PHOSPHORUS TEST EVALUATIONS OF SUGARCANE SOILS IN TAIWAN

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ABSTRACT

PHOSPHORUS TEST EVALUATIONS OF
SUGARCANE SOILS IN TAIWAN

By

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A total of 64 sites covering six widely distributed major soil groups were selected for soil phosphorus (P) test evaluations as related to sugarcane production in Taiwan.

One 15-month sugarcane pot culture and two crop years of field experiments were conducted in 1970-1972 to determine the distribution pattern of the forms of phosphate in soil before and after cropping. The study was designed to evaluate the forms of phosphate removed from the soil by sugarcane; to measure the yield response of sugarcane to phosphate fertilizer; to determine a suitable extractant for P from sugarcane soils; and to discover optimum P recommendations for sugarcane grown on TSC's (Taiwan Sugar Corporation) plantations.

Al-P was the form removed by one sugarcane harvest in the lowest quantity and with the least variation irrespective of soil group. However, if the amount of Al-P removed by cropping was expressed on a % basis of the original level it became the highest and averaged 25.4% varying from a high of 37.9% in the AS_n soil group to a low of 20.0% in the AS_c soil group.

The sugarcane crop removed 20.4% of the Fe-P, 13.2% of the Ca-P and 13.5% of the Red-P.

Fe-P and Ca-P are the most common forms removed by sugar cane in acid soils and in calcareous soils, respectively if the amounts of these two forms used by crop are expressed as the % of total P removed.

Apparently, all four forms of P in the soil were available to sugarcane. The Al-P and Fe-P were the major sources of P utilized by sugarcane.

High correlation between soil P extracted with Bray's No.1 in a 1:50 soil: solution ratio and sugarcane yields were found on pot cultures and field experiments with a statistical significance at the 0.1% and 1% levels, respectively. Therefore it was recommended that Bray's No.1 extractant with a soil to solution ratio of 1:50 be used on the soils of TSC's plantations.

Of the total P added approximately one-third of the P in acid soils and one-quarter of the P in alkaline soils were rapidly adsorbed by the soil.

P recommendations for sugarcane production on TSC's plantations have been proposed on the basis of soil test methods and the natural moisture conditions of the soil.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Chemical soil testing has frequently been used for soil fertility evaluations for a long time. Great volumes of data on soil testing as related to fertilizer use have accumulated, particularly in the area of soil science.

Soil analysis methods developed more rapidly in the temperate climate zone than elsewhere. Good correlations with crop yields and with responses from fertilizer additions have been obtained particularly on acid soils.

In the tropics, however, soil testing has been only partially effective in defining the fertilizer needs of crops, especially sugarcane. There is one notable exception to this. In Hawaii, soil analysis has served for many years as a basis for P, K and lime recommendations for sugarcane. Soil testing has been tried in almost all parts of the world, but many sugarcane growing countries were not entirely satisfied with the results. They had little confidence in the fertilizer and lime recommendations that were made on the basis of soil testing.

Chao(1948) studied the soil P and K status of the Taiwan soils for sugarcane. After he left for the United States in 1954, soil testing studies were suspended for some time.

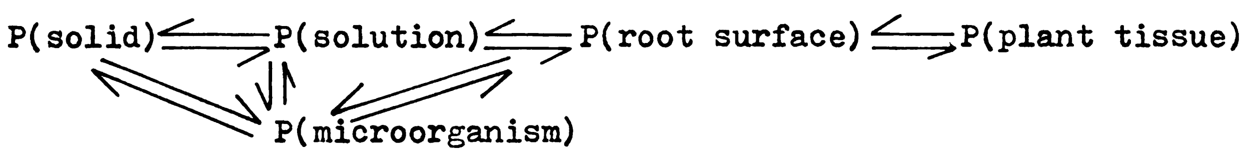
An extensive soil testing program by TSC(Taiwan Sugar Corporation) was initiated in 1962 as suggested by Dr. R.L.Cook of Michigan State University during his visit to Taiwan.

By 1968, Juang and Fong suggested that Bray's No.2 extractant be used. In 1970 the TSC revised the fertilizer recommendations that were based on Bray's tests.

The recommendation made by TSC were momentarily accepted as being valid but in a short time evidence accumulated which suggested that yield responses from fertilizer were actually less than predicted. The intuitive reason was that more than 65% of the total sugarcane acreage was on soils which had a pH above 7.0.

Soil analysis for P is considered to be especially important since this nutrient needs to be applied to the soil prior to planting. At the present time, fertilization costs in Taiwan's sugarcane production still amounts to about one-third of the total cost of production for one crop year. In trying to make the highest return per dollar invested in fertilizer, a program for improving soil testing for P continues to be an integral part of TSC's research project.

The supply of nutrients to sugarcane as well as to the other plants in the soil involves a series of bio-physio-chemical processes which may be represented as follows (Lai, 1970):



When this system is applied to soil testing, there are three parameters that need to be recognized--the intensity or concentration of P supply to roots, the capacity or total supply, and the rate of supply factors. Unless these three parameters can be well defined with a soil testing program under field conditions, it is not logical to expect a high correlation between the test values and crop responses to fertilization. It seems that soil testing programs conducted in the past emphasized the intensity and capacity factors, but little attention had been paid to the rate factor.

Lai in Hawaii (1970) showed that the P uptake by sugarcane varied greatly and was closely related to the ion diffusion rates in the soil studied. Thus P uptake was a function of the combined influence of all three factors.

Two ways of improving soil test correlation with plant growth seem obvious. One is to correlate the "available" P test with other factors such as test levels for other nutrients or soil properties. The other is to group soils based upon natural characteristics such as water holding capacity. In this way, P tests could be related to soil groups under various climatic conditions. This would not be easy to do but correlation with plant growth should be improved.

The general goal of this study was to establish a practical method for evaluating P levels for TSC's 112,000 acres of sugarcane soils.

LITERATURE REVIEW

Tisdale and Nelson (1956) reported that as early as 1833, Hilgard used acids to extract nutrients from soils in an effort to evaluate fertility levels. Liebig studied soil testing between 1840 and 1850. At a later date, Dyer (1894) extracted P with citric acid. The acid concentration used varied between 0.5 and 2.0%. In the early 1900's, Whitney and Hopkins contributed much to the development of soil fertility investigations in the United States. From Liebig's time(1850) until the early 1920's, little progress was made on soil testing. During the late 1920's and early 1930's significant contributions to soil testing were made by Bray(1929), Truog(1930), Morgan(1932), Spurway(1933) and Hester(1934).

With time, new instruments as well as test procedures were developed. As a result, numerous papers were published on soil phosphorus evaluations. Reviews on soil P have been reported every few years when new concepts were developed. Representative literature reviews have been given by Hemwell (1957), Wild(1959), Bradfield(1961), Larson(1967), and Mattingly & Talibudeen(1967). More recently, Chao(1972) made a comprehensive review of the significance and importance of Al and Fe oxides as related to soil P.

Today, available P in the soil is usually extracted by water, dilute acids, dilute alkali or buffered salt solutions.

Comparisons of the amount of P removed from soil by various extractants have been reported in many investigations (Anderson & Noble, 1973; Cho & Caldwell, 1959; Breland & Sierra, 1962; and Chang & Juo, 1963).

Water soluble P

In some studies, distilled water was used as an extractant. The form of P extracted naturally is referred to as "water soluble P". In most soils the level of water soluble P is low and plant growth increases up to a limit with the concentration of P in the soil solution.

Bingham(1949), Martin & Buchanan(1950), and Martin & Mikklesen(1960) found that when more than 0.13 ppm P occurred in a water extract, crops failed to respond to P fertilization Thompson et al (1960) found a high correlation between P uptake by sorghum and water soluble P on 22 soils, most of which were acid.

Fried and Shapiro (1956) obtained a low correlation between water soluble P and P uptake on 8 acid soils for the initial extract, but a higher correlation for the 14th successive extract. Therefore they point out that the level of P in the initial water extract was not a good indication of plant-available P.

Apparently, both the intensity of soil P supply and the capacity of the soil to rapidly renew this supply must be evaluated in order to adequately define plant-available soil P. Pons and Guthrie's (1946) isobutyl alcohol method was considered to be relatively precise, because values of specific activity, which was defined as ^{32}P activity divided by ^{31}P concentration in an aliquot of the soil solution, were constant as the soil/water ratio increased. Watanan & Olsen (1962) concluded that the isobutyl alcohol method of Pons and Guthrie was reasonably accurate for water soluble P evaluations. Beckwith (1964) found that the P concentration in soil solution must be maintained at 0.2 ppm if optimum plant growth is to occur. Fox, et al (1970) found that the yield of millet approached 95% maximum when the concentration of P in solution was adjusted to 0.2 ppm. Ozanne & Shaw (1968) suggested a value of 0.3 ppm in studies involving wheat and rates of P fertilizer. This value varied some depending upon soil moisture levels which influenced phosphate diffusion rates.

Dilute acid P

Soil P extracted by dilute acids has been widely studied. Truog(1930), Dickman & Bray(1940), Peech(1944), Bray & Kurtz (1945), Nelson(1953) developed such methods. The details of these methods as well as other methods involving saturated carbonic acid(Daubeny, McGeorge, Smith, Ensminger and Larson);

and 1% citric acid (Dyer, Wiley) have been discussed by Jackson (1958).

The combination of dilute HCl acid and NH_4F was used by Bray & Kurtz (1945) to extract available P. The inclusion of an acid resulted in the dissolution of the more active calcium phosphate. It also prevented its precipitation. This extract dissolve some tricalcium phosphate, but the amount was considered to be small. The NH_4F was employed to dissolve Al and Fe phosphate. Melsted (1967) stated that this dilute acid-fluoride extractant removes approximately equal parts of the sorbed and Al phosphate plus the water soluble P. A number of studies have shown that Bray's No.1 solution is about as good a universal soil extractant for available P as is available today.

Smith, Ellis and Grava (1957) working with Kansas soils compared NH_4F-HCl at a wider soil: extractant ratio of 1:50 with $NaHCO_3$ (Olsen) at the standard ratio. They found the rank correlation between plant response and extractable P was greater for NH_4F-HCl than for $NaHCO_3$. They also pointed out that the inclusion of fluoride in relatively dilute acids appeared to serve two opposite roles. In calcareous soils, and in acid soils to which rock phosphate has been added, it served to repress the solubility of certain forms of P. With acid soils, where no rock phosphate had been added, it apparently dissolved some additional P that was not removed by extraction with dilute acids alone. In general, Bray's No.1 method has been most successful on acid soils, but if a wider soil-solution ratio is used, it is likely to be satisfactory on calcareous soils. The problem was how wide a soil-to-solution ratio should be used on soils with a wide pH range.

Nelaon, et al (1953) selected a combination of dilute HCl and H_2SO_4 for extracting available P from soils which fix P strongly. Relative greater amounts of Fe-P were removed by this mixed acid solution than by HCl alone.

Truog (1930) used dilute H_2SO_4 (0.002N) to extract available P. A modified Truog method is being used by the Hawaii Sugar Experiment Station.

Alkaline extracting or bufferred salt solutions

An alkaline extracting solution such as 1% K_2CO_3, $(NH_4)_2CO_3$, or Na_2CO_3 was used by Das, 1933; Hockensmith, et al 1933; and Whitney and Gardner, 1936. The most commonly used method involving dilute alkaline solutions was developed by Olsen (1954). With this method P is extracted with 0.5M $NaHCO_3$ at a nearly constant pH of 8.5. This method is now used extensively on calcareous, alkaline or neutral soils. Evidence that $NaHCO_3$ extracts $CaHPO_4$ and Al-P in a quantitative manner was observed by Susuki, et al (1963). They also found that the P removed from soil by the Truog method and by cropping was represented by both Ca-P and Al-P.

The Morgan extractant (1935), which is sodium acetate-acetic acid bufferred at pH 4.8, has been commonly used to represent a bufferred salt extractant for P. Griffin and Lorton (1970) found that the Morgan and modified Morgan procedures gave reliable predictions of soil P availability to alfafa. The ammonium lactate-acetic acid method, originally developed by Egner and Riehm has been used in western Europe (Semb & Uhlen, 1955, Egner, 1932, Riehm, 1942, 1948, Lemmermam, 1946, Finck & Schlichting, 1955--also see references of "Soil-plant System" by Fried and Broeshart, 1967).

Isotopic dilution of ^{32}P and resin adsorption methods were used to evaluate surface adsorbed P by Caro & Hill (1956); McAuliffe, et al (1948), Olsen (1952), Russell et al (1954), Talibudeen (1957), and Amer, et al (1955). Although this method does not give much information concerning the source and nature of phosphate bonds, good agreement with other conventional extraction methods has been obtained.

Chemical forms of P in the soil

The chemical forms of P in the soil greatly influence the amount of P available to plants. Therefore, it seems that a knowledge of the distribution of soil P among discrete chemical forms should be useful in diagnosing the supplying power of a soil.

The idea of fractionation of inorganic P in the soil was proposed as early as 1938 by Dean.

Bray & Dickman (1941); Chirkov & Volkova (1945); and Bhangoo & Smith (1957) studied methods of fractionation of inorganic P in soils. In 1957, Chang and Jackson developed a method to fractionate inorganic soil P discretely into Ca-P, Al-P, Fe-P and occluded phosphates. This method, however, was modified by Fife (1959), Chang & Liaw (1962), Petersen & Corey (1966), and Williams (1967). Since this soil P fractionation system has been developed, numerous papers have been published on available soil P which involved this method.

Al-Abbas & Barber (1964) also studied a P soil test based upon the fractionation of P. They believed that a soil test should provide a quantitative measure of the degree to which each soil fraction is related to plant P availability. The relationship between each soil P form and plant availability was used as a basic criteria for P soil test. They reported that the quantity of Fe-P in the soil indicated a degree of P availability to corn.

By using a radioisotopic technique, Yuan, et al (1960); Dunber & Baker (1965); and Smith (1965) all pointed out that the most active form of phosphate in soils was Al-P which can be extracted with NH_4F. Chiang stated that if the dominant phosphates in soil are Al-P and Fe-P, Ca-P will be taken up most rapidly by rice. When Ca-P is present in relatively large amounts there is a tendency for Al-P and Fe-P uptake to increase.

Many Japanese workers found (1967) that the form of phosphate utilized by naked barley was related to the phosphate materials used and to soil pH. They also observed that Al-P and Fe-P were the major sources of P.

Martens, et al (1969) reported that Al-P was most closely correlated with NH_4F-HCl extractable P for all soil types investigated whereas Ca-P in some soils and Al-P in other soils apparently controlled the P extracted by HCl-H_2SO_4. Mackenzie (1962) reported that the most active P fraction in the soil was Al-P which was extracted with NH_4F. Hanley (1962) gave much significance to Al-P as a source of P to various crops.

Khanna's (1967) studies showed that the Bray's No.2 solution extracted significant amounts of Ca-P while Bray's No.1 extracted more of the Fe-P and saloid-bound P (loosely held soil P).

Since fluoride-extractable soil P is recognized as an important source of P for plants, a series of papers by Fife (1959, 1962, 1963) evaluated NH_4F as a selective extractant for Al-bound soil phosphate. He found that dilution had a small effect on the solubility of Fe-bound phosphate in the soils be examined. He used direct extraction with an alkaline reagent (pH 8.2 to pH 8.5). Tandon (1969, 1970) reported that Al extracted by 0.5N NH_4F (pH 8.2) was highly correlated (r=0.924) with P retained as NH_4F-extractable (Al-P) for 28 widely differing soils. Susuki, et al (1963) also found that P removed from soil by Bray, Olsen, resin and surface P methods was principlly from the Al-P fraction.

Fate of fertilizer P in the soil

The fate of fertilizer P in soils has been investigated. Ghani & Islam (1946) and Volk & McLean (1963) reported that 90% or more of the applied P was accounted for as Al-P and Fe-P. Volk & McLean also found that the application of soluble P to soils with high P fixing capacities decreased the availability of the native P (Bray's No.1 extractable). While P added to soils with low fixing capacities tended to increase the availability of the native P. They also found that they were able to recover more than half of the applied P as $FePO_4$ in soils with high P fixing capacities and more than half of the P as $AlPO_4$ in those with low fixing capacities.

The inorganic P transformation proved to be a complicated problem. Fiskell & Spencer (1964) studied the forms of phosphate in soils after six years of heavy phosphate and lime use. They found that without lime P accumulated in the soil as Al-P. Lime with the lowest rate of P used resulted in the formation of Al-P as 50% of that applied, with the remainder being Fe-P and Ca-P. Lime with highest rate of P resulted in the formation of Al-P with 35% of the P being in this form and 7% as Fe-P, with the remainder as Ca-P.

Shelton & Coleman (1968) showed that fertilizer P was rapidly converted into Al-P and Fe-P when large amounts of P were applied to a high P fixing soil. Over an 8 year period, a decrease in Al-P and an increase in Fe-P occurred. They found that soil test P (0.05N HCl+0.025N H_2SO_4) was highly correlated with Al-P.

Juo and Ellis (1968) reported that when soluble P was applied to an acid upland soil or when Ca-P was dissolved during the process of chemical weathering, the soluble P was precipitated rapidly to form colloial Al-P and Fe-P, which were readily available to plants because of their small particle size, greater surface area and amorphous structure. As the colloidal phosphate crystalized to form hydrated compounds, they were less available to plants. Fe-P crystallized at a much faster rate than Al-P. The native Al-P fraction in the soil seemed always to be more available to plants than the Fe-P fraction.

The forms of P in the soils of Taiwan were investigated by Chu & Chang (1960), and Chang & Juo (1963). They discovered that the distribution of inorganic P was likely to be characteristic of a soil group. There were three different distribution patterns of Ca-P, Al-P and Fe-P in the soils of Taiwan. Soils dominating in Fe-P were latosols; in Ca-P, calcareous alluvial soils; in Ca-P and Fe-P, acid sandstone and shale alluvial soils. A comparison study of various P extracting solutions was made by Chang & Juo to determine the source of the P in 26 soils. They found that apparently the Olsen and Bray No.1 extracting agents evaluate well Al-P but not Ca-P.

Most of the correlation work involving soil test methods and crop yields has been done in the greenhouse or in growth chambers. Relatively little information is available from out door pot tests and field tests where a large number of different kinds of soil are involved.

In regard to P, no extracting method has been universally adopted. All methods apparently are well suited for some soils, but less suited for others.

In conclusion, Fried & Broeshart (1967) summarized the situation well when they stated:

"Most of the present chemical methods are not independent of soil types because they do not measure the capacity, the intensity, or both of plant nutrient supply in the soil. On the other hand, unless the future soil-testing methods are directed toward the development of techniques for the determination of the capacity and intensity factors, there is less chance that a soil testing method will be developed in the future that is independent of soil type. Methods that can determine the capacity or intensity factor or both in the soil (e.g., simple isotope dilution techniques or resin extraction) are probably the most valid, but not necessarily ideally suited for routine testing. The decision of whether the increased accuracy is worth any extra effort is a local one".

MATERIALS AND METHODS

Soils for this project represented well the major sugarcane growing areas of Taiwan.

Field experiments involving the use of P fertilizer were scattered on six major types of soil at 47 locations during the 1970-71 crop years.

Outdoor pot tests involved the use of 41 soils from TSC's plantations. Twenty four of the locations from which soil was collected represented sites used for field experiments.

Ten acid samples and 14 alkaline samples were chosen from both field experimental plot locations and from fields not representing research area for relatively rapid P fixation capacity determination.

The field experiments were designed as a 4x4 Latin square. The plots measured 8 rows x 8m which is equal to 80 m^2.

Nitrogen was used on all plots at the equivalent rate of 250 kg/ha. The rate for K_2O was 150 kg/ha. P_2O_5 was used at four rates 0, 50, 100 and 200 kg/ha.

Autumn cane was planted at the rate of 25,000 to 30,000 cuttings per hectare between August and December of both 1969 and 1970. These were harvested in November and December in 1970 and 1971. Spring cane was planted in January and February of 1970 and 1971 and harvested in January and February of 1971 and 1972.

The variety of cane grown varied, but all varieties represented highly recommended varieties. While F160 was used at most locations. F146, F155, F153, F157, F162 and N:Co310 were involved in these studies.

Large (70cm diameter-75cm high) cement pots which contained 300 kg of soil were used in the pot test research. Two replications of treatments were placed at random outdoors. Also 2 F160 cuttings-4 buds-per pot were planted in September of 1969 and harvested in December of 1970. No P was used on these soils which were otherwise treated with the equivalent of 300 kg of N and 150 kg of K_2O per ha.

The fractionation of the P in the soil was done with Chang and Jackson's method as modified by Peterson and Corey (1966) on samples collected both prior to planting and after harvest.

The available P levels were evaluated by Bray's No.1 test (1945) at various soil to extractant ratios (1:7, 1:10, 1:20, 1:30, 1:40, and 1:50) and by Bray's No.2 test (1945), Amer, et al (1955) resin adsorption method, and by extraction with 0.5M NH_4F solution adjusted to pH 7.2 and 8.2.

The pH measurements were made in a 1:1 soil water mixture using a glass electrode.

The leaf analyses were made at 3 month intervals after planting by the method described by Hutton & Nye (1958).

RESULTS AND DISCUSSION

Forms of P and availability to sugarcane

While sugarcane is grown to some extent in most of the nonmountainous areas of Taiwan, production is concentrated in the western one third and the southern one half of the country. This also represents the area where most of the field experimental plots were located as well as the origin of the soil used in this research (Fig. 1).

The pertinent information for identifying the location of the field plots as well as the broad soil groups represented at each location are shown in Table 1. The pH value for each site are included in the Table to assist in interpreting the character of the soil at each location.

The soil in the plot areas represented a typical range in pH as might be predicted from the non-saline areas (pH 5.0-8.5). Attempts to produce profitable sugarcane crops have been made on soils that are both more acid and more alkaline than the soils used in these studies. In Table 1, under the "sample number" heading the letter "B" represents the subsoil.

In these studies, the soils have been grouped as follows:

1. H: Low humic gley soil (Vertisols).
2. AS_c: Sandstone alluvial soil, calcareous (Inceptisols).
3. AS_n: Sandstone alluvial soil, non-calcareous (Inceptisols).
4. ATL: Slate alluvial soil (Inceptisols).

5. RY: Red yellow podzolic soil (Ultisols).

6. R: Red soil (Oxisols).

The following is a brief description of the soil management groups involved in these studies.

1. $H, 1a_2c-h_2$:

Fine textured low humic gley soils. These soils are well drained in the dry season and the ground water supply is inadequate. These soils are poorly drained in the wet season. A compacted subsoil is usually found at 25-50cm.

2. $AS_c, 3a_1b-h_1$:

Medium textured calcareous sandstone alluvial soils which are well drained during the dry season. The ground water supply is fairly adequate in the dry seasons. These soils are somewhat poorly drained in the wet season. A relatively compact layer is usually found at a depth of approximately 25-50cm.

3. $AS_c, 5a_2$:

Droughty coarse textured, calcareous sandstone alluvial soils with good internal drainage and poor ground water supply in both dry and rainy seasons.

4. $AS_n, 3a_1b-h_1$:

Medium textured, non-calcareous sandstone alluvial soils. The natural drainage, ground water supply and compactness of these soils are equivalent to those in soil management group #2 described above.

5. $AS_n, 3a_2-h_1$:

Medium textured, non-calcareous sandstone alluvial soils with good natural drainage and poor ground water supply in both dry and wet seasons. A compact subsoil is usually found at approximately 25-50cm.

6. ATL, $4a_{e}b$:

Medium textured well drained alluvial soils with a good ground water supply in dry seasons. During wet season they are somewhat poorly drained.

7. ATL, $3/5a_{0}c$:

Two-story soils of medium textured materials in the upper 25cm and of coarse textured materials in the lower 25-80cm layer. They are well drained with a good ground water supply condition during the dry seasons but become poorly drained during the rainy season.

8. ATL, $3a_{1}b\text{-}h_{1}$:

Slate alluvial soils. The natural drainage, ground water supply condition and compactness of these soils are equivalent to those in soil management group #2 described above.

9. RY, $5a_{2}$:

Coarse textured droughty red yellow podzolic soils with good drainage and a poor ground water supply in both dry and wet seasons.

10. RY, $3/2a_{2}\text{-}h_{2}$:

Two-story red yellow podzolic soils with medium textured materials in the upper 25cm, and fine textured materials in

the lower 25-80cm layer. They are well drained and inadequately ground water supplied in both dry and wet seasons. A compact subsoil is frequently found in the subsoil (25-50cm).

11. $R,2a_2-h_2$:

Fine textured red soils. The natural drainage, ground water supply and compactness of these soils are equivalent to those in soil management group #10. A compact subsoil is usually found in subsoil (25-50cm).

12. $R,3/2a_2-h_2$:

Red soils. The texture of the profile, natural drainage condition, ground water supply and compactness of these soils are equivalent to those in soil management group #10.

(1) Field experiments

The yields of sugarcane produced in the field experiments are shown in Table 2. The data have been grouped so that the soils within a given soil group are together in one part of the Table.

In the 47 field experiments, the use of P fertilizer increased yields in only 8 experiments and in 2 of the soil groups. Yield responses to P fertilizer were obtained at 6 locations in the ATL soil group and at 2 locations in the H soil group.

The experimental results are in good agreement with the observations of TSC's field men. Many of these men feel that

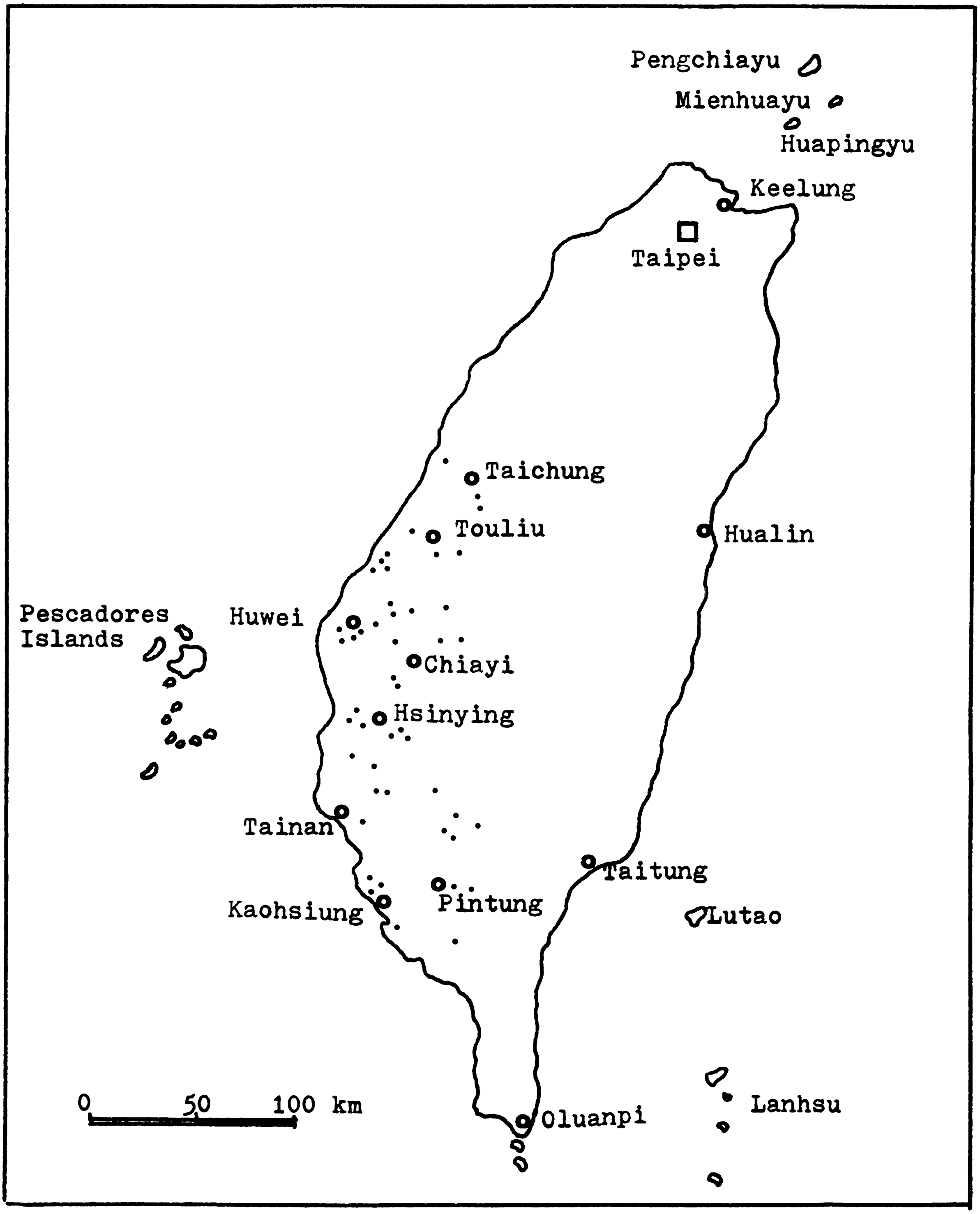


Fig. 1. Locations of 47 field experiments

Table 1. Locations, soil management groups and pH levels of soil in field experiments

Sample number	Sugar mill	Plantation & field No.		Soil management group (SMG)	pH
F-1-A*	Hsinying	Taikong	11	$H,1a_2c$-h_2	8.1
F-1-B	"	"		"	8.0
F-2-A*	Annei	Hsinchung	18	"	8.3
F-2-B	"	"		"	8.3
F-3-A*	Hsiaokong	Yenshuikong	24	"	7.8
F-3-B	"	"		"	8.1
F-4-A	Shanhua	Shanhua	10	"	7.8
F-4-B	"	"		"	8.0
F-5-A	Chiayi	Houliao	5	"	7.9
F-5-B	"	"		"	7.9
F-6-A	Suantou	Machouhou	40	"	6.9
F-6-B	"	"		"	7.2
F-7-A	Annei	Hsinchung	19	"	8.0
F-7-B	"	"		"	8.1
F-8-A	Kaohsiung	Penchou	34	"	7.9
F-8-B	"	"		"	8.1
F-9-A	Hsiaokong	Fengkong	24	"	8.1
F-9-B	"	"		"	8.2
F-10-A*	Shanhua	Liufenliao	14	$AS_c,3a_1b$-h_1	8.2
F-10-B	"	"		"	8.3
F-11-A*	Shanhua	Tsengwen	4	$AS_c,5a_2$	8.0
F-11-B*	"	"		"	8.1

Table 1. cont'd

F-12-A*	Machia	Hsinchia	2	AS_c, $3a_1b$-h_1	7.8
F-12-B	"	"		"	7.9
F-13-A	Chiayi	Nanching	8	"	7.9
F-13-B	"	"		"	7.8
F-14-A	Suantou	Suantou	19	"	7.2
F-14-B	"	"		"	7.7
F-15-A	Annei	Chichou	23	"	8.3
F-15-B	"	"		"	8.3
F-16-A	Wushulin	Anchi	20	"	8.2
F-16-B	"	"		"	8.2
F-17-A*	Wushulin	Kantzutou	20	AS_n, $3a_1b$-h_1	6.9
F-17-B	"	"		"	7.3
F-18-A*	Taichung	Wantouliu	33	AS_n, $3a_2$-h_1	5.9
F-18-B*	"	"		"	6.5
F-19-A	Touliu	Nantzu	22	"	7.8
F-19-B	"	"		"	7.9
F-20-A	Taichung	Fantzuliao	15	"	5.0
F-20-B	"	"		"	5.9
F-21-A	Hsinying	Hsintso	16	AS_n, $3a_1b$-h_1	5.0
F-21-B	"	"		"	5.1
F-22-A	Touliu	Nantzu	22	AS_n, $3a_2$-h_1	6.6
F-22-B	"	"		"	7.0
F-23-A*	Huwei	Mahsi	31	ATL, $4a_ob$	8.2
F-23-B	"	"		"	8.2
F-24-A*	"	Hsinhsing	7	ATL, $3/5a_oc$	8.3
F-24-B	"	"		"	8.4

Table 1 cont'd

F-25-A	Chihu	Erhlin	57	ATL,$3a_1b$-h_1	8.1
F-25-B	"	"		"	8.4
F-26-A	"	Yuanpu	19	ATL,$4/6a_1c$	7.8
F-26-B	"	"		"	8.0
F-27-A*	Chishan	Shouchinliao	85	ATL,$3a_1b$-h_1	8.2
F-27-B	"	"		"	8.1
F-28-A*	Nanchou	Kanting	4	"	8.2
F-28-B	"	"		"	8.2
F-29-A*	Chishan	Chiehyang	102	"	8.4
F-29-B	"	"		"	8.4
F-30-A*	Pintung	Chunglan	99-1	"	8.0
F-30-B	"	"		"	8.2
F-31-A*	Chihu	Yuanan	19	ATL,$2a_1b$-h_2	7.8
F-31-B	"	"		"	7.9
F-32-A*	Peikong	Tsaitso	24-1	ATL,$5/3a_1b$-h_1	8.2
F-32-B	"	"		"	8.3
F-33-A*	"	Fantzukou	172	ATL,$3/2a_1b$-h_2	8.4
F-33-B	"	"		"	8.5
F-34-A	Pintung	Pengtso	26	ATL,$3a_1b$-h_1	8.2
F-34-B	"	"		"	8.2
F-35-A	Chishan	Tuku	59	ATL,$5/6a_2a_1$	8.3
F-35-B	"	"		"	8.3
F-36-A	Chihu	Erhlin	46	ATL,$3a_1b$-h_1	8.3
F-36-B	"	"		"	8.5
F-37-A	"	Shuiwei	9	ATL,$4/6a_1b$	8.1
F-37-B	"	"		"	8.3

Table 1. cont'd

F-38-A	Huwei	Achuan	3	ATL,$4a_ob$	8.4
F-38-B	"	"		"	8.5
F-39-A	Jente	Shalun	36	RY,$5a_2$	5.7
F-39-B	"	"		"	6.1
F-40-A*	Kaohsiung	Chiuchiawei	8	"	6.0
F-40-B*	"	"		"	5.8
F-41-A*	Touliu	Kanting	82	RY,$3/2a_2$-h_2	8.3#
F-41-B*	"	"		"	8.2#
F-42-A	Chishan	Yuehmei	51	RY,$2a_1b$-h_2	6.7
F-42-B	"	"		"	6.8
F-43-A*	Yuehmei	Chihsing	3	R,$2a_2$-h_2B	5.3
F-43-B	"	"		"	5.4
F-44-A	Touliu	Shangkanchueh	31	"	8.1#
F-44-B	"	"		"	7.3#
F-45-A	Talin	Tapumei	60	R,$3/2a_2$-h_2B	5.4
F-45-B	"	"		"	5.2
F-46-A	Touliu	Kancheuh	14	R,$2a_2$-h_2B	7.0#
F-46-B	"	"		"	7.2#
F-47-A	Talin	Tapumei	68	R,$3/2a_2$-h_2B	6.9#
F-47-B	"	"		"	7.1#

* soil materials also used for pot tests.

A: surface soils.

B: subsoils.

#: limed.

Table 2. Sugarcane yields(T/ha) as affected by 4 rates of P fertilizer

Sample No. & soil group	Treatment(P_2O_5,kg/ha) & yield				Yield %	Significance & LSD (T/ha)
	0	50	100	200		
F-1A, H	109.5	107.8	109.1	108.1	100.0	ns
F-2A, "	94.5	97.6	104.2	101.2	90.7	ns
F-3A, "	94.8	98.6	96.0	104.8	90.5	ns
F-4A, "	84.1	90.6	80.1	83.8	92.9	ns
F-5A, "	103.7	98.0	101.5	107.7	96.3	ns
F-6A, "	94.0	101.4	105.4	101.7	89.2	ns
F-7A, "	62.6	69.8	71.6	60.6	87.4	ns
F-8A, "	114.2	122.7	127.2	135.0	84.6	5%,10.0
F-9A, "	104.2	107.2	115.5	117.5	93.6	1%,5.4
F-10A,AS_c	125.2	127.1	127.1	128.5	97.5	ns
F-11A, "	95.4	103.1	105.1	99.8	90.8	ns
F-12A, "	94.2	95.7	98.1	103.7	90.9	ns
F-13A, "	102.0	103.2	106.2	105.2	96.0	ns
F-14A, "	106.2	113.7	108.9	118.4	89.7	ns
F-15A, "	94.7	95.0	97.2	96.0	97.4	ns
F-16A, "	101.2	98.2	106.0	107.7	94.0	ns
F-17A,AS_n	130.6	139.0	145.4	153.6	85.1	ns
F-18A, "	116.5	122.7	117.7	112.9	94.9	ns
F-19A, "	157.8	155.4	145.3	151.9	100.0	ns
F-20A, "	109.2	109.6	108.1	107.8	99.6	ns
F-21A, "	94.0	111.7	107.5	105.0	84.1	ns
F-22A, "	138.5	127.2	134.5	132.7	100.0	ns

Table 2. cont'd

F-23A,ATL	92.2	105.1	105.3	102.5	87.9	ns
F-24A, "	113.5	112.4	116.7	116.1	97.3	ns
F-25A, "	97.4	104.2	104.4	107.4	90.7	5%,3.5
F-26A, "	127.8	125.6	134.0	128.4	95.4	ns
F-27A, "	146.0	151.7	149.6	149.2	96.2	ns
F-28A, "	121.1	168.5	160.7	162.1	71.9	1%,19.3
F-29A, "	115.6	115.2	124.7	122.1	92.7	ns
F-30A, "	125.7	137.2	170.7	158.2	73.6	5%,28.5
F-31A, "	133.2	145.2	148.7	156.0	85.4	5%,14.6
F-32A, "	117.9	117.1	108.9	123.1	95.8	ns
F-33A, "	138.4	128.0	125.8	137.9	100.0	ns
F-34A, "	119.0	130.5	134.2	128.2	88.6	ns
F-35A, "	110.2	123.5	120.5	109.2	89.2	ns
F-36A, "	125.2	130.2	137.7	133.7	89.8	5%,4.0
F-37A, "	134.0	131.0	138.0	139.0	96.4	ns
F-38A, "	71.5	77.5	79.0	79.5	89.9	5%,5.0
F-39A,RY	61.0	61.5	59.7	66.5	91.7	ns
F-40A, "	143.7	157.5	155.5	150.0	91.3	ns
F-41A, "	127.1	150.8	153.9	163.6	77.7	ns
F-42A, "	116.7	119.2	108.7	134.2	86.9	ns
F-43A, R	121.4	115.4	121.7	118.1	99.8	ns
F-44A, "	134.8	134.6	134.0	132.0	100.0	ns
F-45A, "	84.4	84.8	83.1	80.6	99.6	ns
F-46A, "	131.0	123.0	123.5	130.2	100.0	ns
F-47A, "	92.0	89.3	88.6	91.0	100.0	ns

the response of sugarcane to P fertilizers is not significant for the first two years unless the P level in the soil is unusually low. Thus the problem of knowing where and how much P fertilizer to use becomes evident.

Prior to 1969, 30 to 50 kg/ha of P_2O_5 was used on TSC's farms. After the extensive soil testing program was initiated, up to 70 kg/ha was tentatively recommended. Now it is believed that it is unlikely that in most fields yield responses were obtained where such rates were recommended.

(2) Outdoor pot tests

In order to obtain a better understanding of the P status in sugarcane soils, pot tests were established in 1969-1970 to study the availability of soil P as related to forms in the soil. This approach to the problem hopefully would provide a basis for interpreting a soil test for available P.

The yields produced as well as the mechanical analysis of the soil, the percent organic matter and the pH of the soil are shown in Table 3. Yields varied greatly, between 3.3 and 17.9 kg/pot. Wide variation in yield was also evident for soils within a soil group.

Since no fertilizer P was used in this study, and it was assumed that other essential nutrients were not limiting, theoretically the yields reflect two situations. One physical and the other chemical.

Table 3. Locations, yields and soil characteristics of samples used in pot tests

Sample No, & soil group	Plantation & field No.	pH	O.M. %	Mech. analysis, % sand	silt	clay	Texture	Yield kg/pot
P-1, H	Tiaochilin 12	8.3	0.51	69.0	22.6	8.4	Sl*	6.1
P-2, "	" (subsoil)	8.1	1.30	7.8	43.0	49.2	Sic	11.4
P-3, "	Taikong 11	8.0	1.26	6.6	50.0	43.4	Sic	14.1
P-4, "	Hsinchung 18	8.3	1.24	7.4	57.6	35.0	Sicl	12.4
P-5, "	Yenshuikong 24	8.0	1.30	27.8	33.2	39.0	Cl	10.7
P-6, AS_c	Tsengwen 4	7.6	0.92	54.0	33.8	12.2	Sl	17.7
P-7, "	" (subsoil)	7.9	0.49	73.4	17.4	9.2	Sl	11.9
P-8, "	Nanching 35	8.1	1.29	21.4	63.6	15.0	Sil	15.3
P-9, "	" (subsoil)	8.2	0.93	19.0	64.0	17.0	Sil	15.0
P-10,"	Liufenliao 14	8.0	1.20	13.0	67.0	20.0	Sil	15.2
P-11,"	Tungshihliao 13	7.5	1.35	21.0	56.0	23.0	Sil	14.8
P-12,"	Hsinchai 2	6.8	0.55	44.6	45.4	10.0	L	15.8
P-13,"	Fantzutien 16	6.7	1.35	33.0	55.0	12.0	Sil	16.4
P-14, AS_n	Nantzu 23	7.2	0.87	30.2	57.4	12.4	Sil	17.3
P-15, "	" (subsoil)	7.5	0.74	30.6	53.6	15.8	Sil	16.9
P-16, "	Wantouliu 35	5.5	1.24	32.6	41.6	25.8	L	15.8
P-17, "	" (subsoil)	5.6	0.89	18.2	52.0	29.8	Sil	14.2
P-18, "	Kantzutou 20	6.5	0.91	36.7	46.0	16.4	L	15.4
P-19, ATL	Yuanan 19	8.1	0.87	6.2	61.4	32.4	Sicl	3.3
P-20, "	Erhlin 17	8.0	0.78	48.2	34.4	17.4	L	11.9
P-21, "	Chunglan 99-1	7.8	0.83	48.6	40.0	11.4	L	9.4

* guesting sand

Table 3.cont'd

P-22,ATL	Tsaitso	24-1	8.0	0.77	76.2	14.4	9.4	Sl	7.1
P-23, "	Fantzukou	172	8.0	1.02	7.2	55.8	37.0	Sicl	11.1
P-24, "	Wanhsing	5	8.1	0.44	84.8	11.0	4.2	Ls	5.8
P-25, "	Yuanpu	19	7.7	0.88	69.0	19.6	11.4	Sl	14.6
P-26, "	Shouchinliao	85	7.8	0.92	44.8	46.8	8.4	L	14.1
P-27, "	Chiehyang	102	7.9	0.96	24.6	74.2	11.2	Sil	10.8
P-28, "	Kanting	4	8.1	0.81	28.4	60.4	11.2	Sil	6.0
P-29, "	Mahsi	31	8.1	0.94	32.2	53.6	14.2	Sil	11.0
P-30, "	Hsinhsing	7	8.1	0.77	36.8	50.0	13.2	Sil	6.5
P-31,RY	Yuehmei	24	5.7	0.89	35.0	42.6	22.4	L	12.6
P-32, "	" (subsoil)		5.8	0.74	31.8	45.2	23.0	L	10.8
P-33,"	Kanting	82	8.3#	0.79	36.6	42.0	21.4	L	10.7
P-34, "	" (subsoil)		8.2#	0.63	34.6	34.4	31.0	Cl	10.0
P-35, "	Chiuchiawei	8	6.3	0.19	76.2	16.4	7.4	Ls	15.4
P-36, "	" (subsoil)		6.1	0.04	78.6	14.8	6.6	Ls	13.1
P-37, "	Shalun	116	6.6	0.62	68.6	26.0	5.4	Sl	14.9
P-38, "	" (subsoil)		6.7	0.42	58.2	28.6	13.2	Sl	13.7
P-39, R	Lintso	14	6.2	1.15	23.0	52.2	24.8	Sil	17.9
P-40, "	Tapumei	27	5.6	0.75	34.8	47.6	17.6	L	16.4
P-41, "	Chihsing	3	6.2	1.00	36.8	37.0	26.2	L	14.7

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It was not possible to regulate the physical condition of the soil within the pots because this seemed to be a natural characteristic of each soil. Therefore, the yields reflect both the physical condition of the soil as well as the levels of available P.

Samples of soil were taken from each pot both before and after cropping. Differences in Al-P, Fe-P, Ca-P, and Red-P are shown in Table 4. Again great differences even within soil groups characterize the data.

The data in Table 4 serve as a basis for calculating both the forms and the amounts of mineral P utilized by the sugar-cane crop. The average levels of Al-P, Fe-P, Ca-P and Red-P in the soil before cropping, the amounts of P removed by the crop and the percent of each form removed as related to soil group are shown in Table 5.

In the R and RY soils, Red-P and Fe-P were the most abundant. These soils were also the lowest in total P due to extensive leaching that occurred in the soil formation process.

The usually acid AS_n soils contained much Ca-P (100ppm) than the usually acid R and RY soils (18 ppm) but far less than did the calcareous soils (300 ppm). However, the difference in amount of the other three forms of P, Al-P, Fe-P, and Red-P in these three acid soil groups was small. This indicated that the AS_n soil was in an intermediate stage of development between the highly weathered R and RY soils and the less

Table 4. Chemical forms of P (ppm) in soil materials before and after cropping to sugarcane

Sample No. & soil group	Al-P		Fe-P		Ca-P		Red-P	
	BC	AC	BC	AC	BC	AC	BC	AC
P-1, H	9.5	7.5	25.0	19.8	229.5	209.5	34.0	32.0
P-2, "	12.2	10.5	72.8	55.3	235.0	232.5	76.0	76.3
P-3, "	23.3	15.7	69.8	69.5	170.0	192.5	85.0	73.5
P-4, "	15.4	11.1	57.5	56.0	281.3	325.0	115.0	99.3
P-5, "	17.6	13.7	41.0	37.6	156.3	132.5	57.5	57.4
P-6, AS_c	27.9	20.6	62.8	52.5	288.0	260.3	45.0	44.5
P-7, "	15.5	14.6	47.8	23.8	295.0	270.0	39.0	22.0
P-8, "	57.5	47.1	32.5	30.0	421.0	400.0	130.0	118.2
P-9, "	48.3	44.9	44.0	39.5	395.3	375.0	142.7	119.3
P-10,"	26.7	15.0	48.0	38.7	435.5	409.5	61.0	56.0
P-11,"	35.9	24.8	102.3	86.8	99.0	89.5	77.5	73.8
P-12,"	18.5	14.6	91.0	54.0	294.5	242.3	73.5	40.0
P-13,"	24.1	19.0	105.0	78.8	68.5	53.5	71.0	62.5
P-14, AS_n	23.1	17.9	50.8	49.8	50.3	40.8	79.8	79.2
P-15,"	19.6	12.8	68.8	62.5	35.3	39.0	81.2	76.0
P-16,"	31.5	16.2	113.0	84.3	206.0	185.8	105.0	107.4
P-17,"	13.4	11.4	73.8	55.8	197.5	192.5	112.2	72.5
P-18,"	18.0	7.5	74.3	62.0	13.5	7.8	61.0	53.5
P-19,ATL	9.1	5.3	18.0	12.6	425.5	416.3	58.3	55.0
P-20,"	16.9	11.7	21.5	20.5	332.5	320.0	47.5	41.5
P-21,"	8.2	5.1	23.5	22.0	456.5	447.5	32.4	28.7

Table 4. cont'd

P-22,ATL	13.5	8.9	27.5	22.2	302.5	302.5	28.0	24.3
P-23,"	14.1	10.5	40.0	38.3	401.0	394.8	79.5	69.8
P-24,"	11.3	7.9	18.5	15.4	368.8	355.0	18.7	11.0
P-25,"	27.7	26.4	42.0	13.0	391.0	367.5	35.9	32.9
P-26,"	22.9	15.4	39.0	31.0	413.8	394.0	35.0	35.0
P-27,"	15.3	13.0	35.5	29.5	459.8	443.5	35.0	33.9
P-28,"	13.4	11.6	26.5	20.8	493.0	478.0	26.0	24.0
P-29,"	17.4	14.6	15.8	15.0	391.5	381.5	49.3	38.3
P-30,"	10.8	9.5	18.9	11.4	384.0	377.5	44.0	32.3
P-31,RY	19.0	15.0	115.0	86.0	20.0	17.5	173.4	125.3
P-32,"	15.3	14.4	114.0	86.8	20.0	18.5	137.4	141.0
P-33,"	19.2	15.4	55.8	41.0	25.0	15.8	67.5	42.0
P-34,"	17.0	13.3	65.8	55.5	12.5	10.0	44.5	48.2
P-35,"	19.7	14.8	134.5	102.3	25.5	16.5	125.0	127.0
P-36,"	20.3	15.3	119.0	94.5	28.8	20.0	137.5	136.7
P-37,"	22.2	12.0	82.8	67.5	15.3	6.1	61.5	68.8
P-38,"	12.3	6.9	59.8	44.5	9.8	7.9	68.3	53.5
P-39, R	30.1	25.6	96.3	67.5	20.0	12.0	107.5	78.8
P-40,"	15.8	11.2	81.3	56.3	15.0	12.0	70.8	54.5
P-41,"	21.7	16.1	90.0	67.5	14.3	7.9	83.0	68.0

BC: before cropping

AC: after cropping

Table 5. Average forms and amounts(ppm) of P present and removed from soil groups by sugarcane

Soil group	No. of samples	Al-P			Fe-P			Ca-P			Red-P		
		Aver.	Ave.R	% R	Aver.	Ave.R	% R	Aver.	Ave.R	% R	Aver.	Ave.R	% R
H	5	15.6	3.9	25.0	47.6	5.6	11.8	214.4	9.2	4.3	73.5	5.9	8.0
AS_c	8	31.8	6.7	21.0	66.7	16.2	24.3	287.1	24.6	8.6	80.0	12.9	16.1
AS_n	5	21.1	8.0	37.9	76.1	13.3	17.5	100.5	8.1	8.1	87.8	10.6	12.1
ATL	12	15.1	3.4	22.5	27.2	6.3	23.2	401.6	11.8	2.9	40.8	5.4	13.2
RY	8	18.1	4.7	26.0	93.3	21.1	22.6	19.6	5.6	28.6	101.9	11.2	11.0
R	3	22.5	4.9	21.8	89.2	25.4	28.5	16.4	5.8	35.4	87.1	20.0	22.9
Average removed,%:				25.4			20.4			13.2			13.5

Aver.: average
Ave.R: average removed
% R: % removed

weathered calcareous soils (AS_c, ATL, and H).

One other observation should be made. The average level of Al-P was not only the lowest among all forms of P in any soil group but also showed the least variation ranging from 15.6 ppm to 31.8 ppm.

In the less weathered ATL soils, Ca-P was present at the highest level accounting for more than 80% of the total P. The other three forms of P, Al-P, Fe-P, and Red-P always represented the lowest values in this soil group.

Apatite is the most wide spread P containing mineral in igneous rock. In this young slate alluvial soil, apatite was probably still in its original form. In addition to this, the relatively high calcium levels in this calcareous soil group probably resulted in the formation of more Ca-P when P containing fertilizers were used.

The quantity of each form of P removed by cropping with sugarcane varied with the soil group. As indicated in Table 5, the average quantity of Al-P removed by sugarcane was always less than the amounts of Fe-P, Ca-P, or Red-P. Furthermore, there was less variation in the amount of Al-P removed than with any other phosphate. The average amount of Al-P that was removed by one sugarcane crop ranged between 3.4 ppm in the ATL soils and 8.0 ppm in the AS_n soils. If the amount of Al-P removed from the soil is expressed as a % of the amount present, a different interpretation is possible. With this interpretation Al-P becomes a major source of P utilized by sugarcane. It is interesting that on a % basis there was not much difference among the six soil groups. The percentage of Al-P removed from all soils by cropping averaged 25.4% and varied from a high of 37.9% for the AS_n soil to a low of 20.0% for the AS_c soil. A possible explanation to this situation is that Al-P is a most active form of P in the soil, and the solubility of Al-P in the soil increases with an increase in pH. Above pH 7.0, the concentration of Al-P is likely to be higher than Ca-P. In 27 out of 41 pot tests, the soils had pH levels greater than 7.0. Thus the availability of Al-P would be higher than any of the other forms of P in the soils considered giving sugarcane a better chance for utilization.

A relatively high % removal of Fe-P was also found in the R soil (28.5%). The H soil had the lowest % removal values for Fe-P (11.8%). The calcareous ATL soil had the lowest average Fe-P test but also it had a relatively high % removal value (23.2%). For all of the soils, the average % removal of Fe-P was equal to 20.4%. This value is less than that for Al-P. It is likely that Al-P was more soluble in these soils than was the Fe-P.

The test values for Ca-P varied between 16.4 ppm for the R soils and 401.6 ppm for the ATL soils. The R and RY soils averaged 16.4 ppm and 19.6 ppm of Ca-P, respectively, which were the lowest values found. Interestingly much of this Ca-P was utilized by the sugarcane crop and the % removal values were the highest, 35.4 and 28.6% respectively.

The pH values of R and RY soil groups in this study ranged from 5.6 to 6.7. The concentration of Ca-P in solution in soils within this pH range would be higher than in those soils with a more alkaline reaction. Thus the Ca-P was more readily available to sugarcane in the R and RY soil groups than that in those less weathered AS_n, AS_c, ATL and H soils.

Higher average amounts of Ca-P in the soil does not necessarily imply a higher % removal of Ca-P by sugarcane. The less weathered high Ca-P containing soils (ATL, AS_c, AS_n and H) were able to supply larger amounts of Ca-P than the more weathered R and RY soils. The opposite was the case when the figures were expressed on a % removal basis. The % of Ca-P removed by one sugarcane crop averaged 13.2% which was much less than the amounts of Al-P and Fe-P removed.

The Red-P in the soil was no doubt of secondary origin. Little information is available which suggests that Red-P can be utilized by plants. Sugarcane is a perennial crop and the uptake of P is not limited to the early six months of growth but lasts through the next year. Theoretically, there is a possibility that Red-P can be used by sugarcane when soil conditions are favorable as they must have been in these experiments. The average % of Red-P removed by one sugarcane crop was 13.5% which was about equal to that of Ca-P. The dissolution and precipitation of iron oxides due to alternate reduction and oxidation seem to favor the uptake of Red-P.

A few soils (Table 4) showed a slight increase in Ca-P and Red-P after cropping. This was probably due to a transformation of organic P to inorganic P. This situation did not develop with the Al-P and Fe-P.

Little variation in average % removal of all four forms of phosphate was observed in the R soils. Values ranged between 21.8% and 35.4%. This was also the situation for the RY soil except in regard to Red-P. As stated above, the effect of pH on P availability seemed to play an important role in the uptake of each form of P in the R and RY soils.

But, if the amounts of Al-P, Fe-P, Ca-P and Red-P removed are expressed as the % of the total P removed by sugarcane crop, the data are shown in Table 6.

In the calcareous H, AS_c, and ATL soil groups, Ca-P is the most common form removed averaging 37.4%, 40.7%, and 43.9% of the total P removed, respectively. While in the acid AS_n, RY, and R soil groups, Fe-P represents the most common form of the P removed by the sugarcane crop averaging 33.2%, 49.5%, and 45.3% of the total P removed, respectively.

Clearly, all of the four forms of P in the soil are important in plant nutrition. The Al-P and Fe-P are no doubt the main forms of P taken up by sugarcane irrespective of soil group. Ca-P and Red-P can also be removed to a certain extent by sugarcane.

Table 6. Forms of P as % of total P removed by sugarcane

Soil group	Al-P		Fe-P		Red-P		Ca-P		Total P removed(ppm)
	Ave.R	% R*	Ave. R	% R	Ave. R	% R	Ave. R	% R	
H	3.9	15.8	5.6	22.8	5.9	24.0	9.2	37.4	24.6
AS_c	6.7	11.1	16.2	26.8	12.9	21.4	24.6	40.7	60.4
AS_n	8.0	20.0	13.3	33.2	10.6	26.5	8.1	20.3	40.0
ATL	3.4	12.6	6.3	23.4	5.4	20.1	11.8	43.9	26.9
RY	4.7	11.0	21.1	45.9	11.2	26.3	5.6	13.1	42.6
R	4.9	8.7	25.4	45.3	20.0	35.7	5.8	10.3	56.1

* As % of the total removed by sugarcane from this soil group.

In interpreting these data, it should be remembered they were obtained from tests in pots where soil moisture conditions and root distribution patterns would be different than in the field. This would influence the removal pattern of the different forms of P. Nevertheless, the method used should provide some useful information on the forms of P in the soil and the uptake of P by sugarcane. This information is essential in selecting an extractant that can be used in a soil testing program involving the growth of sugarcane in Taiwan.

Correlations between extractable P and sugarcane yield

Now that information on the levels of P available in the soils of Taiwan and on the forms of P utilized by sugarcane are available, theoretically it should be possible to formulate a suitable extractant for P. Most certainly, the extractant should remove considerable Al-P and Fe-P and a limited quantity of both Ca-P and Red-P.

The P extracted by various methods from 41 soils used in the pot tests are shown in Table 7. As expected, there were wide ranges with any given extractant and soil to solution ratios used. The ranges in extractable P are reported in ppm as follows:

1. 0.5N NH_4F at pH 7.2 — 10.8-69.9 ppm
2. 0.5N NH_4F at pH 8.2 — 8.2-57.5 ppm
3. Bray's #1 1:7 soil: solution ratio — 2.3-27.9 ppm

4.	Bray's #1 1:10 soil: solution ratio	2.8-25.2 ppm
5.	Bray's #1 1:20 soil: solution ratio	3.6-34.6
6.	Bray's #1 1:30 soil: solution ratio	6.2-35.7
7.	Bray's #1 1:40 soil: solution ratio	5.1-41.6
8.	Bray's #1 1:50 soil: solution ratio	5.5-47.6
9.	Bray's #2	22.6-180
10.	Olsen	3.3-21.2
11.	Resin adsorption	3.0-44.0

Essentially the same ranges were found when the same extractants were used on the field soil samples. Basically where the range was narrow for the samples from the pot tests, the range was also narrow for samples from the field tests. The ranges for the surface samples of the field plots are reported as follows:

1.	0.5N NH_4F at pH 7.2	7.3- 58.0 ppm
2.	0.5N NH_4F at pH 8.2	3.7- 41.1
3.	Bray's #1 1:7 soil: solution ratio	0.8- 33.7
4.	Bray's #1 1:10 soil: solution ratio	1.5- 34.4
5.	Bray's #1 1:20 soil: solution ratio	5.8- 41.6
6.	Bray's #1 1:30 soil: solution ratio	5.1- 44.7
7.	Bray's #1 1:40 soil: solution ratio	9.0- 48.0
8.	Bray's #1 1:50 soil: solution ratio	9.0- 57.0
9.	Bray's #2	7.7-180.0
10.	Olsen	2.3- 27.3

Table 7. Soil P(ppm) extracted with various methods from soil materials used in pot tests

Sample No. & soil group	0.5 N NH_4F		Bray's No.1 at various soil:extractant ratio						Bray's No.2	Olsen	Resin adsorption
	pH 7.2	pH 8.2	1:7	1:10	1:20	1:30	1:40	1:50			
P-1,H	13.3	9.5	4.4	3.1	5.5	9.0	12.2	11.8	78.3	4.6	10.0
P-2,"	20.7	12.2	2.9	5.2	8.1	12.6	14.8	20.5	124.0	6.0	8.7
P-3,"	33.0	23.3	6.9	8.1	13.2	14.3	22.4	26.2	95.8	10.0	13.7
P-4,"	23.3	15.4	4.0	6.9	12.1	12.9	21.0	23.0	100.0	9.0	12.7
P-5,"	23.1	17.6	3.7	4.5	8.1	9.3	14.6	15.7	78.8	4.7	12.5
P-6,AS_c	41.0	27.9	25.2	25.2	24.2	31.7	37.6	43.8	160.5	18.0	30.0
P-7,"	30.0	15.5	8.3	12.9	17.7	17.7	24.0	26.8	127.5	8.6	15.0
P-8,"	69.9	57.5	4.9	9.5	24.5	32.6	41.6	47.6	141.2	11.2	28.3
P-9,"	62.9	48.3	7.9	7.8	24.5	29.6	34.2	39.3	180.0	13.1	25.4
P-10,"	34.0	26.7	7.5	14.5	18.2	19.5	21.6	27.6	142.5	15.8	19.0
P-11,"	46.1	35.9	27.9	23.9	28.5	32.1	35.4	37.7	102.7	21.2	44.0
P-12,"	25.5	18.5	16.7	11.9	15.7	16.1	19.4	21.3	140.5	10.0	19.3
P-13,"	31.8	24.1	18.7	15.4	17.5	20.9	24.0	26.4	71.0	19.6	20.0

Table 7. cont'd

Sample No. & soil group	0.5 N NH_4F		Bray's No.1 at various soil:extractant ratio						Bray's No.2	Olsen	Resin adsorption
	pH 7.2	pH 8.2	1:7	1:10	1:20	1:30	1:40	1:50			
P-14, AS_n	26.8	23.1	16.0	11.8	16.9	21.7	21.8	7.1	64.6	11.6	26.4
P-15,"	23.3	19.6	10.9	8.9	11.7	10.7	15.8	20.0	44.0	8.5	17.4
P-16,"	38.9	31.5	16.1	14.8	20.7	21.5	25.2	29.3	109.2	18.5	27.4
P-17,"	17.9	13.4	7.1	4.6	6.2	6.9	10.0	12.0	82.0	8.8	19.0
P-18,"	23.8	18.0	13.2	9.0	10.5	13.1	13.6	14.0	41.0	7.9	7.0
P-19,ATL	13.8	9.1	2.3	2.8	3.7	7.5	5.1	5.5	29.0	3.5	3.0
P-20,"	27.7	16.9	9.4	7.5	9.8	14.1	14.0	15.5	92.4	6.4	8.2
P-21,"	10.8	8.2	3.9	2.9	3.6	6.2	7.8	7.5	102.8	3.3	5.8
P-22,"	14.0	13.5	6.9	5.2	7.1	12.5	11.7	12.8	105.4	4.5	5.8
P-23,"	18.1	14.1	6.8	4.5	6.4	9.6	11.5	22.7	131.0	6.7	8.8
P-24,"	19.3	11.3	7.9	6.3	6.1	9.6	9.6	16.9	60.1	5.7	6.0
P-25,"	40.1	27.7	24.5	21.5	34.6	35.7	37.0	56.5	171.0	14.0	29.0
P-26,"	32.8	22.9	10.9	11.3	17.2	24.8	21.9	35.9	147.5	9.7	14.0
P-27,"	22.8	15.3	3.3	4.7	6.4	12.0	10.6	19.9	99.8	6.4	5.4
P-28,"	19.3	13.4	2.7	3.5	4.4	9.8	8.9	15.0	108.0	4.1	3.0

Table 7. cont'd

Sample No. & soil group	0.5 N NH_4F		Bray's No.1 at various soil:extractant ratio						Bray's No.2	Olsen	Resin adsorption
	pH 7.2	pH 8.2	1:7	1:10	1:20	1:30	1:40	1:50			
P-29,ATL	19.6	17.4	4.4	4.8	7.8	12.9	10.6	16.9	67.3	4.6	5.4
P-30,"	15.0	10.8	2.9	3.4	5.0	7.7	6.9	10.7	58.0	4.1	6.4
P-31, RY	18.2	19.0	10.0	6.2	9.1	9.5	10.5	15.3	26.7	5.7	8.3
P-32, "	15.0	15.3	8.6	4.9	8.1	7.5	10.2	13.2	22.6	4.6	10.5
P-33, "	17.9	19.2	8.9	7.1	9.3	11.4	14.0	14.5	41.6	6.9	15.8
P-34, "	19.0	17.0	10.0	8.4	4.5	12.8	16.0	18.3	32.6	6.5	13.0
P-35,"	24.5	19.7	18.1	8.3	7.5	6.3	11.4	14.5	34.2	11.0	7.0
P-36, "	26.5	20.3	16.0	6.9	8.7	7.2	11.2	15.0	35.2	12.2	8.4
P-37, "	30.3	22.2	21.9	12.4	13.5	17.7	16.2	18.9	50.5	10.5	13.0
P-38, "	18.6	12.3	12.0	5.9	6.0	8.4	8.6	10.0	30.0	5.3	6.2
P-39, R	35.1	30.1	11.9	14.2	18.4	19.9	21.7	33.2	67.0	14.7	21.6
P-40, "	25.5	15.8	6.5	6.1	7.3	7.5	9.3	17.0	36.0	15.4	4.8
P-41, "	31.3	21.7	8.1	8.7	10.8	12.5	13.5	20.3	46.2	9.1	4.4

Table 8 shows the P extracted by varies methods from the 47 sites used in the field experiments.

The NH_4F-P extracted at pH 7.2 was always higher than that extracted at pH 8.2. The explanation to this is related to the form of P soluble at different pH levels. An appreciable amount of Fe-P was extracted at pH 7.2, while at pH 8.2, most of the extractable P was Al-P (Fife, 1959). The values of extractable P by Bray's No.1 methods were usually increased with an increase in soil-to solution ratio. The wider soil/solution ratio provided sufficient H^+ to react with $CaCO_3$. Thus more Ca-P was extracted (Smith et al, 1957). Bray's No.2 solution is a strong acid-fluoride extractant which extracted much more P from the soils than occurred with the other extractants.

Table 9 shows the coefficients of correlation between the P extracted by various methods and sugarcane yields in both the pot tests and the field experiments. Of the 41 pot tests soils, the extractable P by any of the methods were highly correlated with sugarcane yield at the 0.1% level of significance, except for Bray's No.2 test. The highest correlation r=0.7438, was obtained with the Olsen extractant. The second highest correlation was obtained with Bray's No.1 extractant, at a soil/solution ratio of 1:10. These results were anticipated because 65% of the soils were alkaline in reaction.

When the soils in the 41 pot tests were grouped into four pH classes ($<7.0, \geq 7.0, <7.5, \geq 7.5$) different coefficients were obtained. The results can be summarized as follows:

1. The highest correlation between soil extractants and yield were obtained with the Olsen method irrespective of pH level.
2. With the Bray's No.1 test, the correlation coefficients were increased somewhat when the soil to solution ratios were increased, especially for those soils with a pH greater than 7.5. This agrees with the work of Smith et al (1957). The coefficients, however were not as high as those involving the Olsen extract. For soils with a pH of less than 7.0, the highest correlation coefficient was obtained with a 1:10 soil: solution ratio with Bray's No.1 extract.
3. Bray's P_2 extractant was significantly correlated with sugarcane yields in the pot tests, but the coefficients were lower than some of those obtained with the P_1 extract and lower than all of those obtained with the Olsen extract.
4. The resin adsorption-P was correlated best with yield response on soils with a pH level in excess of 7.0.
5. Reasonably high and statistically significant correlation coefficients were obtained with the NH_4F solutions. Regardless of soil pH, the highest correlation coefficients were obtained with the NH_4F adjusted to pH 7.2. This is probably due to the fact that an alkaline fluoride solution extracts more Al-P and Fe-P at pH 7.2 than at 8.2.

Table 8. Soil P (ppm) extracted with various methods from soil at sites used for field experiments

Sample No. & soil group	0.5 N NH_4F		Bray's No.1						Bray's No.2	Olsen
	pH 7.2	pH 8.2	1:7	1:10	1:20	1:30	1:40	1:50		
F-1A, H	26.8	19.5	3.8	5.8	16.2	25.8	30.0	30.0	84.3	9.2
F-2A, "	26.4	22.1	1.0	5.3	11.8	14.7	23.2	23.5	106.9	14.6
F-3A, "	24.7	16.1	2.8	4.0	7.8	9.3	18.8	26.8	74.3	5.3
F-4A, "	26.4	22.0	7.1	8.2	15.5	14.1	23.6	26.0	78.4	27.3
F-5A, "	16.5	10.7	1.9	7.3	11.0	17.9	22.4	24.9	17.5	5.9
F-6A, "	11.5	10.5	1.4	6.4	8.5	13.1	17.6	20.4	13.5	4.8
F-7A, "	21.8	14.5	3.3	8.8	15.1	21.9	25.9	35.0	86.0	8.4
F-8A, "	12.5	9.2	1.8	5.4	9.2	15.1	19.5	22.1	76.3	2.3
F-9A, "	30.4	18.5	3.6	11.8	17.2	26.3	31.9	42.3	102.0	5.1
F-10A, AS c	44.8	34.7	2.6	10.4	20.2	25.2	34.4	48.0	130.8	16.9
F-11A, "	21.5	15.1	8.8	12.7	16.6	15.9	20.8	28.8	145.3	9.3
F-12A, "	33.7	25.3	33.7	34.4	41.6	44.7	48.0	53.0	134.3	19.9
F-13A, "	35.7	29.8	22.3	27.1	33.3	28.1	47.0	43.8	54.0	16.3
F-14A, "	14.0	9.6	4.7	5.9	11.9	11.9	16.2	19.3	18.0	5.1
F-15A, "	7.3	3.8	1.6	3.0	5.8	7.7	13.4	16.1	66.0	2.7

Table 8. cont'd

Sample No. & soil group	0.5 N NH_4F		Bray's No. 1						Bray's No. 2	Olsen
	pH 7.2	pH 8.2	1:7	1:10	1:20	1:30	1:40	1:50		
F-16A, AS_c	58.0	41.1	0.8	1.5	21.6	34.4	46.7	55.4	100.8	12.7
F-17A, AS_n	17.9	9.7	6.7	9.2	14.4	16.2	20.4	22.5	107.5	8.4
F-18A, "	23.7	15.9	8.7	8.7	16.4	21.8	27.8	31.0	180.0	14.6
F-19A, "	33.8	29.8	17.9	21.8	22.0	28.2	30.6	35.8	70.0	12.8
F-20A, "	38.5	32.8	24.0	26.3	33.4	41.1	45.6	57.0	75.8	21.4
F-21A, "	23.3	15.0	12.8	13.9	20.2	24.8	28.1	28.6	30.0	16.4
F-22A, "	18.1	11.3	9.7	12.0	17.8	21.2	25.0	25.0	30.7	7.6
F-23A, ATL	17.9	16.9	3.3	4.5	11.2	15.5	18.4	20.8	144.8	4.7
F-24A, "	13.0	11.0	0.9	3.4	8.2	15.3	18.4	19.0	105.1	4.1
F-25A, "	30.0	22.1	2.8	6.6	12.7	18.9	23.0	26.0	106.0	6.8
F-26A, "	25.8	18.7	12.9	19.1	23.3	25.8	32.4	36.3	117.3	6.4
F-27A, "	19.7	14.7	5.7	5.9	12.8	18.5	22.0	26.0	47.7	6.2
F-28A, "	15.4	6.9	2.4	2.5	8.3	12.0	14.0	16.0	47.7	4.0
F-29A, "	14.7	10.3	2.6	2.6	11.2	15.3	18.4	19.5	51.5	5.2
F-30A, "	11.5	7.2	1.8	1.7	6.9	5.1	9.0	9.0	92.5	5.1
F-31A, "	14.8	9.4	0.9	1.6	6.5	11.1	11.6	16.0	35.3	3.7

Table 8. cont'd

Sample No. & soil group	0.5 N NH_4F		Bray's No. 1						Bray's No. 2	Olsen
	pH 7.2	pH 8.2	1:7	1:10	1:20	1:30	1:40	1:50		
F-32A, ATL	15.0	9.0	5.0	7.1	15.0	15.3	20.8	22.5	90.3	6.9
F-33A, "	14.1	7.4	4.4	4.4	11.2	15.3	18.4	20.5	115.6	6.0
F-34A, "	10.8	3.7	1.8	4.7	6.0	12.6	13.7	28.8	38.7	2.8
F-35A, "	15.8	6.2	6.2	11.6	15.5	22.3	26.1	32.6	28.0	4.4
F-36A, "	17.1	10.0	1.4	7.3	9.5	10.7	18.4	31.3	33.0	5.4
F-37A, "	17.5	10.2	4.0	8.2	12.5	13.5	20.7	42.5	66.0	6.3
F-38A, "	15.3	8.7	1.5	5.6	8.5	7.8	14.1	28.5	32.3	4.1
F-39A, RY	29.8	19.7	28.8	28.2	31.0	36.0	36.4	43.0	44.8	13.5
F-40A, "	27.5	21.4	11.6	11.7	16.2	18.0	20.8	27.5	16.0	9.6
F-41A, "	16.4	14.9	1.3	5.8	12.5	13.2	19.6	19.5	28.5	7.8
F-42A, "	9.2	7.3	0.9	2.5	10.7	10.1	12.3	14.8	7.7	2.5
F-43A, R	24.1	6.4	7.9	11.6	14.4	17.9	24.0	27.5	58.8	7.4
F-44A, "	40.3	39.1	5.6	12.6	23.0	28.8	33.6	39.0	73.2	20.9
F-45A, "	19.6	14.3	6.2	6.2	13.0	16.2	22.0	23.0	94.0	11.2
F-46A, "	33.1	28.1	3.2	9.7	23.1	25.4	30.8	31.0	41.0	16.4
F-47A, "	49.4	41.0	3.3	18.4	28.1	26.2	39.1	42.6	50.3	22.6

Table 9. Correlations coefficients of extracted P by various methods with sugarcane yields

Soils, pH and No. of samples	Bray's No.1 at various soil:extractant ratio					
	1:7	1:10	1:20	1:30	1:40	1:50
Soils from pot tests, n=41	0.6012***	0.6323***	0.6174***	0.4938**	0.5654***	0.5434***
Soils from pot tests, pH<7.5 n=18	0.2912	0.5361*	0.5004*	0.5012*	0.5421*	0.5932**
Soils from pot tests, pH⩾7.5 n=23	0.4390**	0.6657***	0.7613***	0.7398***	0.7958***	0.7803***
Soils from pot tests, pH<7.0 n=14	0.2681	0.6981**	0.5903*	0.6087*	0.6213*	0.6912**
Soils from pot tests, pH⩾7.0 n=27	0.5897**	0.6815***	0.7394***	0.6806***	0.7592***	0.7192***
Soils from field expt. showing P response, n=8	0.0792	0.3152	0.3654	0.5636	0.6855#	0.8436**

Significant at 10% level   ** Significant at 1% level

* " " 5% level   *** " " 0.1% level

Table 9. cont'd

Soils, pH and No. of samples	0.5 N NH_4F pH 7.2	0.5 N NH_4F pH 8.2	Bray's No.2	Olsen	Resin adsorption
Soils from pot tests, n=41	0.5817***	0.5787***	0.1761	0.7438***	0.5807***
Soils from pot tests, pH < 7.5 n=18	0.5479*	0.4516#	0.4926*	0.5664*	0.4073#
Soils from pot tests, pH ≥ 7.5 n=23	0.7321***	0.7002***	0.6932***	0.8255***	0.7690***
Soils from pot tests, pH < 7.0 n=14	0.7261**	0.5503*	0.4805#	0.7226**	0.4071
Soils from pot tests, pH ≥ 7.0 n=27	0.6653***	0.6572***	0.4820*	0.7710***	0.7541***
Soils from field expt. showing P response, n=8	0.6296#	0.6593#	0.0746	0.2754	———

Significant at 10% level ** Significant at 1% level

* " " 5% level *** Significant at 0.1% level

In summary, an analysis of the 41 pot tests suggests that Olsen's test and Bray's No.1 test with a soil/solution ratio of 1:10 are most reasonably correlated with the available P levels in the soils of TSC's plantations.

Similar correlations were made between the extractable P from field soil and the percent yield of sugarcane (Table 9).

The correlation coefficients are calculated for only those 8 sites which showed statistical significance between P application and % yield. The results are summarized as follows:

1. Though the pH range of the soil at the 8 sites ranged between 7.8 and 8.4, the Olsen extraction was not highly correlated with % yield as was the case with pot tests.
2. Increasing the soil to solution ratio with the Bray's P_1 extractant greatly improved the correlation coefficients for soils with pH values greater than 7.5.
3. Bray's P_1 extractant at a 1:50 soil to solution ratio produced the highest correlation coefficient (r=0.8436) with a significance at the 1% level.
4. With the NH_4F extraction, the coefficients from field tests were decreased slightly as compared to those pot tests with pH greater than 7.5.
5. Bray's P_1 extractant at a 1:7 soil to solution ratio and Bray's P_2 extractant showed extremely low correlation coefficients.

The % yield and the extractable P with Bray's P_1 solution at a 1:50 soil to solution ratio have been plotted in graph form (Fig. 2).

In summary, the correlation analysis of extractable P with % yield in the field experiments showed that Bray's P_1 extractant at a soil to solution ratio of 1:50 would be the best choice for evaluating soil P that is available to sugarcane. As discussed previously, this solution extracts Al-P, Fe-P and Ca-P which are all used by sugarcane. This extractant and soil to solution ratio should be well adapted for evaluating the P status of soils use for sugarcane in Taiwan.

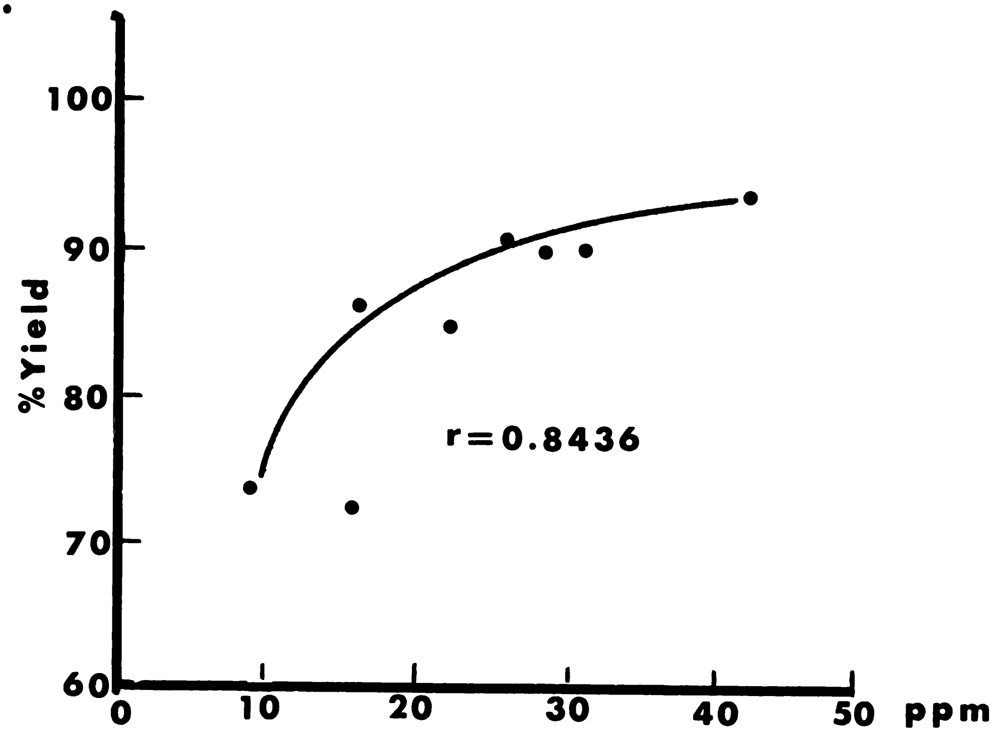

Fig. 2. Relationship between % yield of sugarcane and extractable P by Bray's P_1 extractant at a 1:50 soil to solution ratio.

Leaf analysis as an indication of the N, P and K status of sugarcane grown in pot tests

Since no P was added to the soil in the pot tests, an evaluation of N, P and K status of the vegetation was attempted. Leaf analyses were made by the methods currently used by the Taiwan Sugar Research Institute. Tests were made after 3, 9, and 12-months of growth. Table 10 shows the results of the analysis of sugarcane leaves grown in the pot tests.

For N, no samples were found to indicate a nitrogen deficiency in three month old sugarcane grown in the pots. At nine months of age there were 8 samples that tested below the critical level of 1.7. With two or possibly three exceptions the N levels were only slightly below the standard critical level. If the standards are realistic, nitrogen was not a limiting factor at nine months. At 12 months, 12 samples tested below the critical level although most samples only slightly below the standard.

In these tests, 50% more N was used than would be recommended under field conditions, also in these tests the F 160 variety was grown. It is known that this variety is able to utilize more N than other varieties (Humbert, 1955) so that it is likely that not enough N was used in all instances. N deficiency developed primarily in sugarcane grown in those soils with lower organic matter contents.

Remembering that no fertilizer P was used in the pot

Table 10. Leaf analysis of sugarcane in pot tests (%)

Sample No. & Soil group	3 months ages			9 months ages			12 months ages		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
P-1, H	1.81	0.37	0.95	1.61	0.33	0.99	1.23	0.34	1.14
P-2, "	2.37	0.40	0.70	1.77	0.38	0.96	1.68	0.36	1.24
P-3, "	2.23	0.40	0.71	1.75	0.39	1.05	1.66	0.33	1.25
P-4, "	2.20	0.39	0.64	1.79	0.43	1.12	1.72	0.37	1.15
P-5, "	1.98	0.35	0.82	1.83	0.42	1.02	1.68	0.34	1.61
P-6, AS_c	2.01	0.41	0.84	1.81	0.51	1.02	1.69	0.48	1.21
P-7, "	2.63	0.40	0.70	1.70	0.48	1.07	1.63	0.33	1.17
P-8, "	2.65	0.32	1.02	2.06	0.42	1.04	1.66	0.35	1.27
P-9, "	2.01	0.38	0.77	1.70	0.39	0.95	1.60	0.35	1.18
P-10, "	2.17	0.38	0.90	1.97	0.42	0.99	1.66	0.31	1.01
P-11, "	2.04	0.38	0.80	1.79	0.47	1.03	1.63	0.38	1.21
P-12, "	2.17	0.37	0.89	1.72	0.43	1.02	1.72	0.36	1.19
P-13, "	2.31	0.42	0.63	2.25	0.49	1.06	1.71	0.34	0.92
P-14, AS_n	2.31	0.40	1.28	2.13	0.38	1.04	1.69	0.37	1.21

Table 10. cont'd

Sample No. & soil group	3 months ages			9 months ages			12 months ages		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
P-15, AS_n	2.51	0.47	1.17	1.59	0.44	1.07	1.67	0.38	1.28
P-16, "	2.24	0.36	0.91	1.70	0.47	1.01	1.72	0.38	1.22
P-17, "	2.23	0.35	0.82	1.77	0.40	1.04	1.64	0.31	1.07
P-18, "	2.32	0.41	1.27	1.86	0.40	1.13	1.94	0.42	1.32
P-19, ATL	2.34	0.33	0.83	1.53	0.22	0.97	1.41	0.18	0.98
P-20, "	2.35	0.45	0.57	1.75	0.40	1.08	1.55	0.33	1.00
P-21, "	1.76	0.37	1.10	1.75	0.34	0.98	1.38	0.25	1.06
P-22, "	1.74	0.37	0.89	1.78	0.43	0.92	1.28	0.34	1.14
P-23, "	2.63	0.40	0.99	1.73	0.42	0.92	1.64	0.32	1.14
P-24, "	1.70	0.34	0.66	1.64	0.40	1.10	1.34	0.35	1.05
P-25, "	1.76	0.46	0.85	1.72	0.45	1.10	1.61	0.37	1.24
P-26, "	1.93	0.41	0.94	1.98	0.42	0.98	1.62	0.34	1.27
P-27, "	2.08	0.35	0.89	1.79	0.42	1.06	1.60	0.32	1.14
P-28, "	2.32	0.34	0.96	1.77	0.41	0.88	1.60	0.23	1.14

Table 10. cont'd

Sample No. & soil group	3 months ages			9 months ages			12 months ages		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
P-29,ATL	2.54	0.42	0.61	1.73	0.43	1.02	1.61	0.25	0.94
P-30, "	2.38	0.38	1.14	1.73	0.32	1.10	1.46	0.20	1.08
P-31, RY	2.48	0.41	1.02	1.71	0.40	1.04	1.78	0.34	1.20
P-32, "	2.46	0.44	1.31	1.48	0.39	0.97	1.52	0.29	1.18
P-33, "	2.15	0.40	0.97	1.78	0.38	1.07	1.60	0.33	1.12
P-34, "	1.92	0.39	0.82	1.83	0.39	0.91	1.27	0.32	1.40
P-35, "	2.16	0.38	0.61	1.55	0.32	1.08	1.59	0.34	1.15
P-36, "	2.17	0.38	0.76	1.41	0.32	1.00	1.56	0.34	1.05
P-37, "	2.37	0.48	1.08	1.83	0.49	0.94	1.55	0.36	1.15
P-38, "	2.32	0.41	0.82	1.56	0.33	1.09	1.66	0.31	1.12
P-39, R	2.01	0.33	1.00	1.91	0.48	1.25	1.61	0.34	1.25
P-40, "	2.60	0.42	1.15	2.06	0.46	1.21	1.70	0.33	1.21
P-41, "	2.45	0.44	1.12	1.91	0.48	1.12	1.61	0.33	1.38

tests, it is interesting to note the supplying power of these soils. The P supply was sufficient in all of the soils to take care of the needs of the sugarcane for the first three months of growth. At the end of nine months, leaf analysis for P suggested that 34 out of 41 soils were still supplying adequate amounts of P. Apparently, the P supplying power of the soils studied was fairly adequate. At the end of 12 months, leaf analysis for P showed that 33 of the soils were still able to supply adequate amounts of P. Most of the P deficiency occurred in the ATL and RY soil groups. Heavy applications of P fertilizer to the R soils apparently had resulted in a build up of P so that adequate levels were available to the sugarcane crops.

An unexpected K deficiency was observed with the 3-month sampling. Approximately 70% of the samples contained deficient levels of K, less than 1.0%. The majority of the deficient samples represented sugarcane grown on the H, AS_c, ATL, and RY soils. At a later date the sugarcane out grew the K deficiency and at 9 months only one sample suggested a K deficiency. At the time of the 12 months sampling, none of the sugarcane was considered to be deficient in potassium.

The K deficiency early in the season could be attributed to the high K-fixation capacity of the soils involved in this study. Lai and Lee (1941) reported that the K-fixation capacity of 12 representive Taiwan sugarcane soils was highest in those soils with high clay contents, high pH levels, and where weathering of the soils was not great. Thirty out of the 41 soils studied were either high in clay (H soil group), high in pH (AS_c, ATL, soil groups), or not intensively weathered (AS_c, AS_n, and ATL soil groups). The K-fixation capacity of the soils involved in this research would be expected to be high. It appears likely that K-deficiency could develop during the early stage of growth if significant amounts of K fertilizer were fixed. At a later date as K was released from the colloidal complex, deficiency would disappear.

In summary, while every effort was made to supply ample N and K in this experiment, on occasion and on some soils deficiencies as indicated by leaf analysis did occur. In general, the deficiencies probably were not severe enough to invalidate the results as they pertained to P.

Relatively rapid P fixation capacity of selected soils

Twenty four soil samples were selected from the TSC's plantations (19 samples were also used for the pot tests and field experiments already described) for evaluating the relatively rapid P-fixing capacity of soils.

Bass and Sieling (1950) pointed out that there is no absolute value for the P-fixing capacity of a soil, because changes in conditions of determination could possibly change the value obtained. They developed an indirect method for determing the relative phosphate-fixing capacity of acid soils based on an extraction of the Fe and Al under controlled conditions. Rennie and McKercher (1959) indicated that the fixation of P may proceed at two rates: a rapid one(being completed within a few hours) and a much slower one. They found that a shaking time of 6 hours was preferable for the completion of the adsorption reaction and for the elimilating of complicating secondary reactions. Olsen & Watanabe (1957) made use of the Langmuir isotherm to calculate a P adsorption maxima in soils. Singh (1969) indicated that the Langmuir adsorption equation may be used to predict P concentrations in soil solutions.

In the acid soils 33.7% of the P added was rapidly adsorbed (Table 11). The same value for the alkaline soils was 25.0. In other words, on the average approximately ¼ to 1/3 of P fertilizer was rapidly adsorbed on the soils studied. The acid soils adsorbed more P than the alkaline soils because of the higher Fe and Al contents. The exposed Fe and Al atoms of the crytal lattice were responsible for the activity of the clay in the P-fixation process. Due to the lower surface reactivity of adsorbed P in alkaline soils it appeared that the amount of soluble P taken up by plants would be higher in alkaline soils than in acid soils under equal soil conditions.

The clay as well as organic matter contents appeared to be equally important to the P adsorption capacity of soils. In nine soil samples taken from pot tests (soils with two

Table 11. Locations, pH and relatively rapid P-fixing capacity of selected soils

Sample No.	Plantations & field No.		pH	P in suspension (ppm)	P fixed (ug/gm)	% of P fixed
H-1*	Penchou	34	8.0	36.0	102.5	22.2
H-2**	Taikong	11	8.1	31.3	150.0	32.4
H-3**	Yenshuikong	24	8.0	33.0	132.5	28.6
H-4*	Machouhou	40	7.2	20.0	262.5	56.8
AS_c-1**	Tsenwen	4	8.0	36.3	100.0	21.6
AS_c-2**	Nanching	35	8.1	35.0	112.5	24.3
ATL-1**	Yuanpu	19	7.9	39.3	70.0	15.1
ATL-2*	Shuiwei	9	8.2	33.7	125.0	27.0
ATL-3*	Tuku	57	8.5	38.3	80.0	17.3
ATL-4	Liukuaitso	11	8.6	39.5	67.5	14.6
ATL-5*	Erhlin	57	8.1	33.7	125.0	27.0
ATL-6**	Tsaitso	24-1	8.2	40.7	55.0	11.9
ATL-7**	Chunglan	99-1	8.1	36.0	102.5	22.2
ATL-8*	Achuan	3	8.4	33.0	132.5	28.6
				Alkaline soils average:	115.5	25.0

Table 11. cont'd

Sample No.	Plantations & field No.		pH	P in suspension (ppm)	P fixed (ug/gm)	% of P fixed
R-1*	Tapumei	60	5.8	26.0	202.5	43.8
R-2	Taipinting	14	5.4	15.7	305.0	65.9
R-3**	Chihsing	3	6.1	33.0	132.5	28.6
RY-1	Napalin	4	6.2	37.7	85.0	18.4
RY-2	W. Chingpu	27	6.1	37.5	87.5	18.9
RY-3*	Yuehmei	24	6.0	29.5	167.5	36.2
RY-4	Chiapa	12	5.0	39.7	65.0	14.0
RY-5*	Shalun	36	6.4	28.0	182.5	39.5
AS_n-1**	Wantouliu	33	6.8	27.7	185.0	40.0
AS_n-2*	Hsintso	16	5.7	31.7	145.0	31.3
				Acid soils average:	155.7	33.7

Notes: 1. 46.25 ppm P was added for each soil sample.
2. * soils also used for field experiments.
3. ** soils also used for pot tests.

asterisks in Table 11) the P adsorption increased with an increase in clay and organic matter levels (Table 3).

In summary, the fixation capacity appears to be an essential and significant facts to consider when making P fertilizer recommendations.

P recommendations for sugarcane on TSC's plantations

P fertilizer recommendations are discussed and proposed on the basis of the previously discussed studies including:

1. Soil P test values with Bray's No.1 extractant at a soil/solution ratio of 1:50 from pot culture experiments and from field trials.
2. Sugarcane yield data of 47 field experiments conducted in 1970-1972 (Table 2).
3. Natural soil moisture condition as indicated by soil management groups which was proposed by the author.
4. Relatively rapid P fixation capacity of the soils.

The ranges and average values of P extracted from the surface soil of pot tests and field experiments of each soil group with Bray's No.1 solution at a soil/solution ratio of 1:50 are as follows:

Soil group	No. of sample	Range	Average (ppm)
H:	13	42.3-11.8	25.2
AS_c:	13	55.4-16.1	36.1
AS_n:	9	57.0- 7.1	27.8

Soil group	No. of sample	Range	Average (ppm)
ATL:	28	56.5- 5.5	22.5
RY:	8	43.0-14.5	21.0
R:	8	42.6-17.0	29.2

As indicated above, the average values of Bray's No.1 extractable P at a soil/solution ratio of 1:50 varied from a high of 36.1 ppm for the AS_c soil group to a low of 21.0 ppm for the RY soil group. On the basis of these data, and the regression analysis of the 8 field experiments which showed response to P application, it seem logical to reduce the amount of P that is currently recommended. Fifty to 75 kg/ha of P_2O_5 may well serve as a middle of the range recommendation.

The % of P rapidly adsorbed on the R soil averaged 46.1% (Table 11). The values of the other soil groups studied were much less than in the R soil. Thus it appears likely that more P should be added to an R soil for optimum growth. An upper limit of 100-125 kg/ha P_2O_5 is recommended.

Soil moisture condition will influence the rate of P difussion to plant roots. In order to make P use more efficient on those soils with favorable ground water supplies, more P should be applied to the soils with a good natural moisture condition. The ATL soil group was the lowest in available P and the % of P rapidly adsorbed. Therefore the high rate of 100-125 kg/ha of P_2O_5 is recommended for the ATL soil with natural moisture conditions in the a_ob and a_oc classes.

The proposed P fertilizer recommendations for sugarcane on TSC's plantations are summarized in Table 12.

Symbols used in Table 12 denoting natural moisture conditions of Taiwan sugarcane soils are proposed by the author as an important parameter for classifying TSC's soils into soil management groups. It may be summarized as follows:

Natural drainage condition	Ground water supply condition	Coarse texture	Medium texture	Fine texture	Symbol
good	good	80-100	100-140	120-150 cm	a_0
	fair	100-130	140-180	150-200	a_1
	poor	>130	>180	>200	a_2
fair	good	60-90	80-120	100-130	b
	fair	-	-	-	-
	poor	-	-	-	-
poor	good	<60	<80	<100	c
	fair	-	-	-	-
	poor	-	-	-	-

Table 12. P recommendations for sugarcane on TSC's plantations

Soil P, (ppm)* / P_2O_5 recommendations (kg/ha) / Soils & moisture conditions**		125-100	100-75	75-50	50-25	25-0
H:	a_2c	---	<20	21-30	31-40	>41
AS_c:	a_1b, a_2, a_oc	---	25	26-40	41-50	51
		<25	26-40	41-50	>51	---
AS_n:	a_1b, a_2, a_1c	---	<20	21-30	31-40	>41
ATL: / RY:	a_1b, a_2a_1, a_2 / a_2	---	<15	16-25	26-35	>36
ATL:	a_ob, a_oc	<15	16-25	26-35	>35	---
R:	a_2	<20	21-35	36-40	>41	---

* Based on Bray's No.1 extractant at a soil to solution ratio of 1:50

** see page 66

SUMMARY AND CONCLUSIONS

Fourty one soil samples, representing six major soil groups were selected from TSC's plantations for a 15 month sugarcane pot culture experiment. The purpose was to investigate the availability of P in the soil as related to forms of P. P fractions were determined before and after cropping. Except in the R soils, Al-P represented the smallest quantity of P considered in these studies. The Al-P in the R group of soils also was present in the narrowest range--15.6 to 31.8 ppm. The quantity of each form of P removed from the soil by sugarcane varied with the soil group. Al-P was the form removed in the least amount ranging from 3.4 ppm to 8.0 ppm. However, if the amount of Al-P removed is expressed in % of the original Al-P content, Al-P becomes the greatest amount removed by cropping with sugarcane. The averaged value for the six soil groups was 25.4%.

A secondary important source of P taken up by sugarcane was Fe-P which averaged 20.4% for the six soil groups. The Fe-P was most abundant in the RY soil, the highest removable % occurred in R soils.

Ca-P was also removed by cropping and averaged 13.2%. Although the average levels of Ca-P in R and RY soil groups were lower than in the other soil groups, the percentage of Ca-P removed by cropping was highest in the two strongly weathered soil groups.

In the RY soils, the Red-P was most abundant. The highest % of Red-P removed by sugarcane occurred in the R soil group. On the average, 13.5% of the Red-P was removed by one cropping.

If the amounts of Ca-P and Fe-P are expressed as a % of total P removed, the Ca-P was removed in largest amount from the calcareous soils and the Fe-P from the acid soil.

Clearly, all of the four forms of P are important in sugarcane production. The Al-P and Fe-P are no doubt the most important sources of P utilized by sugarcane.

Two crop years of field experiments at 47 locations involving six widely distributed major soil groups were studied from 1970 to 1972 in order to correlate extractable soil P with sugarcane yields. The extractants used in this study were:

(1) 0.5N NH_4F at pH 7.2

(2) 0.5N NH_4F at pH 8.2

(3) Bray's No.1 at soil/solution ratios of 1:7, 1:10, 1:20, 1:30, 1:40, and 1:50

(4) Bray's No.2

(5) Olsen

(6) Resin adsorption (not in use for the soils of field experiments).

Correlation analysis demonstrated that the Bray's No.1

extractant at a soil/solution ratio of 1:50 was highly correlated with sugarcane yield or % yield at the 0.1% and 1% levels of significance in pot tests and field experiments, respectively. The results of these investigation are in agreement with previous work which suggested that when a dilute acid-fluoride solution is used at a high extraction volume ratio, it extracts Al-P, Fe-P as well as Ca-P. This improved the correlation between extractable P and yield responses. Therefore, the Bray's No.1 extractant at a soil/solution ratio of 1:50 is proposed as the best testing method for evaluating the P status in the soil of Taiwan's sugarcane fields. This is important because not all soils are deficient in P. Of those 47 field experiments, only 8 showed a statistically significant yield response to P fertilization.

Twenty four soil samples from TSC's farms (including 19 samples which were also used for pot tests and field experiments) were selected to determine the relatively rapid P-fixing capacity of soils. For the acid soils 33.7% of the total P added as fertilizer was rapidly adsorbed. The same value for the alkaline soils was 25.0%. The R soil group had the highest P-fixing capacity. The ATL soil group had the lowest. An adjustable rate of P fertilization has been recommended for those soils with high rapid P-fixing capacity.

P fertilizer recommendations for sugarcane on TSC's plantations are proposed on the basis of three factors. Soil test levels for P represent the intensity factor. The natural moisture condition of the soils are related to P availability represents the rate factor. And the rapid P-fixing capacity of soils represents the capacity factor. In order to produce the best P fertilizer recommendations, all three factors should be recognized.

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