40.00	40.00	70.00	30.00	27.50
48	5.00	15.00	10.00	0.00	10.00	25.00	10.00	25.00	5.00	45.00	17.50
49	15.00	10.00	15.00	0.00	10.00	30.00	40.00	30.00	0.00	30.00	20.00
50	100.00	105.00	55.00	35.00	140.00	135.00	280.00	110.00	145.00	150.00	147.50
51	25.00	25.00	15.00	20.00	30.00	30.00	35.00	30.00	35.00	35.00	30.00
52	60.00	60.00	55.00	20.00	60.00	60.00	65.00	65.00	75.00	65.00	62.50

Table 40 Contd......

Soil sample No.	0.1M NH_4F + 0.001M DTPA	0.1M NH_4F + 0.003M DTPA	0.3M NH_4F + 0.001M DTPA	0.5M NH_4F + 0.005M DTPA	0.06N H_2SO_4 + 0.06N HCl + 0.05N oxalic acid	0.03M NH_4F + 0.025M HCl + (Bray No.1)	0.03M NH_4F + 0.025M HCl + 0.005M DTPA	0.05M NH_4F + 0.05M acetic acid	0.5M $NaHCO_3$ pH 8.5 (Olsen)	N neutral NH_4OAc	N neutral NH_4OAc (std)
53	45.00	40.00	25.00	40.00	40.00	45.00	320.00	100.00	55.00	60.00	40.00
54	55.00	50.00	70.00	55.00	70.00	80.00	75.00	55.00	55.00	85.00	82.50
55	160.00	150.00	195.00	60.00	160.00	170.00	160.00	155.00	145.00	200.00	250.00
56	25.00	20.00	35.00	40.00	20.00	20.00	20.00	20.00	25.00	20.00	20.00
57	45.00	40.00	45.00	60.00	50.00	50.00	50.00	40.00	50.00	100.00	55.00
58	55.00	55.00	90.00	45.00	75.00	70.00	75.00	60.00	85.00	90.00	82.50
59	45.00	45.00	45.00	50.00	45.00	45.00	55.00	40.00	45.00	40.00	35.00
60	165.00	155.00	135.00	85.00	205.00	180.00	185.00	180.00	165.00	250.00	210.00
61	110.00	35.00	20.00	20.00	40.00	40.00	45.00	40.00	55.00	40.00	175.00
62	20.00	20.00	5.00	15.00	25.00	20.00	25.00	20.00	25.00	25.00	20.00
63	120.00	120.00	100.00	85.00	130.00	130.00	140.00	135.00	135.00	150.00	145.00
64	25.00	25.00	55.00	25.00	30.00	30.00	30.00	35.00	30.00	35.00	30.00
65	355.00	340.00	55.00	45.00	375.00	390.00	310.00	360.00	415.00	380.00	385.00

Table 40 Contd.....

Soil sample No.	0.1M NH_4F + 0.001M DTPA	0.1M NH_4F + 0.003M DTPA	0.3M NH_4F + 0.001M DTPA	0.5M NH_4F + 0.005M DTPA	0.06N H_2SO_4 + 0.06N HCl + 0.05N oxalic acid	0.03M NH_4F + 0.025N HCl + (Bray No.1)	0.05M NH_4F + 0.025N HCl + 0.005M DTPA	0.05M NH_4F + 0.05M acetic acid	0.5M $NaHCO_3$ pH 8.5 (Olsen)	N neutral NH_4OAc	N neutral NH_4OAc (std)
66	135.00	120.00	40.00	50.00	190.00	185.00	180.00	155.00	170.00	190.00	185.00
67	135.00	135.00	45.00	35.00	180.00	180.00	175.00	150.00	175.00	180.00	165.00
68	65.00	70.00	55.00	75.00	120.00	90.00	100.00	75.00	95.00	105.00	90.00
69	60.00	65.00	35.00	25.00	60.00	65.00	65.00	60.00	55.00	90.00	42.50
70	100.00	115.00	145.00	60.00	230.00	95.00	110.00	135.00	100.00	190.00	110.00
71	205.00	200.00	225.00	60.00	235.00	205.00	220.00	205.00	215.00	260.00	232.50
72	105.00	100.00	135.00	15.00	130.00	120.00	140.00	120.00	130.00	155.00	130.00
73	65.00	70.00	20.00	65.00	85.00	75.00	75.00	70.00	80.00	55.00	50.00
74	25.00	30.00	15.00	30.00	25.00	20.00	35.00	30.00	25.00	20.00	25.00
75	95.00	100.00	125.00	35.00	130.00	115.00	115.00	110.00	145.00	150.00	120.00
76	55.00	55.00	80.00	10.00	30.00	40.00	35.00	40.00	45.00	30.00	20.00
77	25.00	30.00	15.00	15.00	25.00	20.00	35.00	25.00	35.00	30.00	10.00
78	95.00	105.00	140.00	120.00	170.00	105.00	100.00	90.00	105.00	80.00	60.00

Table 40 Contd.....

Soil sample No.	0.1M NH_4F + 0.001M DTPA	0.1M NH_4F + 0.003M DTPA	0.3M NH_4F + 0.001M DTPA	0.5M NH_4F + 0.005M DTPA	0.06M H_2SO_4 + 0.06M HCl + 0.05M oxalic acid	0.03M NH_4F + 0.025M HCl + (Bray No.1)	0.05M NH_4F + 0.025M HCl + 0.005M DTPA	0.05M NH_4F + 0.05M acetic acid	0.5M $NaHCO_3$ pH 8.5 (Olsen)	N neutral NH_4OAc	N neutral NH_4OAc (std)
79	55.00	60.00	65.00	15.00	65.00	55.00	60.00	55.00	250.00	75.00	52.50
80	40.00	45.00	65.00	20.00	75.00	55.00	70.00	60.00	55.00	65.00	45.00
81	125.00	110.00	155.00	20.00	205.00	150.00	165.00	145.00	150.00	195.00	170.00
82	45.00	50.00	10.00	15.00	50.00	50.00	60.00	60.00	45.00	35.00	20.00
83	25.00	25.00	15.00	10.00	20.00	20.00	20.00	25.00	25.00	25.00	10.00
84	25.00	30.00	50.00	25.00	25.00	20.00	25.00	20.00	140.00	40.00	25.00
85	260.00	265.00	160.00	170.00	420.00	370.00	360.00	295.00	330.00	330.00	340.00
86	15.00	15.00	25.00	10.00	15.00	15.00	25.00	15.00	20.00	20.00	25.00
87	15.00	15.00	5.00	10.00	15.00	40.00	20.00	15.00	20.00	15.00	15.00
Mean	88.1	88.4	83.6	62.0	110.7	101.4	111.0	94.1	100.8	119.1	107.4

When the individual soils were considered separately NH_4OAc using 1:10 soil solution ratio and 30 min equilibration period could release the maximum quantity of K from soil No.35 (1615 ppm). The same soil gave the maximum quantity of K with standard NH_4OAc procedure but the value was only 1300 ppm. Mathew's triacid extractant also could release sufficient quantity of K into the solution (1250 ppm). Olsen's extractant was the least efficient in this respect (965 ppm). In soils of low K status eg., soil No.23 (5 ppm available NH_4OAc K), Bray No.1 + 0.005 M DTPA could release much higher quantity of K (135 ppm).

Coefficients of correlation worked out between the amount of nutrients extracted by the various extractants and that by the standard extractants are given in Table 41. Coefficients of correlation between the P extracted by the different extractants and the available P extracted by Bray No.1 were examined. The correlation coefficients were significant with all the extractants. The highest correlation was obtained with 0.5 M NH_4F + 0.005 M DTPA combination ($0.929\overset{**}{4}$) and the lowest value was given by 0.1 M NH_4F + 0.003 M DTPA ($0.40\overset{**}{8}5$). This may be due to insufficient concentration of NH_4F when combined with high concentration of DTPA. The second high correlation was obtained with 0.05 M NH_4F + 0.05 M acetic acid ($0.91\overset{**}{6}8$). The correlation coefficients with Bray No.1 established by the various extractants were in the following orders: 0.5 M NH_4F + 0.005 M DTPA ($0.92\overset{**}{9}4$) > 0.05 M NH_4F + 0.05 M acetic acid

Table 41

Coefficients of correlation (r) between the P and K extracted by the selected extractants and the P and K extracted by the standard P and K extractants

Sl. No.	Name of extractant	P (Bray No.1)	K N neutral NH_4OAc (Standard procedure)
1	0.1 M NH_4F + 0.001 M DTPA	0.8046**	0.4009**
2	0.1 M NH_4F + 0.003 M DTPA	0.4085**	0.0817
3	0.3 M NH_4F + 0.001 M DTPA	0.8868**	0.0788
4	0.5 M NH_4F + 0.005 M DTPA	0.9294**	-0.0171
5	0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid	0.8913**	0.6436**
6	0.03 N NH_4F + 0.025 N HCl (Bray No.1)	1.0000**	0.1549
7	0.03 M NH_4F + 0.025 N HCl + 0.005 M DTPA	0.8887**	0.0668
8	0.05 M NH_4F + 0.05 M acetic acid	0.9168**	-0.0080
9	0.5 M $NaHCO_3$, pH 8.5 (Olsen)	0.8977**	0.2503*
10	N neutral NH_4OAc (modified)	0.9014**	-0.0153

* Significant at 5 per cent level.

** Significant at 1 per cent level

(0.9168**) > NH_4OAc (0.9014**) > Olsen (0.8977**) > Mathew's triacid (0.8913**) > Bray No.1 + 0.005 M DTPA (0.8887**) > 0.3 M NH_4F + 0.001 M DTPA (0.8868**) > 0.1 M NH_4F + 0.001 M DTPA (0.8046**) > 0.1 M NH_4F + 0.003 M DTPA (0.4085**). The neutral normal NH_4OAc at an equilibration period of 30 min with a soil solution ratio of 1:10 could not extract P from all the soils. It was ineffective in predicting P availability in soils of marginal to low available P status. Not all the extractants could produce significant positive correlation between the amount of K extracted by the extractants and the amount of K extracted by NH_4OAc. Negative correlations were obtained with 0.5 M NH_4F + 0.005 M DTPA and 0.05 M NH_4F + 0.05 M acetic acid. The extractants namely 0.1 M NH_4F + 0.003 M DTPA, 0.3 M NH_4F + 0.001 M DTPA, Bray No.1 + 0.005 M DTPA and Bray No.1 were positively correlated, but the correlation coefficients were statistically significant only with three extractants viz., 0.1 M NH_4F + 0.001 M DTPA, Mathew's triacid and Olsen's extractant. Highest correlation was obtained with Mathew's triacid (0.6436**), followed by 0.1 M NH_4F + 0.001 M DTPA (0.4009**) and Olsen's extractant (0.2503*)

The efficiency of extractants to extract both P and K simultaneously, when studied, found that Mathew's triacid gave better correlations with Bray No.1 P and NH_4OAc K. The relationships between the amounts of nutrients (P and K) extracted by the extractants viz., 0.1 M NH_4F + 0.001 M DTPA and Mathew's triacid and that by the standard extractants are presented in Fig Nos. 3, 4, 5 and 6. As regards the speed of extraction, 0.1 M NH_4F + 0.001 M DTPA would be more convenient for advisory works since it takes only 5 min

FIG:3 RELATIONSHIP BETWEEN P EXTRACTED BY 0.1 M NH_4F + 0.001 M DTPA AND BRAY No. 1

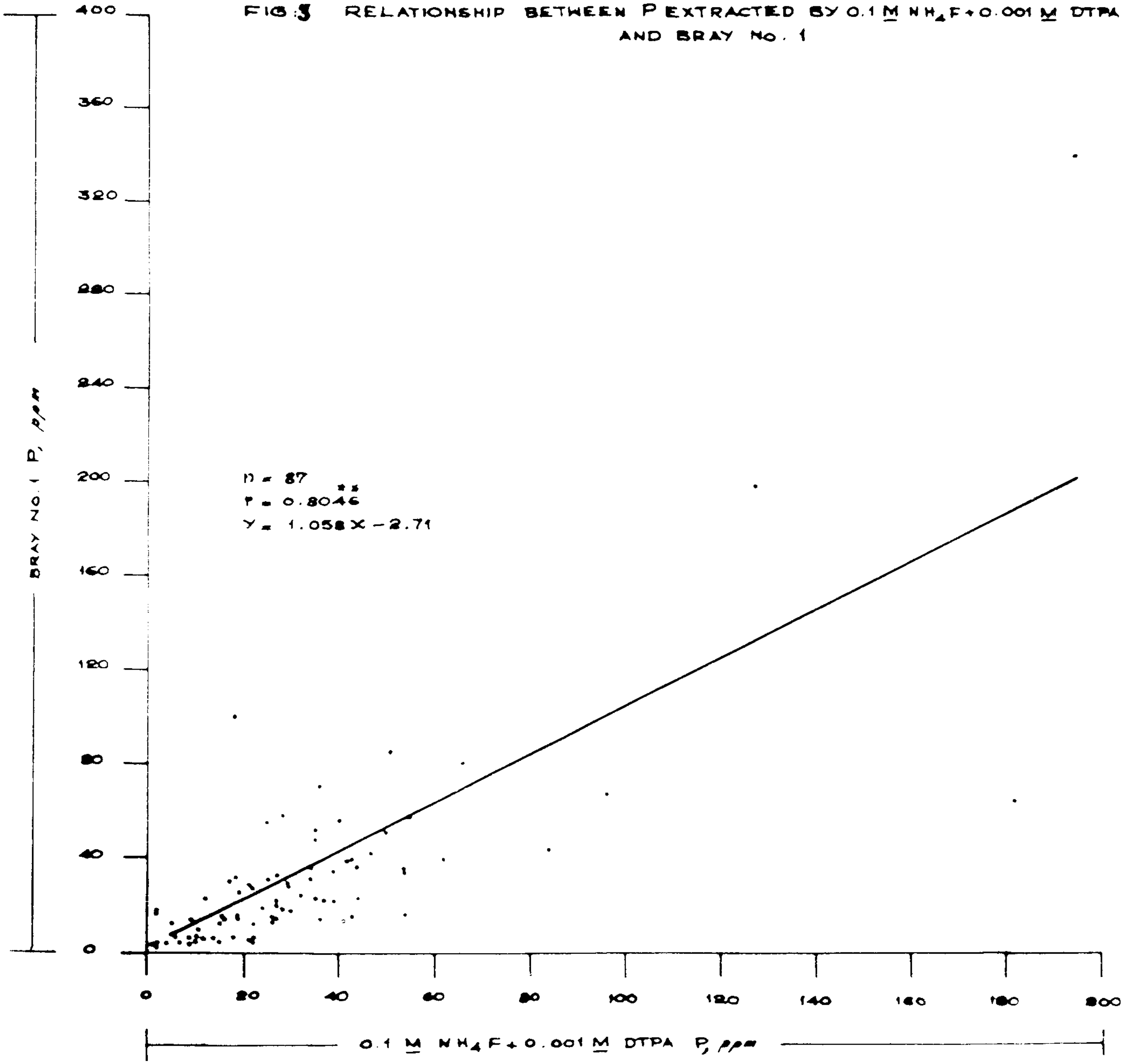
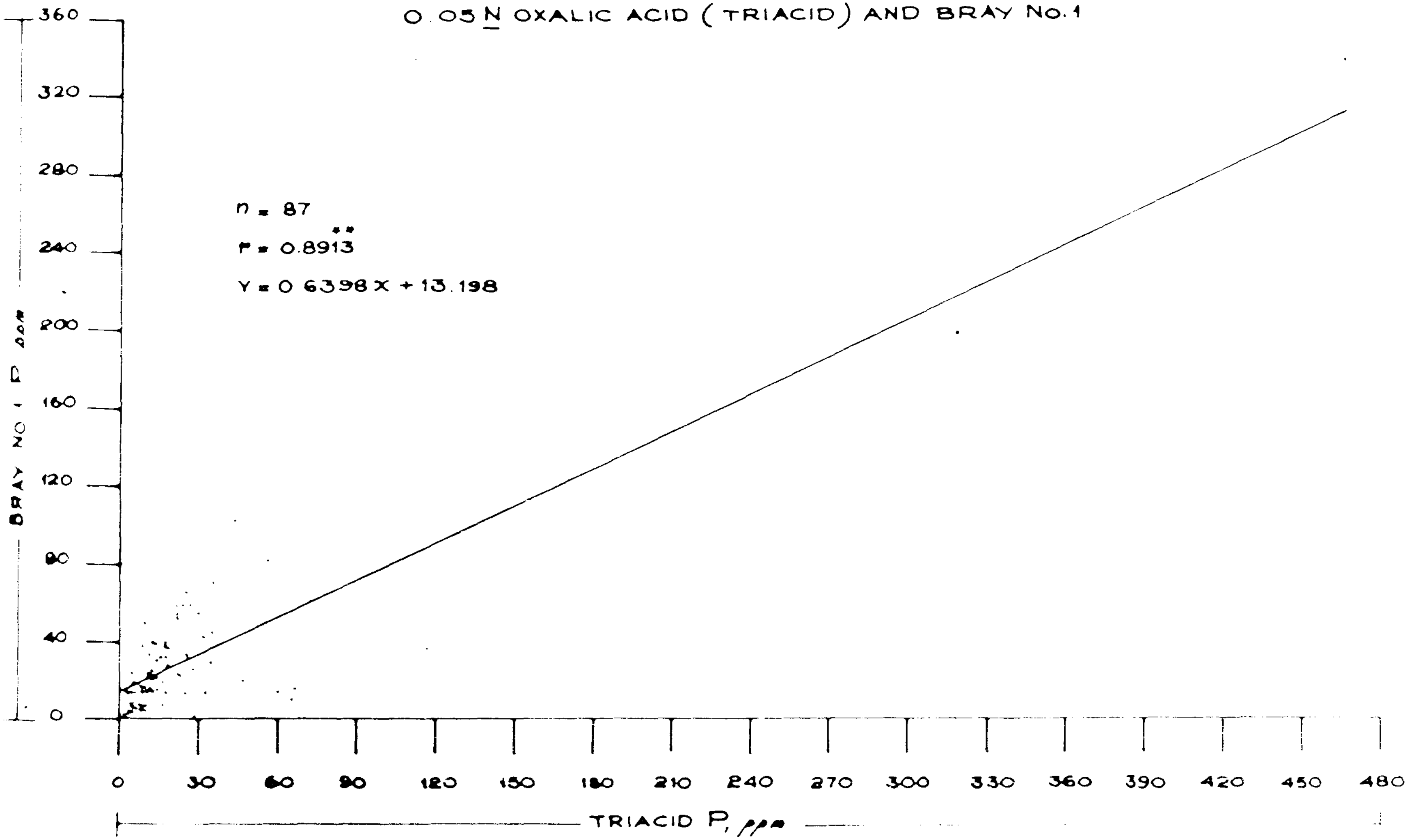


FIG 4 RELATIONSHIP BETWEEN P EXTRACTED BY 0.06 $\underline{N}$ H_2SO_4 + 0.06 $\underline{N}$ HCl + 0.05 $\underline{N}$ OXALIC ACID (TRIACID) AND BRAY No. 1



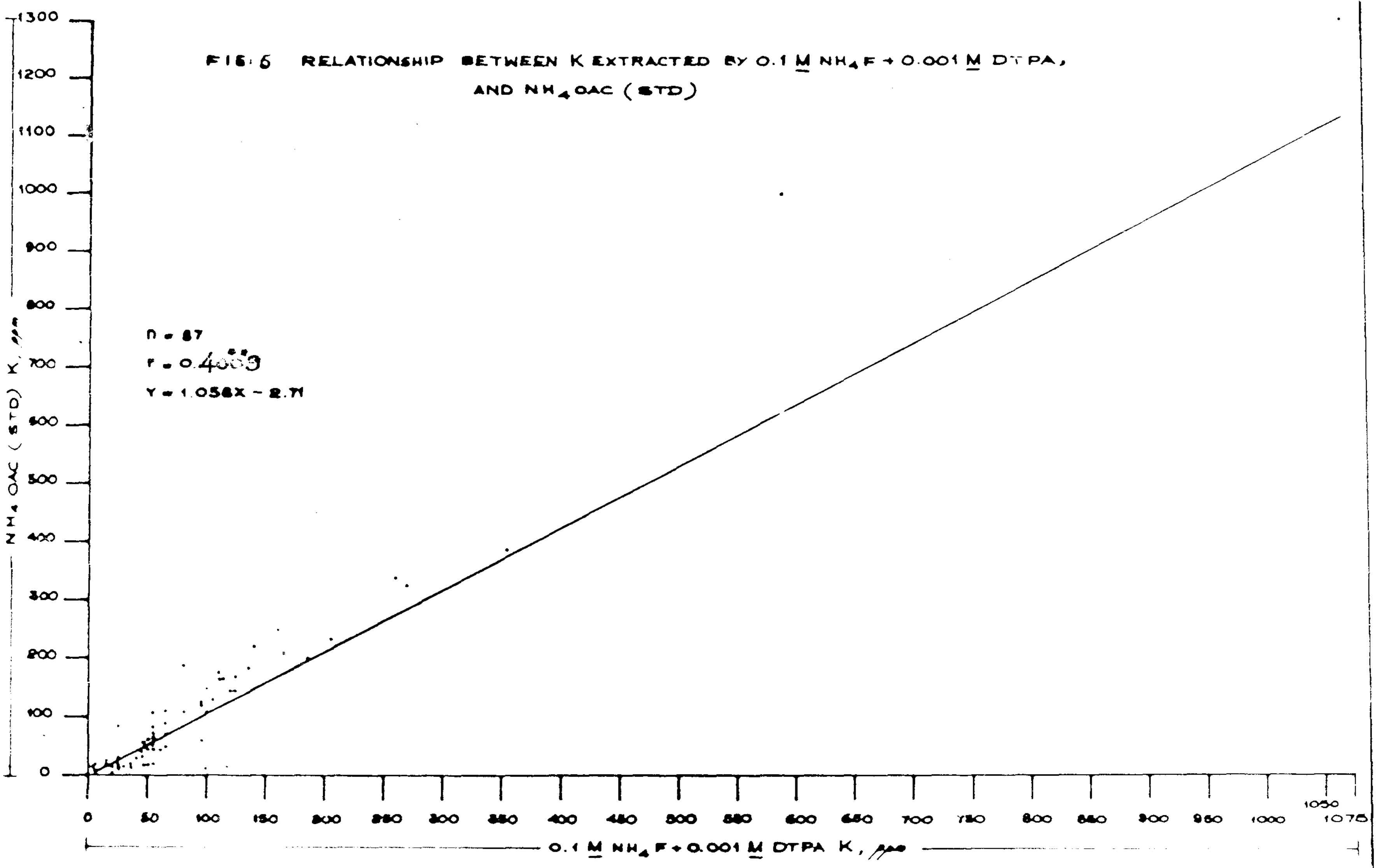
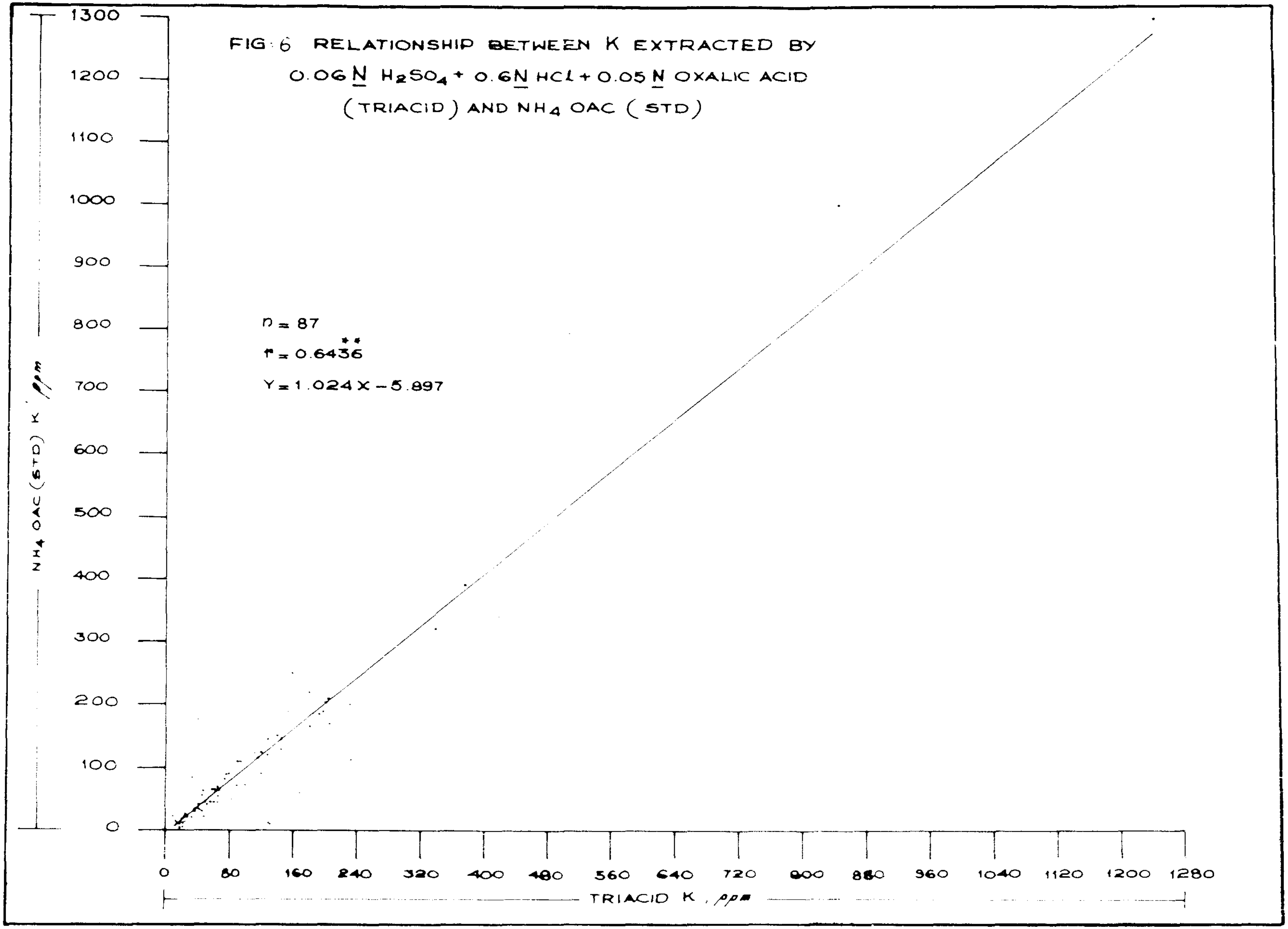


FIG. 6 RELATIONSHIP BETWEEN K EXTRACTED BY 0.1 M NH_4F + 0.001 M DTPA, AND NH_4OAC (STD)

FIG 6 RELATIONSHIP BETWEEN K EXTRACTED BY 0.06 $\underline{N}$ H_2SO_4 + 0.6 $\underline{N}$ HCl + 0.05 $\underline{N}$ OXALIC ACID (TRIACID) AND NH_4 OAC (STD)



n = 87

r = 0.6436**

Y = 1.024 X − 5.897

to attain equilibrium P and K values. But, it was observed that this extractant could not give clear filtrates in all the soils. Considerable amount of organic matter was brought into solution by this extractant along with the extraction of phosphorus and potassium. Since phosphorus is usually estimated by the chlorostannous reduced blue colour method, organic matter will interfere with the blue colour development. When Olsen's extractant is used, shaking with activated charcoal has been established as a standard procedure. In the NH_4F-DTPA combination also activated charcoal will be essential to eliminate the organic matter extraction.

In soils containing relatively small amounts of P, the amounts of P extracted by a chemical extractant will be so small that the error involved in the analytical procedure is relatively high. It has been reported by several workers that activated charcoal would not adsorb reasonable amount of the nutrient ions. But still some error may be expected.

Mathew's triacid, though produced a slight yellow colour in the filtrate it did not interfere with blue colour method of estimation of available P. As reported by Mathew (1979), the triacid proposed by him would be a definite improvement over Bray No.1 for predicting available phosphate reserve of soil. In the present study, it has shown a high degree of efficiency in extracting P as well as K. Since his extractant was studied on 87 soils of different soil properties it can be selected for extracting both P and K availability in different soil types of the State.

4. Inter-relationship between soil properties

The efficiency of an extractant in releasing nutrients from the soil into the solution depends not only on the capacity factor but also on many other factors that are influenced by physical and chemical characteristics of soils. The physico chemical characteristics that influence the release of P and K into the soil solution are moisture, texture, organic carbon, pH, EC, CEC and P fixing capacity.

Coefficients of correlation were worked out between the basic soil properties such as total P, P fixing capacity, Bray No.1 P, Mathew's triacid P, total K, NH_4OAc (std) K, Mathew's triacid K, pH, EC, CEC, organic carbon and moisture percentage. In Table 42, coefficients of correlation (r) between soil properties are presented.

Mathew's triacid P as well as K, total K, Bray No.1 P and NH_4OAc K exhibited significant positive correlations with total P. Significant positive correlations were established between total K and other properties except P fixing capacity, organic carbon, pH and EC. Highest correlations (0.6051^{**}) was obtained with moisture content followed by total P (0.5884^{**}) With P fixing capacity Bray No.1 (-0.2581^{*}) as well as Mathew's triacid P (-0.2927^{**}) had shown significant negative correlations. Total K, Mathew's triacid K, pH, EC and moisture were also negatively correlated with P fixing capacity. CEC was highly correlated with moisture, total K, NH_4OAc (std) K, as well as Mathew's triacid K. Highest correlation (0.5168^{**}) was obtained

Table 42

Coefficients of correlation (r) between basic soil properties

Total P	P fixing capacity	Bray No.1 P	0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid P	Total K	NH_4OAc (std) K	0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid K	pH	EC	CEC	Organic carbon	Moisture
1.0000**	-0.0903	0.5834**	0.5728**	0.5884**	0.4532**	0.4834**	0.1635	0.1034	0.1418	0.1155	0.1131
	1.0000**	-0.2581*	-0.2927**	-0.0649	0.2596*	-0.2612*	-0.3157**	-0.0844	0.1464	0.0310	-0.0636
		1.0000**	0.8913**	0.2593*	0.6377**	0.6700**	0.4432**	0.1744	-0.0518	0.0497	0.1353
			1.0000**	0.3567**	0.6177**	0.6409**	0.3512**	0.1054	0.0145	-0.0428	-0.0348
				1.0000**	0.4955**	0.4780**	0.1486	0.0467	0.5168**	0.1928	0.6051**
					1.0000**	0.6436**	0.3664**	0.2920**	0.3645**	0.1812	0.2297*
						1.0000**	0.3926**	0.3049**	0.3128**	0.1890	0.1880
							1.0000**	0.1997	0.1283	-0.0308	-0.0031
								1.0000**	0.1417	0.0217	0.0707
									1.0000**	0.1509	0.4508**
										1.0000**	0.2598*
											1.0000**

* Significant at 5 per cent level

** Significant at 1 per cent level

with total K. Soils having high CEC would have high total K reserve since large amount of K is fixed by high CEC soils.

6. Improvement made by the new extractant over the existing procedures

It was obvious that there existed a high degree of correlation between the new method and the standard methods of extraction. The high correlation and reproducibility are most appreciated when considering the practical aspects of the soil test. By using a single common extractant for extracting both available P and K, substantial savings in time and materials are now possible especially for advisory works. Another advantage in using this extractant is its higher efficiency in grading the P and K status of soils of low to marginal levels of these nutrients.

SUMMARY

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At present Bray No.1 extractant is used for the extraction of available P and neutral normal ammonium acetate for the extraction of available K in soil in the soil testing laboratories of Kerala. The extraction procedure can be simplified and the need for time, manpower and chemicals can be reduced considerably if a single extractant suitable for extracting both available P and available K is found out. Laboratory evaluation and plant uptake studies were carried out for evolving an extractant suitable for extracting both available P and available K.

Soil samples (87 numbers) of varying characteristics were collected from different parts of the State and the study was conducted in three phases viz.,

(i) an initial study which was conducted mainly to fix up an approximate range in concentration of the reagents. In this initial study 18 extractants were tried, of which 9 were NH_4F - DTPA combinations. The available P extracted by Bray No.1 and available K extracted by neutral normal ammonium acetate were found out and they were compared with that of the different extractants. A single soil solution ratio of 1:10 and two equilibration periods of 30 and 60 min were employed in the initial study using a single soil;

(ii) a preliminary screening consisting of 9 soils, 15 extractants at 5 equilibration periods viz., 5, 10, 15, 30 and

60 min with a single soil solution ratio of 1:10. Neubauer seedling technique was used to find out the uptake of P and K by rice crop from the soils. Correlation coefficients were worked out between the amount of P and K extracted by the various extractants and the P and K uptake by rice based on which extractants with suitable equilibration periods were selected; and

(iii) a final selection of the common extractant which was based on the correlation between the amount of P and K extracted by the various extractants and the amount of P and K extracted by the presently followed standard procedures viz., Bray No.1 for P and neutral normal ammonium acetate for K. Eighty-seven soils, 10 extractants with suitable equilibration periods and a 1:10 soil solution ratio were used in the final selection. The results of the study are summarised as follows:

In NH_4F - DTPA combinations, increasing concentration of NH_4F retarded the extraction of phosphorus as well as potassium and they extracted much smaller quantities of P and K as compared to that of Bray No.1 and neutral normal ammonium acetate.

Maximum release of P and K was obtained by 0.001 M DTPA. A higher amount of P was extracted when the equilibration period was increased to 60 min while the concentration of DTPA was increased to 0.005 M.

Increasing equilibration period had considerable effects in the extraction of P by Bray No.1. The efficiency of extraction decreased when the period of equilibration was increased from 30 to 60 min, possibly due to the absence of a chelating agent in order to prevent resorption. The amount of K extracted by Bray No.1 was higher than that of neutral normal ammonium acetate (std).

Use of ammonium acetate along with Bray No.1 inhibited the release of P drastically, though no effect was noticed on K extraction.

Mathew's triacid extractant viz., 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid released large amount of P and K.

The NH_4F + acetic acid was found to be a good combination in estimating available P and available K. NH_4F (0.05 M) + acetic acid (0.05 M) extracted more quantity of P even at 60 min than Bray No.1 showing the chelating action of acetic acid.

The amount of K extracted by neutral normal NH_4OAc was higher when the soil solution ratio was 1:10 as compared to 1:5 (std)

The pattern of P and K release into the solution when examined together as a function of period of equilibration revealed that the rate of release was varying at different equilibration periods for different extractants. NH_4F + DTPA combinations viz., 0.1 M + 0.005 M, 0.3 M + 0.003 M, 0.3 M + 0.005 M, 0.5 M + 0.001 M, 0.5 M + 0.003 M were not suitable as ~~a~~ common extractants for the estimation of available phosphorus and potassium in soil. The combination of NH_4F + DTPA at the strength 0.1 M + 0.001 M, 0.1 M + 0.003 M, 0.3 M + 0.001 M and 0.5 M + 0.005 M were effective as common extractants for P and K.

The suitable equilibration periods for 0.1 M NH_4F + 0.001 M DTPA, 0.1 M NH_4F + 0.003 M DTPA, 0.5 M NH_4F + 0.005 M DTPA, 0.05 M NH_4F + 0.05 M acetic acid and Bray No.1 is 5 min. For 0.3 M NH_4F + 0.001 M DTPA combination and Bray No.1 + 0.005 M DTPA an equilibration period of 10 min is found to be the best. An equilibration period of 30 min is applicable to Mathew's triacid extractant, Olsen's extractant and neutral normal ammonium acetate.

The coefficients of correlation worked out between the amount of nutrients extracted by the extractants and nutrient uptake by rice were highly significant at all the equilibration periods, most of them being on par. Thus it was very difficult to select an extractant based simply on the correlation between the nutrients extracted by the extractants and nutrient uptake by rice. Since the initial and preliminary studies conducted have established the suitability of Bray No.1 for available P and the neutral normal NH_4OAc for available K, the final selection of a common extractant with 87 soils was oriented towards the highest correlation of the P and K values of the selected extractants with that of Bray No.1 P and neutral normal

NH_4OAc extractable K, since these two extractants are already being used in soil testing laboratories of the State based on which soil fertility maps are being prepared.

When all the soils were considered together, the various extractants showed the following decreasing order in their efficiency for extracting P. 0.1 M NH_4F + 0.003 M DTPA (88.21 ppm) > 0.3 M NH_4F + 0.001 M DTPA (43.43 ppm) > 0.1 M NH_4F + 0.001 M DTPA (31.56 ppm) > 0.5 M NH_4F + 0.005 M DTPA (31.45 ppm) > Bray No.1 (30.67 ppm) > 0.05 M NH_4F + 0.05 M acetic acid (28.56 ppm) > Mathew's triacid extractant (27.31 ppm) > Bray No.1 + 0.005 M DTPA (22.67 ppm) > Olsen's extractant (19.75 ppm) > neutral normal NH_4OAc (7.16 ppm).

The different extractants extracted K in the following decreasing order. NH_4OAc (119.1 ppm) > Bray No.1 + 0.005 M DTPA (111.0 ppm) > Mathew's triacid extractant (110.7 ppm) > NH_4OAc std (107.4 ppm) > Bray No.1 (101.4 ppm) > Olsen's extractant (100.8 ppm) > 0.05 M NH_4F + 0.05 M acetic acid (94.1 ppm) > 0.1 M NH_4F + 0.003 M DTPA (88.4 ppm) > 0.1 M NH_4F + 0.001 M DTPA (88.1 ppm) > 0.3 M NH_4F + 0.001 M DTPA (83.6 ppm) > 0.5 M NH_4F + 0.005 M DTPA (62.0 ppm).

Mathew's triacid extractant could release relatively large amounts of P from soils containing very little as well as very large amounts of P.

When the individual soils were considered separately neutral normal NH_4OAc using 1:10 soil solution ratio and 30 min equilibration period could release maximum quantity of K from the soils of maximum available K status.

The correlation coefficients with Bray No.1 P extracted by the various extractants were in the following order 0.5 M NH_4F + 0.005 M DTPA (0.9294^{**}) > 0.05 M NH_4F + 0.05 M acetic acid (0.9168^{**}) > NH_4OAc (0.9014^{**}) > Olsen (0.8977^{**}) > Mathew's triacid (0.8913^{**}) > Bray No.1 + 0.005 M DTPA (0.8887^{**}) > 0.3 M NH_4F + 0.001 M DTPA (0.8868^{**}) > 0.1 M NH_4F + 0.001 M DTPA (0.8046^{**}) > 0.1 M NH_4F + 0.003 M DTPA (0.4085^{*})

With NH_4OAc (std) K the correlation coefficients established by the various extractants were in the following decreasing order. Mathew's triacid (0.6436^{**}) > 0.1 M NH_4F + 0.001 M DTPA (0.4009^{**}) > Olsen (0.2503^{*}) > Bray No.1 (0.1549) > 0.1 M NH_4F + 0.003 M DTPA (0.0817) > 0.3 M NH_4F + 0.001 M DTPA (0.0788) > Bray No.1 + 0.005 M DTPA (0.0668) > 0.05 M NH_4F + 0.05 M acetic acid (0.0080) > NH_4OAc (-0.0153) > 0.5 M NH_4F + 0.005 M DTPA (-0.0171). Not all the extractants could produce significant positive correlation with NH_4OAc (std) K. Only three extractants viz., Mathew's triacid, 0.1 M NH_4F + 0.001 M DTPA and Olsen's extractant gave significant positive correlation with NH_4OAc (std) K.

The efficiencies of the extractants to extract both P and K simultaneously when studied, found that Mathew's triacid extractant gave better correlations with Bray No.1 P and NH_4OAc (std) K. As regards speed of extraction 0.1 M NH_4F + 0.001 M DTPA would be more convenient for advisory works, since it takes only 5 min to attain equilibrium P and K values. But considerable amount of organic matter brought into the solution by this extractant interferes with the colorimetric determination of P.

Coefficients of correlation were worked out between the basic soil properties such as total P, P fixing capacity, Bray No.1 P, Mathew's triacid P, total K, NH_4OAc (std) K, Mathew's triacid K, pH, EC, CEC, organic carbon and moisture. Mathew's triacid P and K, total K, Bray No.1 P, and NH_4OAc (std) K exhibited significant positive correlations with total P. Significant positive correlations were established between total K and other properties such as total P, available P, available K, CEC and moisture. P fixing capacity was negatively correlated with Bray No.1 P, Mathew's triacid P, and pH. CEC was significantly and positively correlated with total K, moisture, NH_4OAc (std) K, and Mathew's triacid K.

The new procedure (Mathew's triacid extractant) is found to be a definite improvement over the standard procedures. By using a single extracting solution for extracting both available P and available K substantial savings in time and materials are now possible especially for advisory works. The new extractant had shown a higher efficiency in extracting both P and K from the soils containing even low to marginal levels of these nutrients. The new method can be recommended for different soils of the State, since this extractant has performed well in all the 87 different soils collected from Kerala State.

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APPENDICES

APPENDIX I. Location of soils selected for the study

District	Soil No.	Location
Cannanore	1	Nileswar
	2	Tellicherry
	3	Cannanore
	4	Cannanore
	5	Cannanore
Calicut	6	Quilandy
	7	Calicut
	8	Calicut
	9	Mahe
	10	Calicut
	11	Calicut
	12	West Hill
	13	Aliyur
	14	Badagara
	15	Mukkam
	16	Badagara
	17	Elathur
	18	Kuttichera
	19	Payyannur
	20	Calicut
	21	West Nadakkavu
Malappuram	22	Edapal
	23	Ponnam

APPENDIX I Contd.....

District	Soil No.	Location
	24	Perinthalmanna
	25	Trichur
	26	Vattalur
Palghat	27	Karuvappara
	28	Chittoor
	29	Chelakkara
	30	Vadakkanthera
	31	Karuvappara
	32	Koduvayur
	33	Vilayanur
	34	Upputhode
	35	Kalpathy
	36	Kottakkad
Trichur	37	Cherpu
	38	Trichur
	39	Kunnamkulam
	40	Kodungallur
	41	Trichur
	42	Chowannur
	43	Edathuruthy
	44	Vadakkanchery
	45	Kunnamkulam
	46	Kodungallur
	47	Kodungallur
	48	Kottappady

APPENDIX I Contd.....

District	Soil No.	Location
	49	Vadakkanchery
	50	Perumbillissery
	51	Karakkad
	52	Arimbur
	53	Kandassankadavu
	54	Anthikkad
	55	Mannuthy
Ernakulam	56	Ernakulam
	57	Ayroor
	58	Alwaye
	59	Ernakulam
	60	Kalady
	61	Kalady
	62	Ernakulam
	63	Kalady
	64	Alwaye
	65	Ernakulam
	66	Perumbavoor
	67	Cochin
	68	Parur
	69	Cochin
Idukki	70	Thodupuzha
	71	Idukki
	72	Thodupuzha

APPENDIX I Contd....

District	Soil No.	Location
Alleppey	73	Alleppey
	74	Churgam
	75	Alleppey
	76	Thuravoor
Quilon	77	Mavelikkara
	78	Neerattupuram
Kottayam	79	Amalagiri
	80	Manimala
	81	Palai
	82	Mundalmood
Trivandrum	83	Trivandrum
	84	Vellayani
	85	Neyyattinkara
	86	Trivandrum
	87	Trivandrum

APPENDIX II Mean percentage and uptake of P and K of rice grown in the soils

Sl.No.	Soil sample No	Mean Percentage of P	Mean uptake of P, g/pot	Mean Percentage of K	Mean uptake of K, g/pot
1	49	0.34	0.28	0.25	0.21
2	48	1.19	0.19	0.36	0.38
3	22	0.23	0.16	0.29	0.20
4	54	0.42	0.24	1.00	0.57
5	15	0.55	0.36	0.65	0.43
6	4	0.38	0.25	0.56	0.36
7	60	0.26	0.24	0.13	1.04
8	35	0.65	0.52	0.57	2.06
9	32	0.53	0.42	1.08	0.85

EVALUATION OF AVAILABLE PHOSPHORUS AND POTASSIUM IN SOIL USING A COMMON EXTRACTANT

By

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ABSTRACT OF A THESIS

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ABSTRACT

A laboratory evaluation and an uptake study using Neubauer seedling technique was carried out for evolving a single extractant suitable for extracting both available P and available K, so as to simplify the process of extracting these available plant nutrients in soil testing works.

Eighty seven soil samples from different parts of the State were used to evaluate the performance of the selected number of extractants based on a 3 step evaluation i.e., (i) an initial study consisting one soil, 18 extractants at a single soil solution ratio (1:10) and two equilibration periods (30 and 60 min); (ii) a preliminary screening consisting of 9 soils, 15 extractants at a single soil solution ratio (1:10) and 5 equilibration periods (5, 10, 15, 30 and 60 min). An uptake study was also conducted using Neubauer seedling technique and correlation coefficients were worked out between the amount of P extracted by the various extractants and the P and K uptake by rice; (iii) a final selection of the common extractant consisting of 10 extractants with suitable equilibration periods, at 1:10 soil solution ratio and 87 soils.

In combination of NH_4F and DTPA, increasing concentration of NH_4F retarded the extraction of both P and K and they extracted much smaller quantities of P and K as compared to that of Bray No.1 and neutral normal NH_4OAc.

Use of ammonium acetate along with Bray No.1 inhibited the release of P drastically.

Mathew's triacid extractant viz., 0.06 N H_2SO_4 + 0.06 N HCl + 0.05 N oxalic acid extracted relatively large amounts of P and K.

The pattern of P and K release when examined together as a function of period of equilibration found that the equilibration period for different extractants was varying. The suitable equilibration period for 0.1 M NH_4F + 0.001 M DTPA, 0.1 M NH_4F + 0.003 M DTPA, 0.5 M NH_4F + 0.005 M DTPA, 0.05 M NH_4F + 0.05 M acetic acid, and Bray No.1 is 5 min. For 0.3 M NH_4F + 0.001 M DTPA combination and Bray No.1 + 0.005 M DTPA an equilibration period of 10 min is found to be the optimum . An equilibration period of 30 min is suitable for Mathew's triacid extractant, Olsen's extractant and neutral normal ammonium acetate.

Since the initial and preliminary studies established the suitability of Bray No.1 for available P and the neutral normal ammonium acetate for available K and because the coefficient of correlation between the amount of K extracted by the extractants and the K uptake by rice were highly significant at all the equilibration periods the final selection of the common extractant was based on the correlation of the P and K values of the selected extractants with that of Bray No.1 P and neutral normal ammonium acetate extractable K.

The correlation coefficients with Bray No.1 P established by the various extractants have shown the following decreasing order of efficiency. 0.5 $\underline{M}$ NH_4F + 0.005 $\underline{M}$ DTPA > 0.05 $\underline{M}$ NH_4F + 0.05 $\underline{M}$ acetic acid > NH_4OAc > Olsen > Mathew's triacid > Bray No.1 + 0.005 $\underline{M}$ DTPA > 0.3 $\underline{M}$ NH_4F + 0.001 $\underline{M}$ DTPA > 0.1 $\underline{M}$ NH_4F + 0.001 $\underline{M}$ DTPA > 0.1 $\underline{M}$ NH_4F + 0.003 $\underline{M}$ DTPA.

All the extractants were not significantly and positively correlated with NH_4OAc (std) K. The three extractants viz., Mathew's triacid, 0.1 $\underline{M}$ NH_4F + 0.001 $\underline{M}$ DTPA and Olsen's extractant have given significant positive relationship with NH_4OAc (std) K. Highest correlation was obtained with Mathew's triacid followed by 0.1 $\underline{M}$ NH_4F + 0.001 $\underline{M}$ DTPA and Olsen's extractant.

Thus it is confirmed that Mathew's triacid extractant is the best common extractant for available P and available K. No analytical difficulty in the determination both P and K was observed while using this extractant.

Inter-correlations worked out between the various soil properties have cleared the following facts. Mathew's triacid P and Bray No.1 P were significantly and positively correlated with total P and negatively correlated with P fixing capacity. NH_4OAc (std) K and Mathew's triacid K have significant positive correlation with total K as well as CEC.

Mathew's triacid extractant viz., 0.06 $\underline{N}$ H_2SO_4 + 0.06 $\underline{N}$ HCl 0.05 $\underline{N}$ oxalic acid with a soil solution ratio of 1:10 and an equilibration period of 30 min is recommended as a common extractant for available P and available K by the present study, since it saves considerable time and materials in soil testing.