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EFFECTIVENESS OF PHOSPHATE ROCKS IN COLOMBIAN SOILS AS MEASURED BY CROP RESPONSE AND SOIL PHOSPHORUS LEVELS

presented by

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has been accepted towards fulfillment of the requirements for

Ph.D. degree in Crop and Soil Science

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Date October 5, 1977

EFFECTIVENESS OF PHOSPHATE ROCKS IN COLOMBIAN SOILS AS MEASURED BY CROP RESPONSE AND SOIL PHOSPHORUS LEVELS

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Doctor of Philosophy

Department of Crop and Soil Sciences

1977

ABSTRACT

EFFECTIVENESS OF PHOSPHATE ROCKS IN COLOMBIAN SOILS AS MEASURED BY CROP RESPONSE AND SOIL PHOSPHORUS LEVELS

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Phosphate rocks from North Carolina, Central Florida, and Tennessee in the United States, from Huila and Pesca in Colombia, from Sechura in Peru, and from Gafsa in Tunisia were compared with triple superphosphate and/or basic slag as sources of P. A greenhouse experiment with guinea grass and a field experiment with cassava were conducted using an acid oxisol deficient in P, and a field experiment with beans was conducted on an acid andosol deficient in P. Yield responses to P fertilization were obtained in all three experiments.

Marked differences in agronomic effectiveness were noted between the sources of phosphate rock. The solubility of P in neutral ammonium citrate was a good measure of the availability of P in different phosphate rocks. Based on both crop response and citrate solubility, the effectiveness of the phosphate rocks was:

1. North Carolina = Gafsa = Sechura >
2. Central Florida = Huila >
3. Tennessee = Pesca

Crop response was related to soil P extracted with Bray P-1 solution, but response curves obtained with the phosphate rocks did not coincide with those obtained with superphosphate. Water-soluble P in the soil was well related to P uptake at high rates of application in the greenhouse, but did not adequately predict crop response in the field. Soil pH and exchangeable Ca increased with rate of application and relative availability of the phosphate rock, while Al saturation of the effective CEC decreased correspondingly.

This dissertation is dedicated to

Jenny, Linda and Patricia

ACKNOWLEDGMENTS

The author wishes to express gratitude to Dr. Bernard D. Knezek for the assistance and cooperation offered as Chairman of my guidance committee, and to Dr. Charles Cress, Dr. Boyd G. Ellis, Dr. Gerald Schwab, and Dr. Darryl Warncke for their participation on my guidance committee at Michigan State University.

Special appreciation is extended to Dr. Eugene C. Doll for his support and guidance throughout the course of this study, and for the part he played in making possible the investigations carried out in Colombia.

The author is indebted to the International Center for Tropical Agriculture (CIAT) in Cali, Colombia for the assistance and facilities which they provided. Special thanks are due to Dr. James Spain, Dr. Reinhardt Howeler, Dr. Luis Alfredo Leon and Mr. David Harris for their cooperation at CIAT. Acknowledgment is also given to Ing. Agr. Carlos Medina, Ing. Agr. Miguel Angel Ayarza, Ing. Agr. Luis Fernando Cadavid and the entire staff of the CIAT Soils Laboratory for their assistance in the field and in the laboratory.

This research was made possible through financial assistance provided by the International Fertilizer

Development Center (IFDC), Muscle Shoals, Alabama. Appreciation is due to Dr. Richard Booth of IFDC for his assistance with the computer analysis.

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INTRODUCTION

Large areas of agriculturally undeveloped soils are found in the tropics which are strongly acid and deficient in phosphorus (P). The use of phosphate rock as a source of P is attractive for these soils since it is a relatively inexpensive source of P. In countries like Colombia which have local deposits of phosphate rock, both the development costs and energy investments of the deposits would be much lower if the finely ground phosphate rock could be applied directly to the soil.

Many experiments to evaluate the effectiveness of directly-applied phosphate rock have been conducted during the past 60 years, but the results of these experiments have been extremely variable. Generally, broadcast applications of finely ground phosphate rock can result in increased yields of many crops grown on P deficient acid soils. However, the magnitude of this response has almost always been less than that obtained with soluble phosphates, and the degree of response has been erratic.

In the early experiments, only one source of phosphate rock was generally used, with yields being compared to those obtained with superphosphate. In more recent years, however, it has been recognized that different phosphate rocks vary with respect to their effectiveness as sources of P for plants. The use of the more reactive phosphate rocks can produce yields economically attractive when compared to those obtained with the more costly superphosphate. It is probable that the real fertilizer value of phosphate rock cannot be adequately evaluated by the results of a single short-term cropping experiment, since the relative residual effects must also be considered.

The majority of the investigations conducted with phosphate rock have concentrated primarily on crop yields as the measure of phosphate rock effectiveness with little effort to determine the effect on soil chemical parameters. If phosphate rock is to be used as a fertilizer, decisions regarding its application should be made on the basis of the reactivity of the material to be used and of soil test correlations developed specifically for phosphate rock rather than using those obtained from experiments with soluble P sources.

The objectives of this investigation, therefore, were to:

1. Evaluate the agronomic effectiveness of phosphate rocks from sources with different mineral composition.

2. Evaluate relevant soil reactions associated with the direct application of the phosphate rocks, and
3. Relate the results of the first two objectives to the citrate solubility of the phosphate rock to aid in selection and utilization of phosphate rocks for direct applications.

LITERATURE REVIEW

Ground phosphate rock has been used as a source of fertilizer phosphorus for more than 150 years (Terman, 1971). Phosphate rock used for direct application accounts for only a small proportion of the phosphate fertilizer utilized worldwide, but its continued importance is shown by the fact that the amount of phosphate rock consumption rose from 1.8×10^6 tons in 1954 to 4.0×10^6 tons in 1974 (Annual Fertilizer Review, 1974). Most of the increase in consumption has been in the U.S.S.R., Africa, Asia, and South America. Consumption in the United States began to decline in the mid-1960's and continues to be low.

Deposits of phosphate rock have recently been found in a number of developing countries. In Colombia, phosphate rock reserves and resources are now estimated at 690×10^6 tons (G. H. McClellan, personal communication). Colombia's soil resources include extensive areas which are acid and P deficient. Direct application of finely ground phosphate rock in these undeveloped areas may represent the most rapid and economical means of utilization of the new phosphate resources.

Agronomic Potential of Ground Phosphate Rock

The effectiveness of directly applied phosphate rock has been reported over the years to be relatively low when compared to superphosphate. However, until recently, the differences in the agronomic potential of phosphate rocks due to the source of the deposit had not been recognized (Terman, 1976). As a result, the sources largely utilized for direct application were not those best adapted for that use. Russell (1973) states that "rock phosphates differ considerably in their fertilizer value, ranging from samples that are completely ineffective on all soils and on all crops to others that can be as good as superphosphate for some crops with a pH below 6."

Bartholomew (1935) recognized the difference in the availability of P from different phosphate rocks. In an experiment with six types of phosphate rock, he reported that P availability to sudangrass decreased as the fluorine (F) content of the rock increased. In supplemental tests, he found that F itself was not detrimental to plant growth and therefore attributed the correlation to an effect of the F on the solubility of the phosphate rock.

Later experiments by Brown and Jacob (1945) and by Bennett, et al. (1957) showed no definite correlation between F content and yields of crops. Comparisons between

P availability and the citrate solubility, however, did show strong correlation where seven sources of phosphate rock were compared in the greenhouse using sudangrass and ladino clover as the test crops. Other experiments in which the citrate soluble P content of phosphate rock was a good measure of P availability were reported by Caro and Hill (1956), Armiger and Fried (1957), Terman, et al. (1970), Engelstad, et al. (1972), and Engelstad, et al. (1974).

Armiger and Fried (1957) compared the same ten sources of phosphate rock which previously had been characterized by Caro and Hill (1956) in greenhouse experiments with buckwheat and alfalfa. In addition to the good correlation between agronomic response and both ammonium citrate and citric acid solubility, they noted that the most precise relationship was between the apatite-bound carbonate in the phosphate rock and the agronomic response. Lehr and McClellan (1972) reported that the "bound-carbonate" was due to the carbonate substitution for phosphate (P_2O_5) within the crystal lattice of the apatite. Their work identified the apatite in many phosphate rocks as a range of substituted fluor-apatites with the average formula:

$$Ca_{10-0.42x}Na_{0.3x}Mg_{0.12x}(PO_4)_{6-x}(CO_3)_xF_{2+0.4x}$$

For the phosphate rocks which contained these substituted apatites, the chemical reactivity of the rock increased as the degree of carbonate substitution increased.

The ratio between the citrate soluble P_2O_5 and the theoretical content of P_2O_5 in the apatite was termed the Absolute Citrate Solubility (ACS) by Lehr and McClellan (1972). Since the ACS was determined by the properties of the substituted fluor-apatites, the ACS index does not apply to the phosphate rocks which contain hydroxy-apatites. Engelstad, et al. (1974) found a better relationship between yields of flooded rice and the ACS index than was obtained with the standard ammonium citrate solubility test which is the standard method in the United States (AOAC, 1950). Other measures of phosphate rock reactivity outside of the United States include P extractions with 2% citric acid and 2% formic acid.

Phosphorus Availability from Phosphate Rock

The reactivity of a phosphate rock is a measure of its potential as a source of fertilizer phosphorus relative to other phosphate rocks. Phosphate rock, however, is relatively insoluble and rarely produces initial yields equal to those obtained with soluble superphosphate. Plant response to P is a function of the concentration of P which can be maintained in the soil solution (Khasawneh, 1971; Khasawneh and Copeland, 1973; Soltanpour, et al., 1974). When a soluble P source such as superphosphate is applied to an acid soil, the P rapidly enters into solution and is immediately available for plant uptake or retention by the soil (Lindsay, et al., 1962). The major portion of the P obtained by the plant following application of a soluble fertilizer, therefore, is from the reaction products.

Phosphate rock, however, is relatively insoluble and its dissolution in the soil is slow. Russell (1973) states that most phosphate rocks can maintain a P concentration of 10^{-6} to 10^{-7} $\underline{M}$ (.031 to .003 ppm) in mildly acid soils, and possibly more as the acidity increases. He classified a soil with a concentration of 10^{-6} $\underline{M}$ P as being deficient. The concentration of P in the soil solution required for maximum growth varies with the plant. Various levels which have been reported include 0.3 ppm P for wheat (Ozanne and Shaw, 1968), 0.2 ppm P for millet (Fox and Kamprath, 1970), and 0.1 ppm P was sufficient for 90% of the maximum yield of rice (Hossner, et al., 1973).

It has been shown that the mechanism which most commonly limits the uptake of P by plants is the diffusion of P to the thin absorption zone surrounding the plant root (Barber, et al., 1963; Olsen, et al., 1962; Olsen and Watanabe, 1963 and 1966). Because the concentration of P made available during the dissolution of phosphate rock is low, the diffusion of P from the rock particle is small.

As a result, distribution of the phosphate rock in the soil as affected by fineness of grinding, method of application, and rate of application, all influence agronomic effectiveness.

In an early investigation regarding the fineness of grinding of phosphate rock, Salter and Barnes (1935) found no significant difference in efficiency by grinding so that 97% would pass 100 mesh as compared to 60% passing 100 mesh. The phosphate rock utilized in their experiment, however, was the Tennessee brown rock which is relatively unreactive. Joos and Black (1950), also using the Tennessee brown phosphate rock, did find an increase in effectiveness with material that was ground to less than 400 mesh.

Armiger and Fried (1957) evaluated the effect of fineness of grinding on several rocks that did vary in reactivity. They reported that the finest material tested (-325 mesh) was only slightly more effective than material less than 100 mesh in size. It was also noted that the citrate solubility of the various sources influenced the agronomic effectiveness more than the difference in the fineness of grinding. Increased yields with decreased particle size were also reported by Howeler and Woodruff (1968) with igneous apatite from Missouri, and by Fassbender (1967) with Sechura phosphate rock from Peru.

In an incubation study with North Carolina phosphate rock, Barnes and Kamprath (1975) found that 60 days was required for maximum P availability on a Hyde soil at pH 4.1 when the rock was ground to 100-115 mesh, while 90 days was required when 32% of the material was <65 mesh. At pH 4.7, both size fractions required 90 days, but the courser material was only 67 to 83% as effective.

In reviews of experiments with finely ground phosphate rock in the United States (Rogers, et al., 1953), and in the United Kingdom (Cooke, 1956), it was concluded that the small degree of increase in P availability obtained by grinding to extreme fineness was not justified. Cooke (1956) suggested that it was not necessary to grind finer than for 80% of the material to be less than 100 mesh.

Soil and Plant Factors Related to Utilization

Soil pH has been identified throughout the years as the single most important agronomic factor influencing the utilization of P from directly applied phosphate rock (Joos and Black, 1950; Barnes and Kamprath, 1975). In order for a raw phosphate rock which has been finely ground and applied to the soil to release P, the rock must undergo a partial dissolution which, due to its apatitic composition, is enhanced by an acid environment. Jones (1948) found that at pH 5.0, 235% more P was taken up by rye from phosphate rock than when the soil was limed to pH 6.5.

In an experiment with oats, Ellis, et al. (1955) found the yield and P uptake from phosphate rock to be equal to superphosphate between pH 5.0 and 5.5, but when limed to pH 7.0, the availability from phosphate rock was greatly diminished.

In a series of field experiments in the United Kingdom between 1951 and 1953, Russell (1973) reported that the relative effectiveness of Gafsa phosphate rock (PR) was greatly reduced for both swedes and potatoes with the pH above 6.5 as shown below:

	Kg of P from Superphosphate Required to Give Equivalent Yield Obtained with 100 Kg Gafsa PR		
	$<$pH 5.5	pH 5.5-6.5	$>$pH 6.5
Swedes	91	86	12
Potatoes	34	37	4

In greenhouse experiments with corn, Barnes and Kamprath (1975) reported that with a pH at or below 5.2 on Hyde and Cecil soils, North Carolina PR was 73 to 100% as effective as superphosphate. However, when these soils were limed to pH 5.7 and 6.0, respectively, there was no response to the phosphate rock. It was suggested that the effective pH range for directly applied phosphate rock was pH 5.8 to 6.2 for soils low in organic matter and pH 4.8 to 5.0 for organic soils.

Paauw (1955) showed that the optimum pH for the release of P from phosphate rock varied with the source of the rock. He found that effective P utilization by rye and potatoes was encountered at a pH in KCl of 4.2 or lower with Gafsa PR, while pH 3.8 or lower was required with Florida PR. It was noted, however, that although there was greater P availability in these pH ranges from phosphate rock, it was too acid for optimum plant growth. An example where liming showed beneficial effects to plant utilization of P from phosphate rock was reported by Bennett, et al. (1957). In this case, lime was applied in amounts which did not raise the pH sufficiently to inhibit dissolution of the phosphate rock, but did provide improved calcium (Ca) nutrition. Phosphorus uptake by sudangrass and clover was greater from phosphate rock on an unlimed Eutaw clay (pH 5.0, Exch Ca 11.7 meq/100 g) than on an unlimed Cecil clay loam (pH 5.0, Exch Ca 1.2 meq/100 g). However, when lime was applied, the P uptake from the phosphate rock on these two soils was similar.

Chu, et al. (1962), in a study with five soils from Virginia, found best response to phosphate rock on soils with low pH and relatively low free iron (Fe). With the high Fe soils, there was a greater total decomposition of phosphate rock, so the reduced response may have been due to a more effective removal of $H_2PO_4^-$ in solution by Fe compounds. Paauw (1955) and Ensminger, et al. (1967) also suggested that soluble P is more completely fixed by aluminum (Al) at the low pH levels. The importance of the P fixation capacity as related to the solubility of P fertilizers was addressed by McLean and Logan (1970). In their comparison of several phosphate fertilizers with varying water solubility, it was found that the P content of corn decreased as the water solubility of the available P increased when applied to a soil with a high fixation capacity (Venago series). In contrast, when grown on an Alexandria soil which has a low P fixation capacity, the P uptake by corn increased progressively with the percent water soluble P of the available P. Their findings suggest that phosphate rock (raw or partially acidulated) may be well adapted to acid soils with a high P fixation capacity.

McLean and Logan (1970) utilized six crops in Their studies of P fixation, and showed that the P fixation tendencies of the soil appeared to be more important than the crop species with regard to response to phosphate rock. It has been shown by other investigators, however, that the efficiency of utilization of P from phosphate rock varies considerably with different crops. The results referred to on page 11 from the United Kingdom (Russell, 1973) show the striking contrast in the effectiveness of Gafsa PR when utilized for the production of swedes and potatoes. The Gafsa rock was nearly as effective as superphosphate with swedes when applied to acid soils while it was only about one-third as effective as superphosphate with potatoes in the same pH range.

Rogers, et al. (1953) cited findings of Odland and Cox (1942) showing that barley, oats, parsnips, spinach, and endive grown for one year were more responsive to superphosphate than to phosphate rock (rock source not cited), but that cabbage, carrots, and rape showed phosphate rock to be more effective. McLean (1956) found that buckwheat responded better to phosphate rock than oats and alfalfa. Murdock and Seay (1955) reported that clover responded greater to P than wheat from both superphosphate and phosphate rock, but that the percent yield increase exhibited by clover as compared to wheat was strikingly more pronounced with phosphate rock than with superphosphate. They concluded that clover was a better feeder on phosphate rock than is wheat.

It is probable that the characteristics of the root system largely affect the differences in the plant species to utilize P from phosphate rock as compared to the soluble P fertilizers. With low concentrations of P released from the phosphate rock, diffusion of P from the site of the rock particle in the soil is minimal and the availability of this P to the plant may depend upon the probability of the roots coming in contact with the absorption zone surrounding the particle. This zone is much smaller with phosphate rock than with superphosphate. It was generalized by Rogers, et al. (1953) that most of the cereals are poor feeders on phosphate rock while buckwheat, and some of the legumes such as sweet clover, alfalfa, and red clover are strong feeders. It was concluded from greenhouse and field tests (Brown and Jacob, 1945) that raw phosphates can be used to better advantage for long season and perennial crops than for short season crops.

Residual Effect of P from Phosphate Rock

An assumption usually cited when comparing the value of phosphate rock to soluble P fertilizer is that, although the initial effect is usually lower for the phosphate rock sources, the higher residual value of these materials improve the overall fertilizer effectiveness. All phosphate fertilizers have residual value as demonstrated in areas which have received heavy applications of superphosphate and eventually show low crop response to further P application. Russell (1973) estimated that 20 to 30% of the applied P is taken up during a 4 to 5 year period following application of superphosphate.

When the slow dissolution of phosphate rock occurs in the soil, it is subjected to the same processes of adsorption by the soil and absorption by the plant as the P supplied by superphosphate. The concentration of P released by superphosphate, however, is initially very high, resulting in rapid and relatively complete reaction with the soil in the formation of Fe and Al phosphate compounds. The availability of this P is then controlled by the desorption characteristics of the soil. The P from phosphate rock, on the other hand, is much slower to enter the labile pool of P in the soil, and the availability of P to the plants may be controlled by the concentration of P in the soil solution which can be maintained by the phosphate rock over a long period of time.

Results obtained by Doll, et al. (1960) show that the yields of corn, wheat, and hay in Kentucky were nearly as high 25 years after the phosphate rock applications were discontinued as when frequent applications of phosphate rock had been continued. Moschler, et al. (1957) reported finding apatite in the sand fraction of a soil 40 years after receiving applications of phosphate rock, while Mattingly (1963) found that up to 80% of the phosphate rock in the sand fraction of a soil had not reacted three years after application. Chu, et al. (1962) found that at pH 5.2 in a Nason soil, only 18% of the applied phosphate rock had reacted after four years, and on a Wattston soil at pH 5.7, only 12% had reacted after ten years.

Results of comparisons between the residual effect of P from phosphate rock and superphosphate have frequently been published. In 1956, McLean compared finely ground Florida land pebble and superphosphate in a greenhouse test with oats. It was reported from this work that the superiority of superphosphate was not evident and that there was no significant difference in yield between the sources for the 3rd, 4th, or 5th crop of oats. The phosphate rock, however, had been applied at a rate of about 480 lb/ac P_2O_5 while superphosphate was at a level of only 180 lb/ac P_2O_5.

McLachlan (1959) compared equivalent levels of P from both phosphate rock and superphosphate as a pasture top-dressing on two acid soils. It was found in this case that superphosphate was better than phosphate rock in the early years, but that over a seven-year period the total yield of pasture was similar for both, even though each source showed a good residual fertilizer value. It was suggested that superphosphate may be of more benefit if annual dressings are used, but that there was little difference between the two sources if dressings are infrequent.

Armiger and Fried (1957) also reported that there was increased relative value for phosphate rocks at later cutting of alfalfa as compared to superphosphate. This was attributed to a long growing season and consequent early depletion of the more readily available superphosphate. This explanation conformed to results obtained by Cooke (1956) who compared Gafsa phosphate rock to superphosphate in a greenhouse experiment with radishes on three acid soils. It was shown that 52% of the added P from superphosphate was recovered in the first crop of radishes, but only 6% in the second. On the other hand, Gafsa phosphate rock recovered only 19% in the first crop, but increased to 27% from the second. Other less soluble phosphate rocks included in the experiment also showed increases in P uptake during the second crop, but not to the extent as Gafsa phosphate rock.

In an experiment with sorghum which compared milled Nauru phosphate rock with superphosphate (Arndt and McIntyre, 1963), it was found that during the first five years, the residues from superphosphate became progressively less effective than the initial application, while the residues from the phosphate rock remained almost the same. For superphosphate, the residual value left after one year was 50% of the initial value, and after seven years, only about 8%. Phosphate rock was still 60 to 70% as effective as the initial value seven years after application. The positive residual value received from phosphate rock has also been reported by Cooke and Widdowson (1959) who found Gafsa phosphate rock as effective as superphosphate in the second year after application with grass experiments, and by Mokwunye (1977) who concluded that the performance of phosphate rock with millet and maize approached that of single superphosphate over a period of several crops.

When comparing the residual effect over a five-year period in the greenhouse with ladino clover of a single application of Florida phosphate rock to superphosphate which had been applied in annual portions to supply an equivalent amount of P_2O_5, Ensminger, et al. (1967) found the phosphate rock to be generally less effective. However, on two soils, a Henry silt loam and a Leon fine sand, the results showed no difference between phosphate rock and superphosphate. When phosphate rock (source not cited) and superphosphate were both applied annually to a Bolivar fine sandy loam for a rotation of corn, oats, wheat, and clover, Fine and Bartholomew (1946) found that it took 15 years for yields from phosphate rocks to consistently approach superphosphate yields even when phosphate rock was used at twice the rate of P_2O_5/ac.

Cooke and Widdowson (1959) suggested that the practical value of phosphate rock application probably depended upon economic considerations. In their investigations with swedes and kale, only two-thirds as much P from superphosphate as from Gafsa phosphate rock was required to give similar yields, but if the price of Gafsa was only one-half that of superphosphate, it would be economical to accept lower yields.

METHODS AND MATERIALS

A greenhouse experiment with guinea grass and field experiments with cassava and field beans were conducted in Colombia comparing seven phosphate rocks as sources of P for direct application. A Colombian basic slag and triple superphosphate were used as standard phosphorus sources. In addition to yield data, soil and plant samples from each experiment were obtained to more precisely evaluate the effectiveness of the phosphorus sources.

Phosphorus Fertilizer Materials

The seven sources of phosphate rock were selected to represent a range of reactivity as measured by their citrate soluble P content. Samples of each source were characterized by chemical composition, X-Ray diffraction pattern, infrared absorption, and citrate solubility. The source and the particle size distribution of the phosphate rocks used are given in Table 1.

Characterization of the Phosphate Rock

Each phosphate rock was chemically characterized by determination of total Ca, P, Na, Mg, CO_2, and F (Table 2). Phosphate minerals other than apatite were

TABLE 1.--Particle Size Distribution of the Phosphate Rocks.

Source	Screen Analysis, Tyler, %*								
	+48	+65	-48 +80	-65 +100	-80 +100	-100 +150	-150 +200	-200 +325	-325
North Carolina	-	0.4	-	2.5	-	5.2	9.0	15.8	67.1
Sechura	1.0	-	6.0	-	19.9	47.2	16.2	8.3	1.5
Gafsa	0.2	-	0.4	-	0.7	3.1	15.9	44.3	35.5
Central Florida	-	0.0	-	4.2	-	7.8	20.2	16.8	51.0
Tennessee	-	0.1	-	0.3	-	1.5	3.5	4.3	90.3
Pesca	6.4	-	19.9	-	14.5	15.4	10.1	18.0	15.6
Huila	1.0	-	4.8	-	4.5	9.6	21.7	36.0	22.4

*Blanks indicate that this screen was not used in analysis.

TABLE 2.--Chemical Composition of Phosphate Rocks.

Source	Composition (%)					
	CaO	P_2O_5	Na_2O	MgO	CO_2	F
North Carolina	48.3	32.4	0.68	0.46	5.4	3.7
Sechura	45.9	30.0	2.10	0.53	4.1	2.8
Gafsa	49.3	30.0	1.20	0.52	5.8	3.9
Central Florida	47.5	32.7	0.66	0.32	3.3	3.6
Tennessee	42.3	30.1	0.40	0.28	1.4	3.2
Pesca	28.1	19.8	0.16	0.11	1.3	2.2
Huila	39.4	20.9	0.28	0.21	8.0	2.4

not present in the accessory mineral groups of the phosphate rocks as shown by X-ray diffraction and infrared absorption. The empirical formula (Table 3) of each apatite in the phosphate rocks, except Sechura, was determined from the unit cell a-dimension by the X-ray method as described by Lehr and McClellan (1972). The formula for the apatite of the Sechura phosphate rock was derived from the actual chemical analysis since the models of Lehr and McClellan (1972) do not apply to apatites with significant OH substitution for F. The OH substitution was identified by infrared absorption.

Chemical Reactivity of the Phosphate Rock

Citrate soluble P was extracted from a 1-gram sample of each phosphate rock with 100 ml of neutral ammonium citrate solution at 65°C for 1 hour (Association of Official Agricultural Chemists, 1950). A second P extraction was also made with neutral ammonium citrate on the filtered residue from the initial extractions. Citrate soluble P_2O_5 was calculated both as percent of the rock and as percent of the total P_2O_5 in the rock (Table 4).

The absolute citrate solubility (Lehr and McClellan, 1972), is defined as:

$$\text{ACS (\%)} = \frac{\text{AOAC citrate soluble } P_2O_5\text{, \%}}{\text{Theoretical } P_2O_5 \text{ (\%) of apatite}} \qquad (1)$$

TABLE 3.--Calculated Formula for Apatites.

Source	Length of a-axis, A°	Empirical Formula
North Carolina	9.322	$Ca_{9.53} Na_{0.34} Mg_{0.13} (PO_4)_{4.77} (CO_3)_{1.23} F_{2.49}$
Sechura	9.337	$Ca_{9.03} Na_{0.74} Mg_{0.13} (PO_4)_{4.88} (CO_3)_{1.12} F_{1.73} (OH)_{0.72}$
Gafsa	9.325	$Ca_{9.56} Na_{0.32} Mg_{0.12} (PO_4)_{4.84} (CO_3)_{1.16} F_{2.46}$
Central Florida	9.345	$Ca_{9.74} Na_{0.19} Mg_{0.07} (PO_4)_{5.26} (CO_3)_{0.74} F_{2.30}$
Tennessee	9.357	$Ca_{9.85} Na_{0.11} Mg_{0.04} (PO_4)_{5.54} (CO_3)_{0.46} F_{2.18}$
Pesca	9.346	$Ca_{9.75} Na_{0.18} Mg_{0.07} (PO_4)_{5.28} (CO_3)_{0.72} F_{2.29}$
Huila	9.340	$Ca_{9.69} Na_{0.22} Mg_{0.09} (PO_4)_{5.14} (CO_3)_{0.86} F_{2.34}$

TABLE 4.--Sources and Citrate Solubility of P in the Phosphate Rocks.

Source	Country	Citrate Soluble Phosphorus				Absolute Citrate Solubility
		First Extraction		Second Extraction		
		% Rock	% Total P_2O_5	% Rock	% Total P_2O_5	
North Carolina	United States	7.2	24.1	6.7	22.4	19.8
Sechura	Peru	5.3	17.7	5.4	18.0	14.9
Gafsa	Tunisia	4.9	16.3	5.6	18.7	18.5
Central Florida	United States	3.0	9.2	3.2	9.8	10.1
Tennessee	United States	2.6	8.6	2.7	9.0	5.1
Pesca	Colombia	1.9	9.6	1.9	9.6	9.7
Huila	Colombia	0.8	3.8	3.4	16.3	12.2

The ACS for all of the phosphate rocks, except Sechura, was estimated (Table 4) as described by Lehr and McClellan (1972) with the equation:

$$ACS\ (\%) = 421.4\ (9.369 - A) \qquad (2)$$

Where A is the a-axis length of the apatite unit cell as measured by X-ray diffraction. The ACS of the Sechura was calculated using equation (1) since equation (2) does not apply to apatites in which OH substitutes for F (Lehr and McClellan, 1972).

Standard Sources

The basic slag (Escorias Thomas) used as one of the standard sources of P was produced at the Pas del Rio steel works in Colombia and contained 15% total P_2O_5. The triple superphosphate contained 46% total P_2O_5.

Greenhouse Experiment

For the greenhouse experiment, samples of a silty clay loam surface soil were obtained from the agronomy field of the Carimagua CIAT-ICA Research Station in the eastern plains of Meta, Colombia. This soil, an oxisol, is classified as a typic haplustox; clayey, kaolinitic, isohyperthermic family. Upon arrival at the CIAT greenhouses in Palmira, Colombia, the soil was fumugated with methyl bromide for four days, air-dried, screened, mixed, and stored in plastic bags. Properties of the soil before fertilization are shown in Table 5.

Plastic pots, each containing 3 kg of air dry soil, were used as greenhouse containers. Each of the sources of phosphorus was added at rates to supply 50, 100, 200, and 400 ppm P. A treatment with no phorphorus was also included. The pots were arranged in a randomized block design with six replications. Uniform levels of urea, K_2SO_4, and $MgSO_4.7H_2O$ were applied to all pots to supply 5 ppm N, 38 ppm K, and 38 ppm Mg, respectively. Lime was not applied. All fertilizer materials were thoroughly mixed with the soil prior to planting.

Of the six replications in the experiment, three were not cropped, but were maintained at approximately field capacity to be sampled periodically for selected laboratory measurements. The three remaining replications were initially allowed to incubate for 30 days before planting the legume <u>Stylosanthes guyanensis</u> (CIAT 136). Because of inadequate stands and poor growth, the soil in the pots was remixed, incorporating the Stylosanthes residue, additional urea added to supply 200 ppm N, and planted to guinea grass (<u>Panicum maximum</u>). The total time between the initial application of the fertilizers and the planting of guinea grass was 90 days. Moisture levels were maintained at approximately 60% of field capacity in all pots during the cropping period.

TABLE 5.--Initial Soil Properties.

	Greenhouse	Field Experiment 1	Field Experiment 2	
U.S. Classification	Typic Haplustox	Typic Haplustox	Typic unbrandept	
			Before Liming	At Planting
Organic matter (%)	4.3	1.9	12.4	
pH (1:1 soil:water)	4.7	5.0	4.9	5.5
Bray P-1 (ppm P)	1.9	1.2	2.6	2.6
Exch Ca (meq/100 gm)	0.12	0.15	2.16	12.30
Exch Mg (meq/100 gm)	0.08	0.02	0.76	1.31
Exch K (meq/100 gm)	0.04	0.04	0.51	0.60
Exch Al (meq/100 gm)	2.70	1.50	2.55	0.39
Effective CEC (meq/100 g)	2.94	1.71	5.98	14.60
Al saturation (% Effective CEC)	92	88	43	3

Soil samples were collected from the uncropped replications 10, 30, 50, 70, 90, and 190 days after the initial fertilizer application. Three cuttings of guinea grass were harvested 50, 70, and 100 days after planting. Soil samples were also collected from the cropped pots at the time of the third cutting.

Field Experiment with Cassava

The field experiment with cassava (*Manihot esculenta crantz*), Llanera variety, was conducted in the Tabaquera field of the Carimagua CIAT-ICA Research Station in the eastern plains of Meta, Colombia. The soil in the experimental area was an oxisol with the same classification as the soil described in the greenhouse experiment. Properties of the soil at the beginning of the experiment are shown in Table 5. Rainfall in the area during the growing period of the experiment (October 20, 1975 to October 13, 1976) totaled 2,668.6 mm with a three-month dry period during January through March, 1976. The average temperature was 26.2^{o}C. Monthly climatic data are shown in Table 6.

On September 25, 1975, dolomitic limestone was broadcast at the rate of one-half ton/ha and incorporated into the soil by disking. At the time of planting (October 20, 1975), each source of phosphorus (except Sechura phosphate rock) was applied at rates to supply

TABLE 6.--Carimagua Climatic Data.

Date	Precip. mm	Temperature °C			Relative Humidity (%)
		Mean	Max.	Min.	
October 75	210.6	26.2	30.4	22.0	81
November	136.5	26.3	30.3	22.2	79
December	158.7	26.0	30.1	21.8	77
January 76	0	26.1	30.8	21.3	-
February	30.3	27.1	32.5	21.7	61
March	66.8	27.4	31.9	22.9	66
April	293.1	26.7	30.8	22.5	79
May	240.1	25.8	29.3	22.4	83
June	453.9	25.1	28.2	22.0	88
July	425.0	24.6	27.8	21.3	86
August	197.0	25.8	29.9	21.7	85
September	317.0	26.4	30.5	22.2	85
October	139.6	27.6	31.6	23.6	80

50, 100, and 400 kg P_2O_5/ha. A treatment with no P was also included. Each of the finely ground phosphate rocks and the basic slag were broadcast and incorporated to a depth of approximately 12 cm with a rototiller. The triple superphosphate was applied in a band 5 cm deep and 10 cm to the side of the seed. Uniform levels of nitrogen, potassium and zinc were applied to each treatment as follows:

1. Nitrogen: 50 kg N/ha as urea banded at the time of planting and 50 kg N/ha banded after 60 days.
2. Potassium: 100 kg K_2O/ha as K_2SO_4 banded at the time of planting and 100 kg K_2O/ha as KCl banded after 60 days.
3. Zinc: 10 kg Zn/ha as $ZnSO_4$ banded at the time of planting.

The cassava was planted in plots 5.6 m by 6.4 m in rows 80 cm apart with 80 cm between plants within the row. The plots were arranged in a split plot design, with levels of application as the main plots and sources of P as the sub plots. There were three replications. Each treatment with triple superphosphate was duplicated so that the effectiveness of initial P application could be compared to annual applications of triple superphosphate.

Soil samples were obtained 50, 110, and 360 days following application of the fertilizer from a composite of 10 random probes to a depth of 20 cm collected from each plot. On October 13, 1976 (360 days after planting), the center 12 plants in each plot were harvested. Fresh weights were measured for edible roots and above ground forage.

Field Experiments with Beans

The field experiment with beans (Phaseolus vulgaris L.), Variety Huasano P 588, was conducted at the "Las Guacas" Research Station, Cauca, Colombia. The soil in the experimental area is an Andosol which, under the U.S. comprehensive system, is classified as a typic umbrandept. It is situated on a gently sloping altiplane in a region of volcanic mountains. The average annual rainfall is 1923 mm with a ten-month wet and a two-month dry season. The average temperature is 17.5^{o}C.

Agricultural limestone was broadcast at the rate of 4.7 tons/ha 42 days before planting, and incorporated into the soil by disking. Properties of the soil before liming and at planting are shown in Table 6. At the time of planting (March 11, 1976), all sources of phosphate rock and the triple superphosphate were broadcast at rates to supply 50, 100, 200, and 400 kg P_2O_5/ha. A treatment with no phopshorus was included, and all treatments with triple superphosphate were duplicated for later evaluation of residual effect, as described in the field experiment with cassava. All sources were incorporated into the soil to a depth of approximately 12 cm with a rototiller.

Uniform rates of urea, KCl, $MgSO_4.7H_2O$, and Borax were applied to all plots in a band approximately 5 cm to the side of the bean row and 5 cm deep at the time of planting to provide 80 kg N/ha, 40 kg K_2O/ha, 5 kg Mg/ha, and 1 kg B/ha, respectively. A solution of 1% $MgSO_4.7H_2O$ was applied as a foliar spray at mid-season. Furadan was also applied in the band at planting at a rate of 30 kg/ha.

The beans were planted in plots 3.15 m wide and 5.5 m long, with 45 cm between rows. The plots were arranged in a split-plot design with levels of application as the main plots and sources of phosphorus as the sub plots. There were four replications, but because of variation due to a drainage system in one area, only three replications were harvested and sampled.

Soil samples were collected from a composite of ten probes to a depth of 20 cm from each plot 30, 65, and 120 days after treatment application. Ten randomly selected plants (entire above ground portion) were collected 30 days after planting and five randomly selected plants were collected 65 days after planting. At the time of harvest (120 days after planting), the bean plants were counted and pulled by hand. A border of 68 cm on each side and 75 cm on each end was left unharvested in each plot. The edible beans were weighed and analyzed for moisture content. Yields were adjusted to a uniform level of 14% moisture.

The same variety of beans was replanted on October 4, 1976. Triple superphosphate was reapplied to appropriate plots at the same rate as the initial applications in each replication. The treatments involving phosphate rock and the remaining triple superphosphate plots received no further additions of phosphorus, but were used for residual evaluations. Uniform rates of N, K, Mg, and B were repeated in the same manner as for the first crop. The second crop was harvested January 20, 1977.

Laboratory Procedures

Soil Analysis

All soil samples were air dried and ground to pass a 20-mesh sieve.

Available P was extracted for one minute with Bray P-1 reagent (0.03 $\underline{N}$ NH_4F + 0.025 $\underline{N}$ HCl) at a 1:8 soil-solution ratio. The phosphomolybdate blue complex was developed using the Ammonium Molybdate-Ascorbic Acid method (Watanabe and Olsen, 1965). Transmittance was measured on a spectronic 20 colorimeter at 660 millimicrons.

Water soluble P was determined in 1:1 soil-water mixture (50 g soil + 50 ml distilled water) following a 24 hour equilibration which included three 1-hour shaking periods. The mixtures were first vacuum filtered through Whatman #40 filter paper, and then through metrical 0.20 µm filters. Phosphorus in solution was concentrated using the iso-butanol procedure described by Kempers (1975) but modified to develop color by the ammonium molybdate-ascorbic acid method (Watanabe and Olsen, 1965).

Soil pH was determined in both distilled water and 0.01 M $CaCl_2$ in a 1:1 soil-solution ratio. The suspensions were allowed to equilibrate for 30 minutes with three periods of stirring. Readings were taken on a Coleman Model 38A pH meter.

Exchangeable Al was extracted with 1 N KCl and measured by titration with 0.1 N NaOH (McLean, 1965). Titration with NaF on random samples of the three soils showed negligible amounts of exchangeable hydrogen, so analysis was limited to a single titration with NaOH and the resulting measurement of total acidity was assumed to represent exchangeable Al.

Exchangeable cations were extracted for 30 minutes with 1 N ammonium acetate, pH 7, with a 1:5 soil-solution ratio. Calcium and Mg were determined by atomic absorption spectroscopy with a Techtron AA 120 atomic absorption spectrophotometer. Lanthanum (La) was added to the filtered extract to a final concentration of 2000 ppm La. Potassium in the filtered extract was determined by emission spectroscopy with the Techtron AA 120 unit. Effective CEC was calculated by summation of the exchangeable Al, Ca, K, and Mg.

Plant Analysis

Phosphorus, Ca, Mg, and K content of the plant tissue was determined following digestion of a 0.1 g sample of plant material which had been ground to pass a 40-mesh sieve and dried at 65^{o}C. The samples were digested with a 2:1 mixture of nitric acid and perchloric acid in an aluminum digestion block. The digested material was diluted to 50 ml with distilled water. Concentration of P, Ca, Mg, and K were measured as described for the soil analysis.

Aluminum, Mg, and Zn were determined following digestion of 0.5 g plant samples in the nitric acid and perchloric acid mixture, and dilution to 50 ml with distilled water. Aluminum was measured by the aluminon method (Jackson, 1958 and Hsu, 1963). Transmittance was measured colorimetrically at 520 millimicrons. Manganese and Zn concentrations were measured on the Techtron AA 120 atomic absorption spectrophotometer.

Statistical Analysis

A statistical analysis of variance was conducted for all data collected from the greenhouse, field and laboratory measurements. A randomized block design was utilized in the greenhouse while a split-plot design was used in the field. In both field experiments, level of application represented the main plots with source of phosphorus as the sub plots. A Duncan's Multiple Range Test was used to identify statistical differences between treatments.

Simple linear regressions were calculated to describe the relationships between the citrate soluble P_2O_5 content of the phosphate rocks and source effects on yield and soil test measurements.

RESULTS AND DISCUSSION

The various phosphate materials were evaluated in a greenhouse experiment with guinea grass and field experiments with cassava and beans. The results of the field experiments are for the first year from plots designed for residual studies.

Greenhouse Experiment with Guinea Grass

The soil used in the greenhouse experiment, an Oxisol, was extremely low in P (1.3 ppm P extracted with Bray P-1 solution), and strongly acid (ph 4.7).

Plant Response to Phosphorus

When no P was applied, growth was so poor that no yields were obtained in any of the three cuttings. At rates of 50, 100, 200, and 400 ppm P, the average yields of all sources for each rate of P were 1.74, 6.44, 11.47, and 13.37 g/pot, respectively (Table 7). Comparisons of average yields of all rates for each P source were as follows: Basic slag = Sechura PR > North Carolina PR = Gafsa PR > TSP = Central Florida > Huila PR = Tennessee PR > Pesca PR.

The highest yield (19.67 g) was obtained with Sechura PR at the 400 ppm rate. Highest yields when 50

TABLE 7.--Total Yield (Dry Weight) of Three Cuttings of Guinea Grass in the Greenhouse as Affected by Rate and Source of Phosphorus.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	gm/pot				
Triple superphosphate	1.35	5.94	12.16	12.60	8.01 c
Basic slag	4.11	13.50	16.80	17.35	12.94 a
Sechura PR	2.95	9.18	16.59	19.67	12.10 a
North Carolina PR	1.32	6.95	15.10	19.09	10.61 b
Gafsa PR	3.31	7.35	13.42	17.08	10.29 b
Central Florida PR	1.41	4.78	9.59	11.61	6.86 c
Huila PR	0.20	4.36	7.41	9.49	5.36 d
Tennessee PR	0.81	3.44	6.77	7.18	4.55 de
Pesca PR	0.20	2.47	5.38	6.22	3.44 e
Control	____	____	____	____	0.00
Average	1.74	6.44	11.47	13.37	

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05) and 100 ppm P were applied were obtained with basic slag, but yields with basic slag were lower than those with Sechura and North Carolina PR when 440 ppm P was applied. Tissue analysis suggest that Zn may have been limiting and Mn excessive for plants grown at the 200 and 400 ppm levels of P when basic slag was applied (Appendix Tables A34-A39). This may have been related to the higher soil pH values when basic slag was applied with respect to the Zn and to the high Mn content of the slag. The lower yields obtained with TSP as compared to those obtained with basic slag, Sechura, North Carolina, and Gafsa PR is probably related to the lower pH and Ca values associated with the TSP treatments. These effects will be discussed in detail in a later section.

The Relative Agronomic Effectiveness (RAE) has been related to the citrate solubility of P in phosphate rocks (Caro and Hill, 1956; Bennett, et al., 1957; Terman, et al., 1970; and Engelstad, et al., 1974). If the RAE of the average yield of all rates of application of basic slag is 100%, the RAE of the phosphate rocks varied from 27% to 94% (Table 8). The citrate soluble P content of the phosphate rocks was linearly correlated ($p = 0.01$) with yields of guinea grass at all rates of application (Figure 1). The degree of correlation as measured by R values increased as the rate of P application increased. This may indicate that, although the

TABLE 8.--Relative Agronomic Effectiveness (RAE) of Nine Phosphate Fertilizers in the Greenhouse Experiment with Guinea Grass.

Source	RAE (%)
Triple superphosphate	62
Basic slag	100
Sechura PR	94
North Carolina PR	82
Gafsa PR	80
Central Florida PR	53
Huila PR	41
Tennessee PR	35
Pesca PR	27

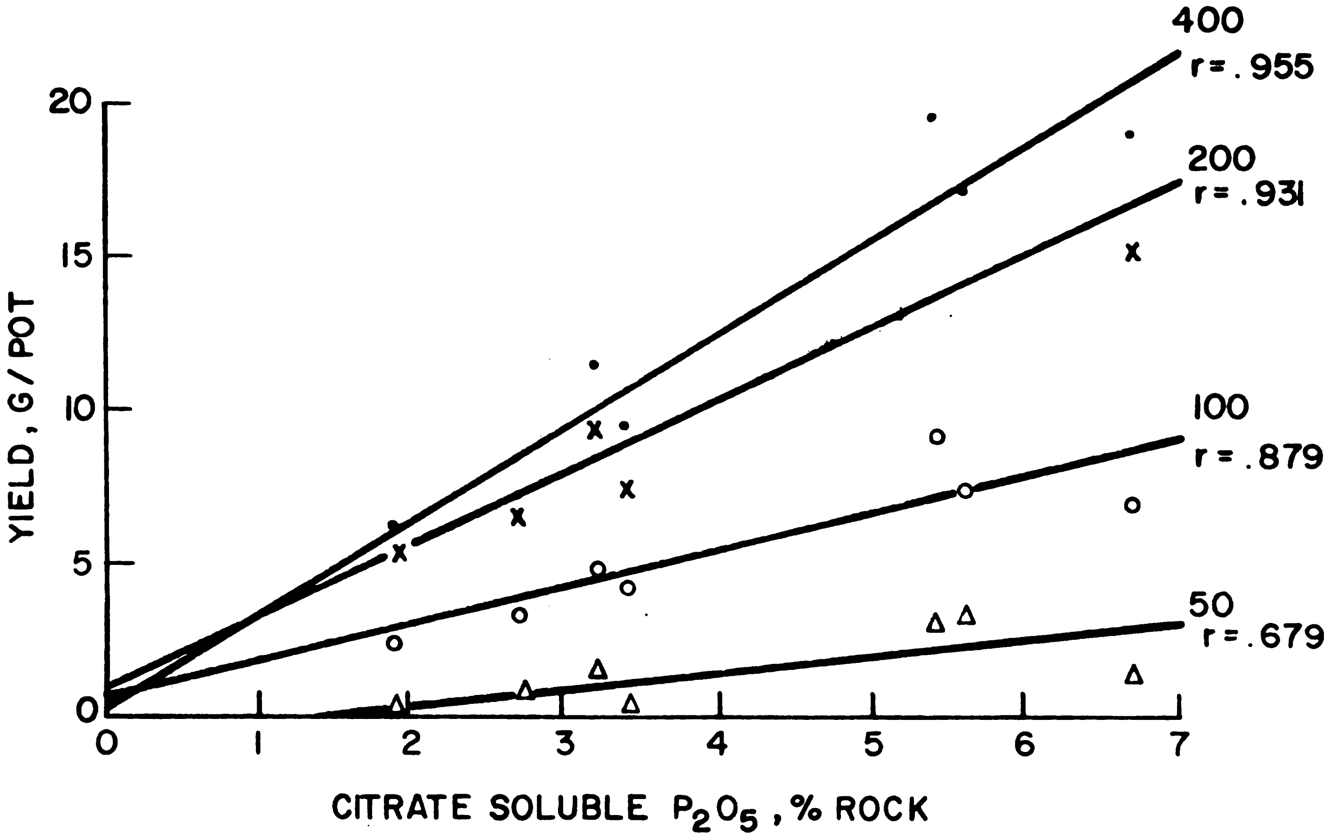

Figure 1.--Relationship between yield of three cuttings of guinea grass and citrate soluble P in phosphate rocks.

citrate solubility of P in phosphate rock is a highly significant factor in determining its relative effectiveness, the lower number of phosphate rock particles in the lower rates of application do not provide sufficient probability for near contact between phosphate rock particles and plant roots to fully reflect the phosphate rock potential.

Extractable Soil Phosphorus (Bray P-1)

Extractable soil P (Bray P-1) was higher when TSP was applied than when basic slag or the phosphate rocks were applied (Table 9). At the time of planting 90 days after P application, the extractable P levels were as follows: TSP > basic slag = North Carolina PR > Gafsa PR = Sechura PR > Central Florida PR > Huila PR = Tennessee PR > Pesca PR. Yields followed the same order except for TSP and Sechura PR. Possible reasons for the deviations of these two materials will be discussed later.

The response curves (Figure 2) for the phosphate rocks and TSP were separate and distinct. The plant response was much lower at a given Bray P-1 level with TSP than with the other sources. Barnes and Kamprath (1975) found this same relationship with corn on a Hyde soil, and suggested that this could indicate the presence of some acidulation product from the phosphate rock that the plant can utilize but is not measured by the extractant.

TABLE 9.--Extractable P (Bray P-1) in Greenhouse Soils 90 Days After P Application as Affected by Rate and Source of P.

Source	Extractable P (ppm)					
	Rate of P (ppm P)				Average*	
	50	100	200	400		
Triple superphosphate	9.3	19.0	49.2	91.3	42.2	a
Basic slag	7.9	20.9	46.9	75.3	37.7	b
Sechura PR	8.4	16.2	37.4	56.8	29.7	c
North Carolina PR	7.4	16.5	44.1	80.6	37.2	b
Gafsa PR	8.3	18.7	36.8	61.6	31.4	c
Central Florida PR	6.2	13.6	20.9	37.9	19.6	d
Huila PR	4.7	8.8	15.6	20.2	12.3	ef
Tennessee PR	5.3	9.3	17.6	24.5	14.2	e
Pesca PR	3.2	6.6	9.4	17.7	9.2	f
Control					1.3	

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

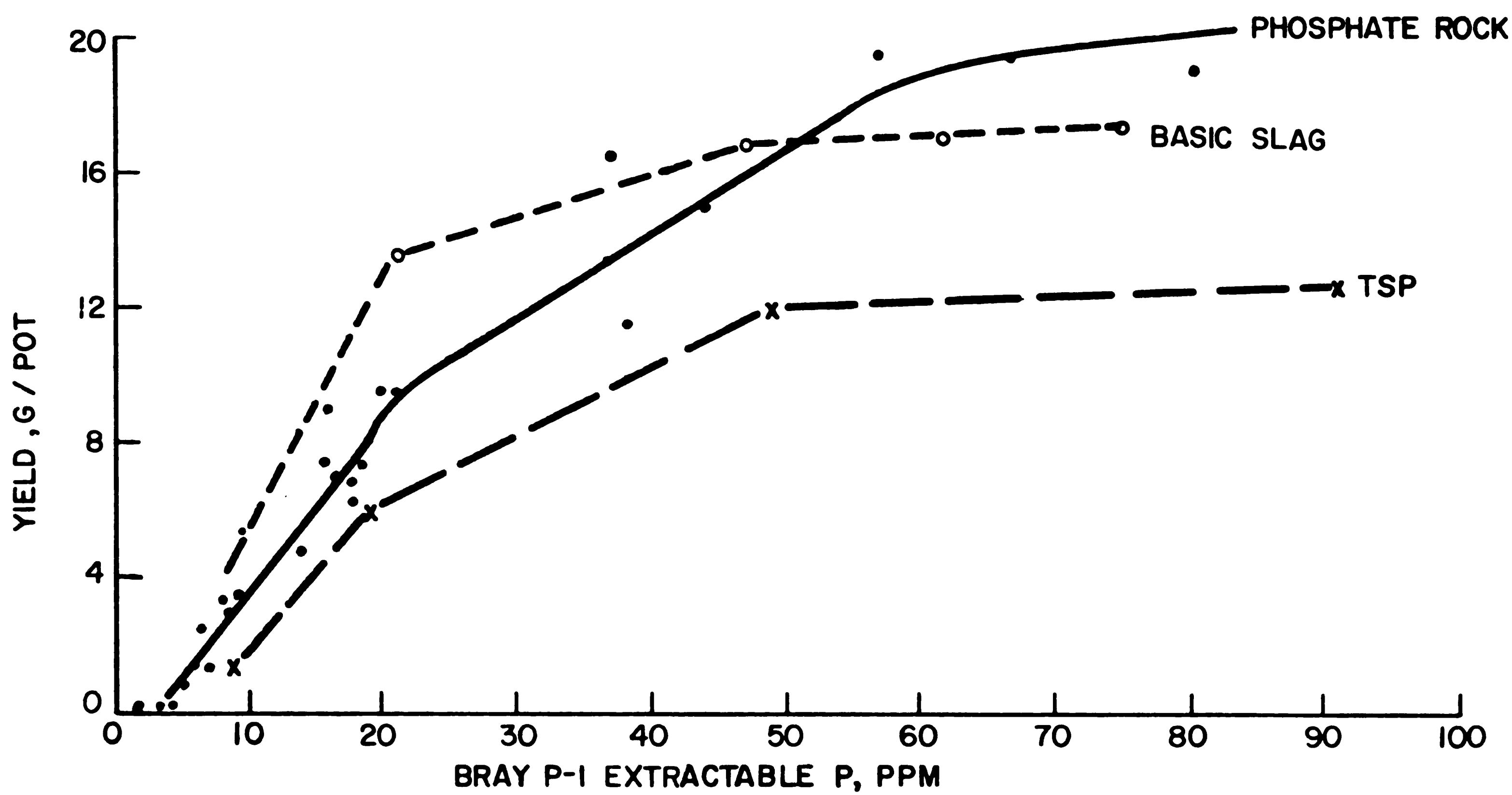

Figure 2.--Relationship between yield of three cuttings of guinea grass and Bray P-1 extractable P measured 90 days after application.

Higher levels of exchangeable Ca where PR and basic slag were applied may explain the yield difference (Table 10). Calcium levels probably do not explain the results of Barnes and Kamprath since lime had been applied at the rate of five tons per acre in their experiment.

Barnes and Kamprath (1975) alternatively suggested that the possible difference in response curves could be due to the fact that P diffusing from the TSP granules was immediately available for reaction with the soil and subsequent extraction with the Bray P-1 solution. The dissolution of the phosphate rock, on the other hand, is a slow process and only a relatively small portion of the P from this material would be extracted by the Bray P-1 solution. It is possible that both of these factors contributed to the difference in the shape of the response curves obtained in this greenhouse experiment where supplemental Ca had not been supplied. The response curve obtained with basic slag (Figure 2) as the source of P would tend to suggest the contribution of Ca as the primary factor since it is a source which is highly soluble, and yet showed the maximum response to a given level of extractable P while, at the same time, having the highest levels of extractable Ca. This trend continued up to the highest rate of application where both a Zn deficiency and Mn toxicity limited plant response as described previously. The extractable soil P (Bray P-1) was highly correlated

TABLE 10.--Exchangeable Ca in Cropped Greenhouse Soil at Time of Final Harvest (190 Days After Application).

Source	Rate of Application (ppm P)				Average*	
	50	100	200	400		
	meq/100 gm					
Triple superphosphate	0.463	0.583	0.656	1.307	0.752	g
Basic Slag	1.062	1.916	3.119	4.658	2.689	a
Sechura PR	0.718	1.072	1.573	2.484	1.462	cd
North Carolina PR	0.682	1.124	1,812	2.786	1.601	bc
Gafsa PR	0.797	1.492	1.744	2.593	1.656	b
Central Florida PR	0.500	0.786	1.166	2.057	1.127	e
Huila PR	0.692	1.031	1.583	2.130	1.359	d
Tennessee PR	0.531	0.776	1.041	1.432	0.945	f
Pesca PR	0.468	0.546	0.807	1.188	0.752	f
Control					0.333	

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (P = .05)

(P = 0.01) with citrate-soluble P in the phosphate rock at each rate of application (Figure 3). The degree of correlation increased (higher r values) as the rate of application increased, but the magnitude of their increases was not as great as that noted for yields. Extractable P was removed by a solution that was in contact with all soil particles in the sample used, while uptake by the plants was probably related to the extent and distribution of the root system.

Assuming a random distribution of both PR particles and plant roots in each pot, the probability of an adequate number of roots being close enough to a sufficient number of PR particles to absorb enough P to reflect differences in reactivity between different phosphate rocks is much greater at higher rates of application. Variation from the phosphate rock potential would therefore be amplified to a greater extent at low rates of application than would be measured by P extraction. When a soil sample is extracted with a relatively large volume of extracting solution, a more complete contact between soil, phosphate rock particles and extracting solution would be expected, and differences in reactivity between phosphate rocks would be more precisely reflected.

Water Soluble Soil Phosphorus

Extractable P (Bray P-1) was highly correlated with water soluble P in the soil for all rates and

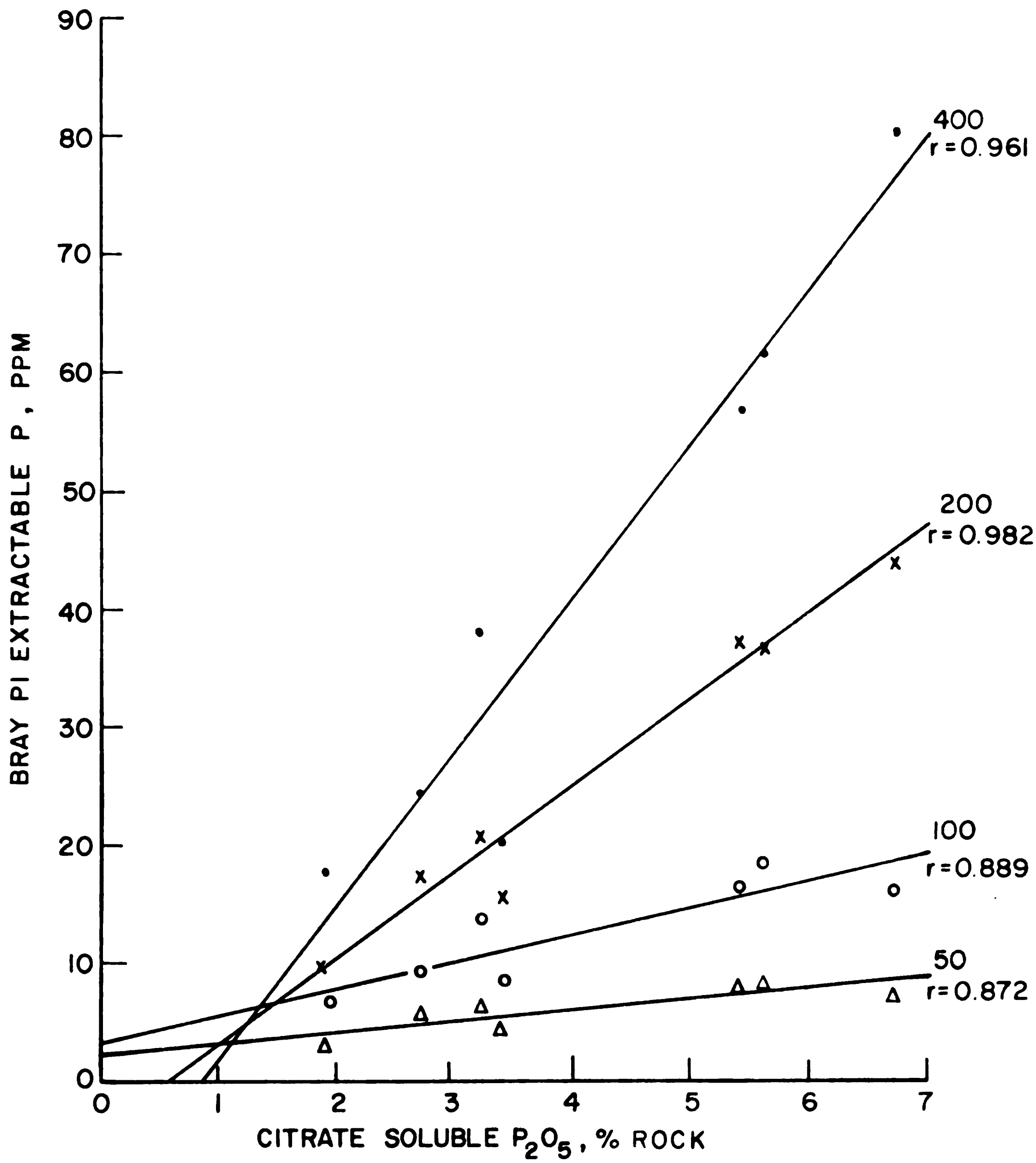

Figure 3.--Relationship between Bray P-1 extractable P in greenhouse soil and citrate soluble P in phosphate rocks.

sources of P (Figure 4). The amount of water soluble P varied from 0.004 ppm P in the control treatment to 0.061 ppm P when 400 ppm P was applied as basic slag (Table 11). The concentration of water soluble P was highly correlated with P uptake (Figure 5) and to yield (Figure 6). There was a single linear relationship between water soluble P and P uptake for all sources while yields demonstrated one curvilinear relationship with TSP and a different curvilinear relationship for the basic slag and the phosphate rocks. This would tend to support the contention previously discussed that a factor other than P was limiting yields when TSP was applied.

Water soluble P 10 days following TSP application was much higher than when the other sources were applied, and decreased rapidly for all sources (Figure 7). Measurements obtained from completely remixed samples at each sampling date showed that by the time of the final harvest, the phosphate rocks from both North Carolina and Gafsa were maintaining higher, but nonsignificantly higher, levels of water soluble P than the TSP treatment, while the Sechura PR was equivalent to the TSP (Appendix Table A11). The decrease in water soluble P between the time of planting and the time of the final harvest was greatest at the high rates of application. The level of water soluble P at the time of planting was highly correlated with the citrate soluble P in the phosphate rocks at both

TABLE 11.--Water Soluble P in Uncropped Greenhouse Soil 70 Days after Application.

Source	Rate of Application (ppm P)				Average*	
	50	100	200	400		
	ppm P					
Triple superphosphate	.015	.010	.049	.112	.047	ab
Basic slag	.011	.010	.029	.161	.053	a
Sechura PR	.012	.017	.031	.096	.039	abc
North Carolina PR	.008	.011	.025	.110	.039	abc
Gafsa PR	.004	.005	.032	.053	.023	dc
Central Florida PR	.016	.015	.024	.057	.028	bcd
Huila PR	.006	.008	.018	.023	.014	d
Tennessee PR	.008	.009	.006	.014	.009	d
Pesca PR	.006	.010	.010	.019	.011	d
Control					.004	

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

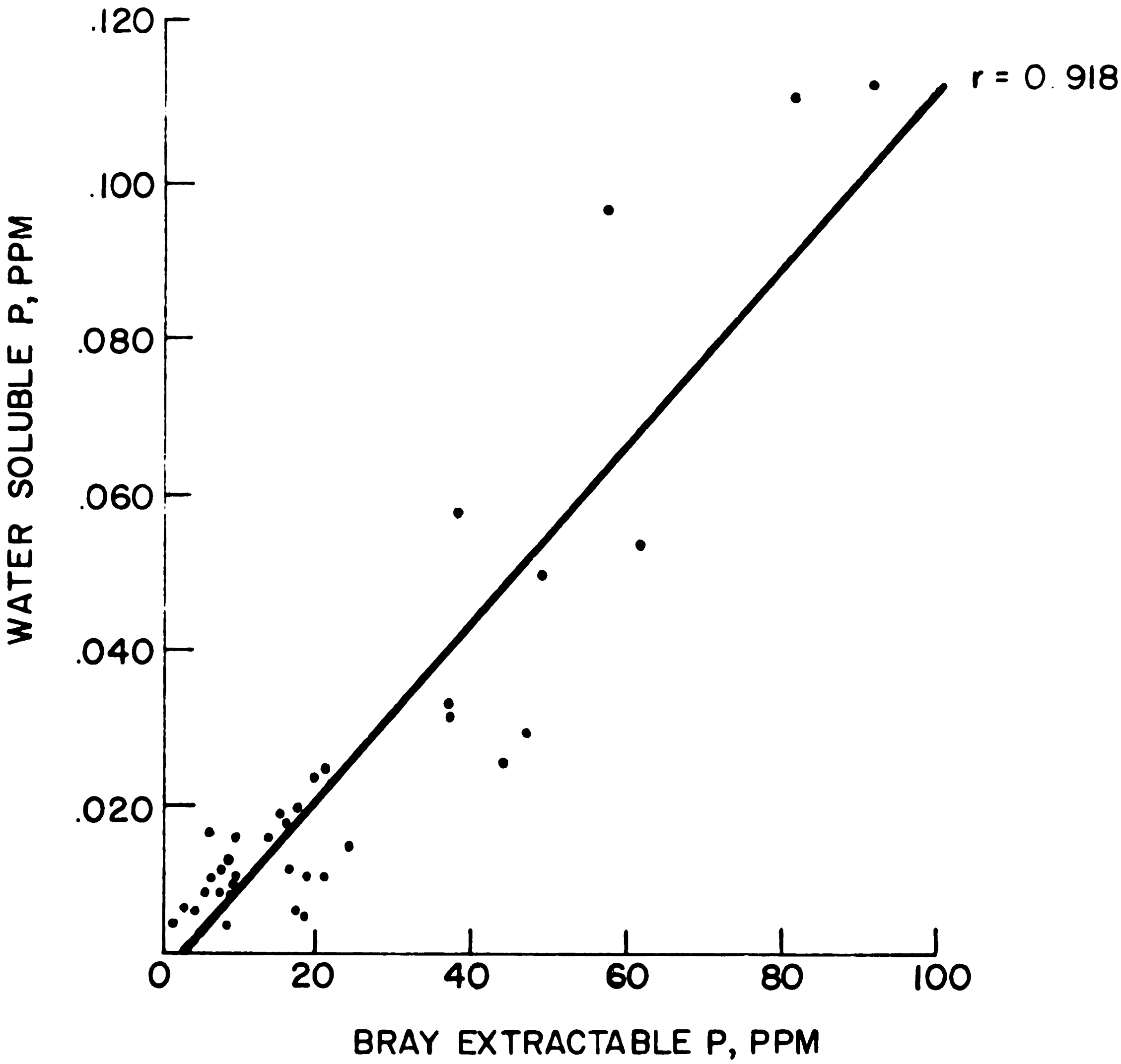

Figure 4.--Relationship between water soluble P and Bray P-1 extractable P in greenhouse soil 90 days after application.

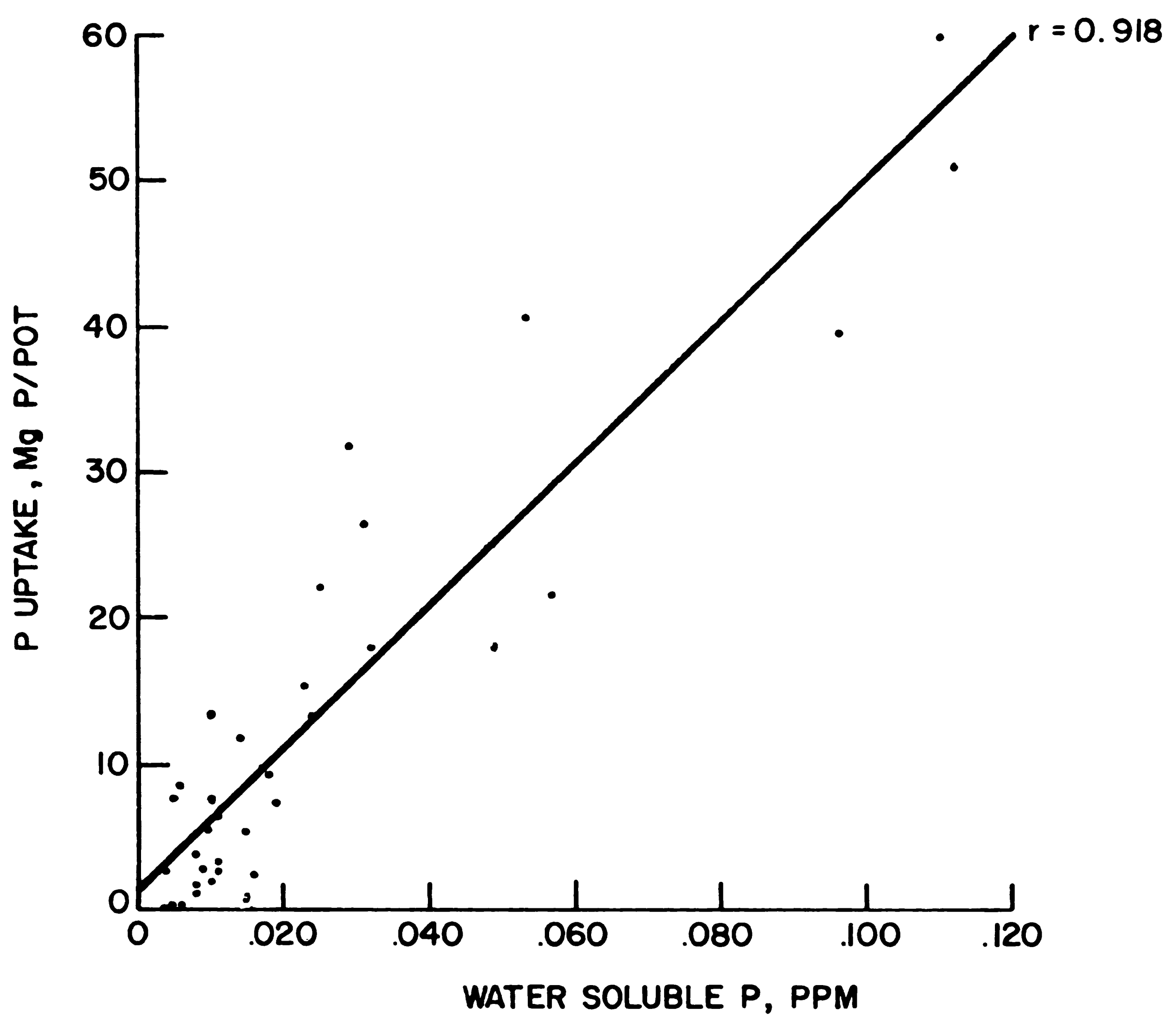

Figure 5.--Relationship between uptake of P by three cuttings of guinea grass and water soluble P in greenhouse soil.

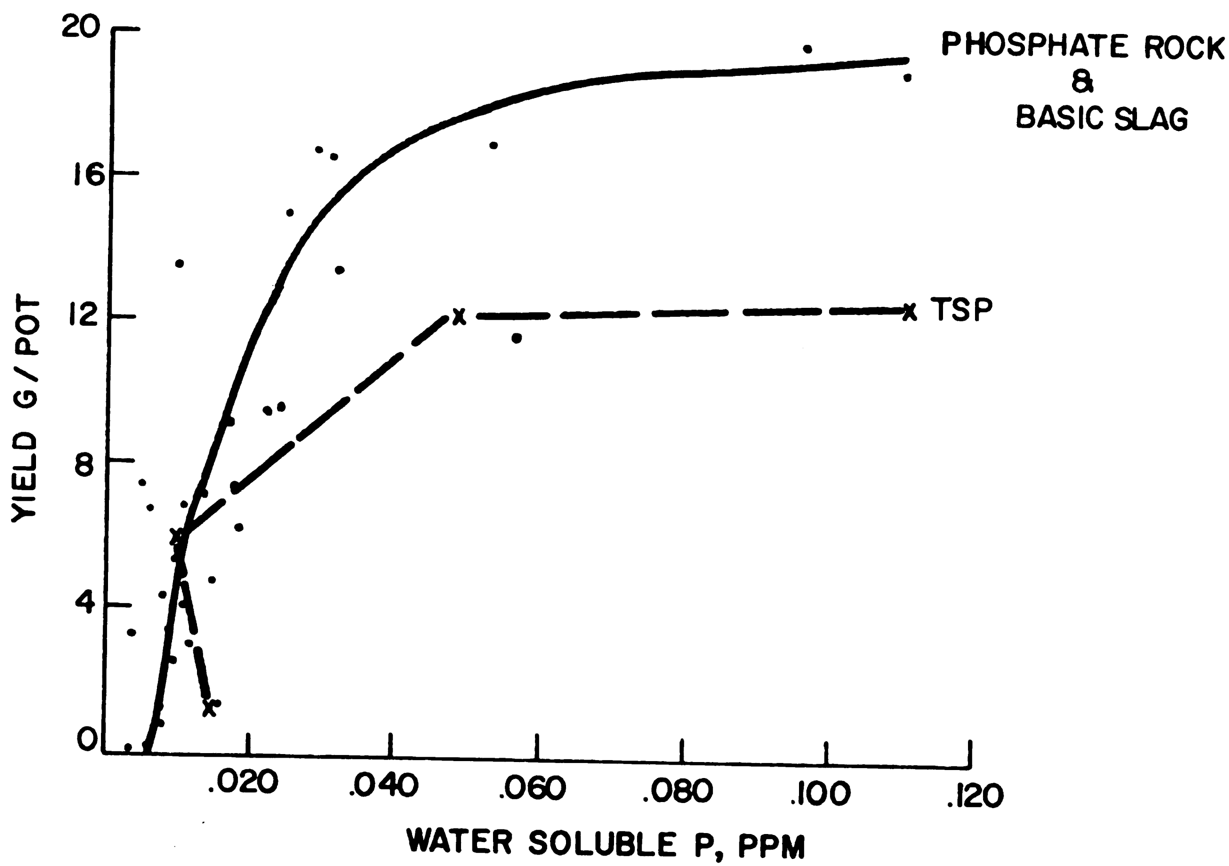

Figure 6.--Relationship between yield of three cuttings of guinea grass and water soluble P in greenhouse soil.

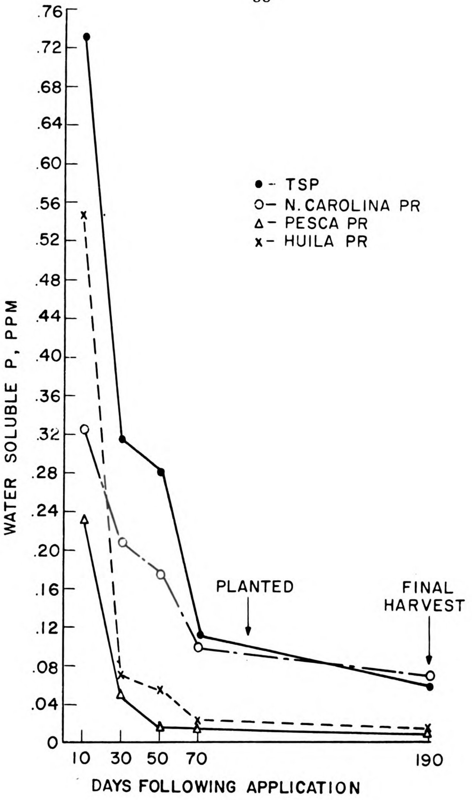

Figure 7.--Relationship between concentration of water soluble P in greenhouse soil receiving 400 ppm P and time following application.

the 200 and 400 ppm P rate of application (Figure 8). At the low rates of application, water soluble P was very low and was not significantly correlated with citrate soluble P in the phosphate rocks.

Effect of Phosphate Rocks on Soil pH

Soil pH increased as the rate of P application increased for basic slag and for the North Carolina, Sechura, Gafsa, Central Florida, and Huila phosphate rocks (Table 12). When soil pH was increased by phosphate rock applications, exchangeable Al decreased and exchangeable Ca increased. The percentage of the effective CEC that was saturated with Al decreased when phosphate rocks were applied which had high citrate solubility of P, but decreased very little with TSP or phosphate rocks with low levels of citrate soluble P (Figure 9). Marked decreases in Al saturation were noted when basic slag was applied. Correlation coefficients indicate that the effect of citrate solubility on Al saturation is greater at high rates of application than at low rates (Figure 10). This would suggest that the liming effect of phosphate rock would not be of substantial benefit, regardless of rock reactivity, unless it were applied at heavy rates.

TABLE 12.--pH in 1:1 Soil-Water Mixture in Uncropped Greenhouse Soil 70 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	pH				
Triple superphosphate	4.77	4.63	4.65	4.67	4.68 d
Basic slag	4.78	5.00	5.18	5.80	5.19 a
Sechura PR	4.75	4.83	4.87	4.97	4.85 bc
North Carolina PR	4.80	4.88	4.97	5.05	4.93 b
Gafsa PR	4.77	4.67	4.92	4.92	4.82 c
Central Florida PR	4.78	4.73	4.88	4.98	4.85 bc
Huila PR	4.67	4.82	4.90	5.07	4.86 bc
Tennessee PR	4.70	4.62	4.70	4.70	4.68 d
Pesca PR	4.78	4.63	4.75	4.70	4.72 d
Control					4.65

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

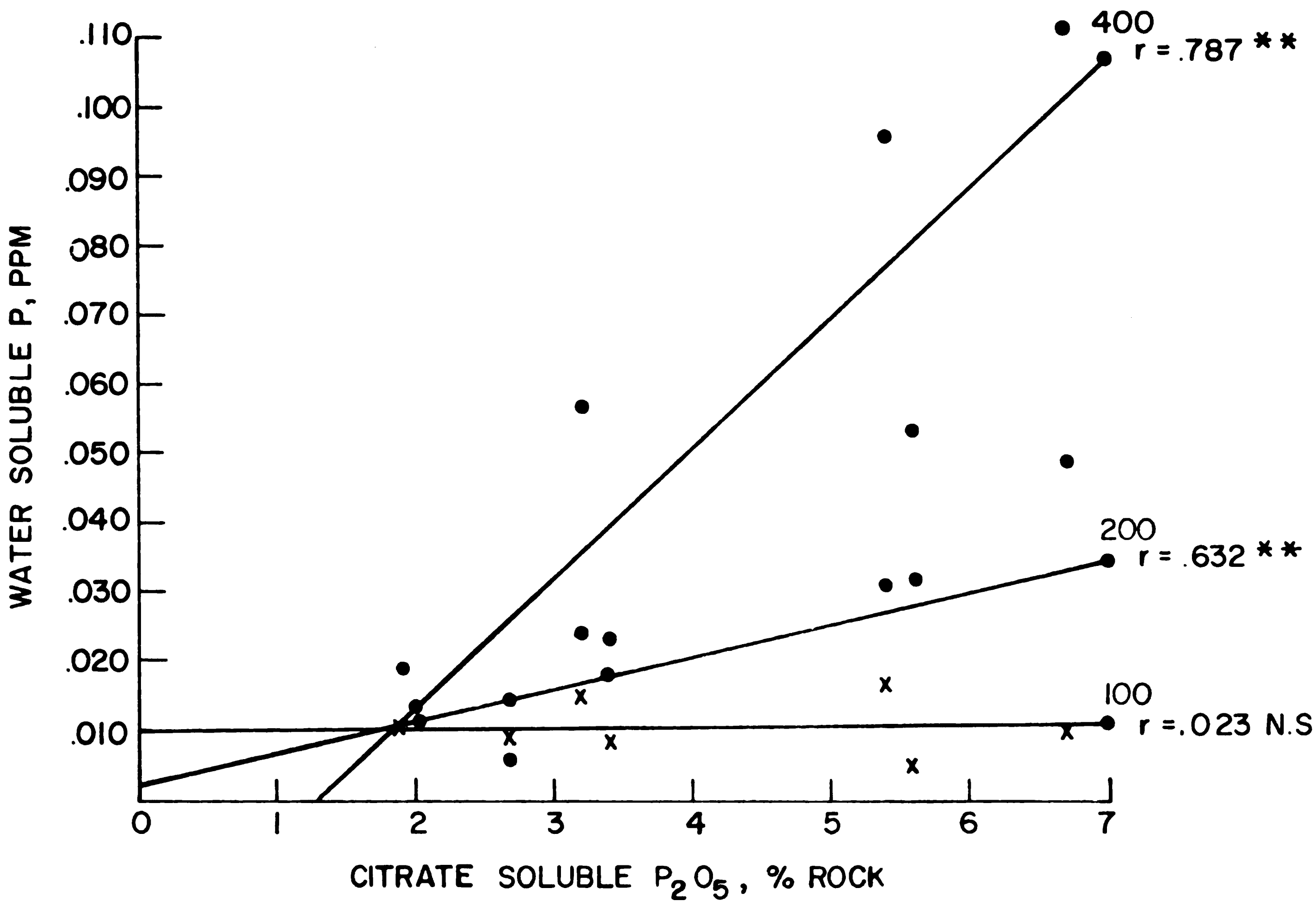

Figure 8.--Relationship between water soluble P in greenhouse soil 70 days following application and citrate soluble P in phosphate rocks.

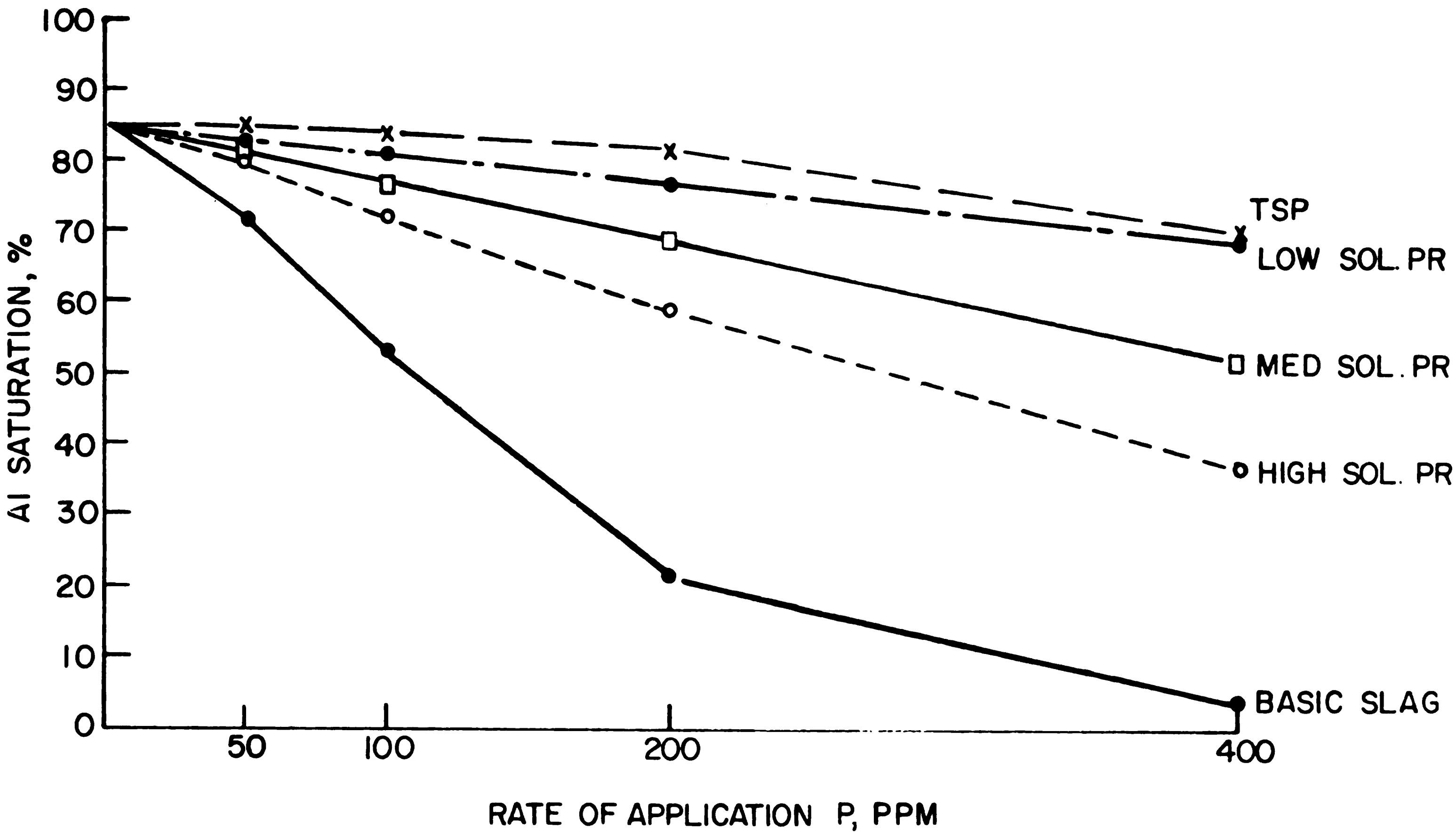

Figure 9.--Aluminum saturation of effective CEC of greenhouse soil 190 days after application as affected by rate of application (Low: Tennessee and Pesca; Medium: Florida and Huila; High: North Carolina, Gafsa, and Sechura).

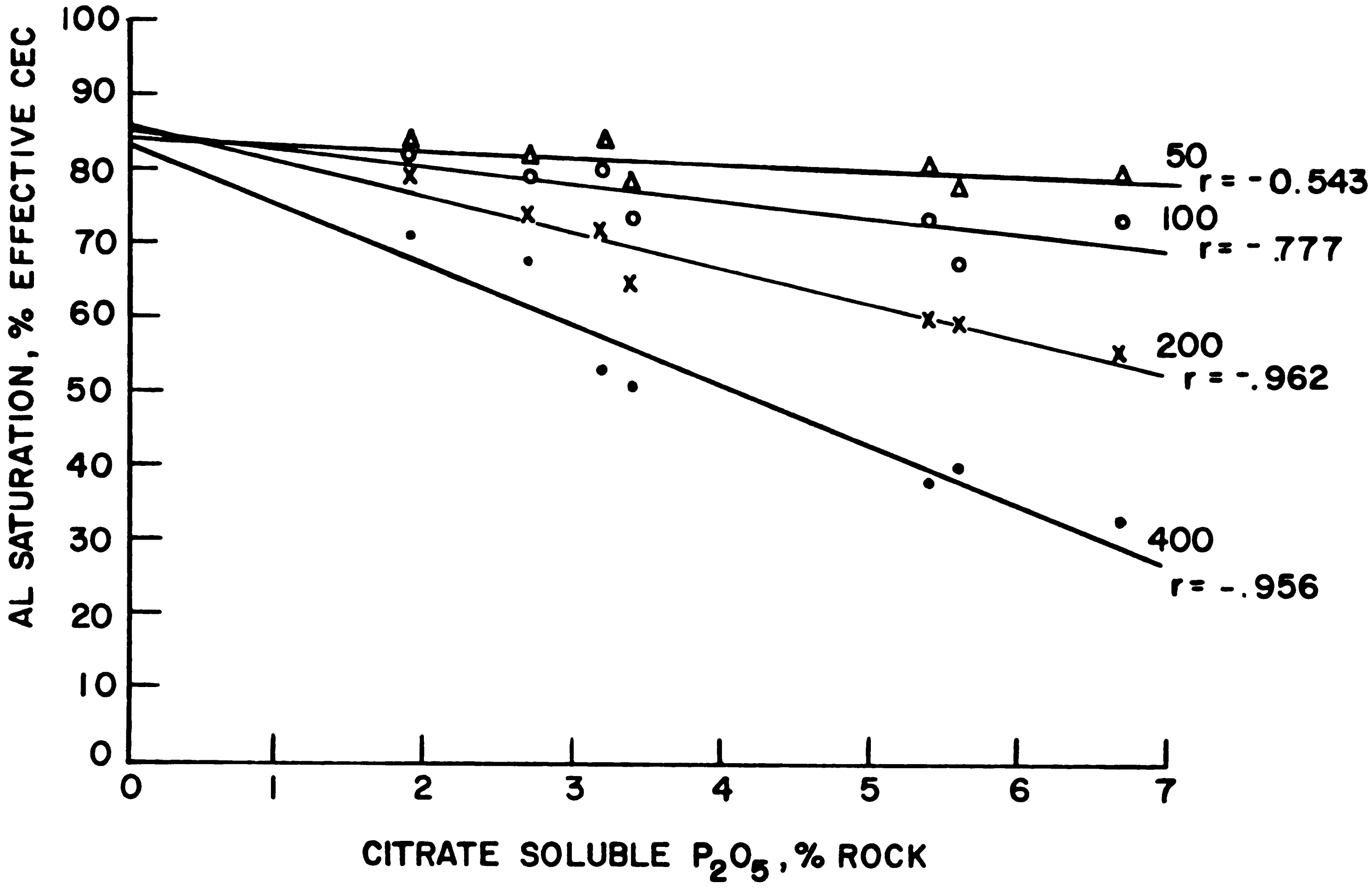

Figure 10.--Relationship between Al saturation of greenhouse soil and citrate soluble P in phosphate rocks.

Field Experiment with Cassava

The field experiment with Cassava was located on an oxisol similar to that used in the greenhouse experiments; the greenhouse soil sample was obtained about 10 km from the site of the field experiment. Extractable P (Bray P-1) was 1.2 ppm P, about the same as that of the soil used in the greenhouse, while the soil pH of 5.0 was slightly higher.

Cassava Yields as Affected by Rate and Source of P

Marked yield increases were obtained with applied P. The average yields from all sources at each rate of applied P were increased 96%, 145%, and 180% with applications of 50, 100 and 400 kg P_2O_5/ha, respectively (Table 13). Yields were significantly increased by all rates and sources of P as compared to that when no P was applied.

Yields at each rate of P application were related to the source of P. Highest average yield for the three P rates for each source were obtained with TSP and basic slag at 20.3 t/ha of edible roots. Since the TSP was applied in bands, the results with TSP cannot be used to evaluate the other sources; therefore, basic slag was used as the standard P source. The yield obtained with basic slag was significantly higher than that obtained with any of the phosphate rocks.

TABLE 13.--Yield of Edible Cassava Root.

Source	Rate of Application (kg P_2O_5/ha)			Average***
	50	100	400	
	---------- tons/ha ----------			
Triple superphosphate*	16.8	22.3	22.2	20.5 a
Triple superphosphate**	15.9	21.7	22.6	20.1 a
Basic slag	15.7	20.3	24.8	20.3 a
North Carolina PR	13.8	19.1	21.1	18.0 b
Gafsa PR	15.5	19.3	20.1	18.3 b
Central Florida PR	12.6	16.4	21.2	16.8 bc
Huila PR	14.5	16.5	18.3	16.4 bc
Tennessee PR	15.3	13.5	18.8	15.9 c
Pesca PR	12.2	16.4	19.7	16.1 c
Control				7.5

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05)

Yields obtained with the North Carolina and Gafsa phosphate rocks were significantly higher than those obtained with the Tennessee and Pesca rocks, with intermediate yields from the Central Florida and Huila rocks. As seen in Figure 11, yields tended to increase with increasing rates of all sources to 40 kg/ha of phosphorus except TSP. In similar experiments on this soil type, maximum yields were obtained with about 300 kg/ha of banded phosphorus (R. H. Howeler, Personal Communication, 1976). It is probable, however, that maximum yields cannot be obtained with band applications of P on soils as severely deficient in P as that where this experiment was located. Even higher yields might have been obtained with broadcast rates of TSP.

The mean RAE (Table 14) indicates the same relative order of effectiveness in the field as in the greenhouse, but the relative differences between sources was less in the field. Coefficients measuring the degree of correlation between citrate soluble P_2O_5 in the rocks and yields indicate that when 50 kg P_2O_5/ha was applied, there was no significant effect on yields as citrate soluble P in phosphate rocks increased (Table 15). At this rate, there was little difference between the sources with only 3.3 t/ha separating the highest and lowest yield of edible root, and 4.4 t/ha difference in total plant yield (root and forage combined).

TABLE 14.--Relative Agronomic Effectiveness of Eight P Fertilizer Materials on Cassava in the Field.

Source	RAE (%)
Triple superphosphate	100
Basic slag	100
North Carolina PR	82
Gafsa PR	84
Central Florida PR	73
Huila PR	70
Tennessee PR	66
Pesca PR	67

TABLE 15.--Correlation Coefficients Between Cassava Production and Citrate Soluble P_2O_5 of Phosphate Rock as Affected by Rate of Application.

	Rate of Application (kg P_2O_5/ha)		
	50	100	400
Citrate Sol. vs Root Production	.377	.808	.489
Citrate Sol. vs Forage Production	.273	.718	.847
Citrate Sol. vs Total Production	.355	.792	.795

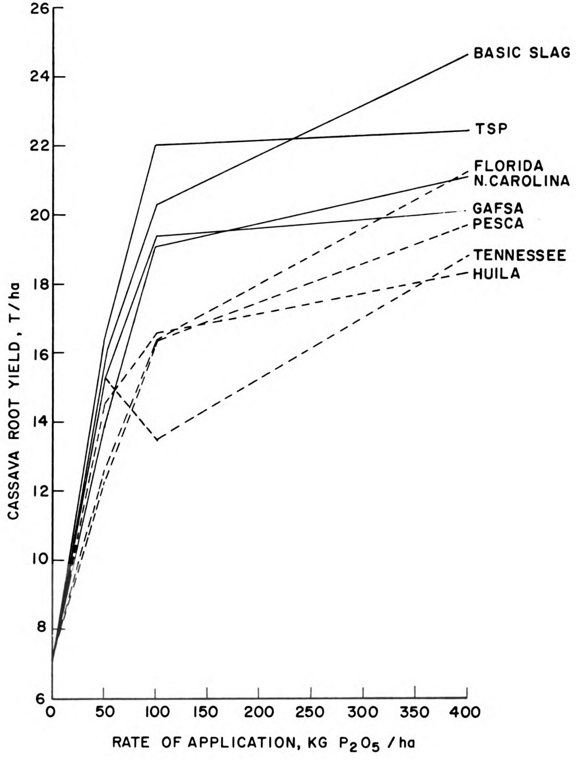

Figure 11.--Yield of edible Cassava as affected by rate of application. All sources were broadcast except TSP which was banded.

As the rate of application increased to 100 kg P_2O_5/ha, citrate solubility was significantly correlated with both root and total plant yields. However, at the highest rate of application, total plant yields continued to be related to the citrate solubility, but root yield was not. In this case, as with the low rate of application, root production was relatively constant regardless of P source, with only 2.9 t/ha difference between the highest and the lowest.

This would suggest that the cassava plant, by continuing to respond to increased application of phosphate rock, depleted available K to a level which restricted root growth (Appendix Table B-13). CIAT (1974) has shown that cassava root production is significantly decreased by low K levels. Thus, it is possible that continued response to P would be obtained only at higher levels of K.

Extractable Soil Phosphorus

The level of Bray P-1 extractable P was related to both the rate of application and the phosphate source (Table 16). The mean available P increased over the control plot by 185%, 335%, and 1023% with applications of 50, 100, and 400 kg P_2O_5/ha, respectively. For the sources which were broadcast, the level of Bray P-1 extractable P when basic slag was applied was significantly higher than

TABLE 16.--Extractable P (Bray P-1) in Field Experiment with Cassava 51 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			Average*
	50	100	400	
	ppm P			
Basic Slag	2.9	7.6	24.2	11.6 a
North Carolina PR	2.9	3.5	18.3	8.2 b
Gafsa PR	2.2	6.2	16.6	8.3 b
Central Florida PR	1.8	2.6	7.5	4.0 c
Huila PR	1.9	3.8	7.4	4.4 c
Tennessee PR	2.3	2.5	7.3	4.0 c
Pesca PR	1.5	1.9	4.6	2.6 c
Control				1.2

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

the phosphate rock sources. Among the phosphate rocks extractable P levels were higher when North Carolina PR and Gafsa PR were applied than when the other rocks were applied. No statistical differences were found between the Central Florida PR, Huila PR, Tennessee PR, or Pesca PR. As time progressed, the available P increased with all treatments on which cassava was planted (Figure 12). This was in contrast to the results obtained in the greenhouse experiment with Guinea grass in which there was a progressive decrease in Bray P-1 values. It is possible the increase was due either to the mineralization of organic P following the first tillage of a virgin soil, or excretions from the cassava root systems which were not associated with the Guinea grass in the greenhouse.

The correlation between extractable P and citrate solubility of P in phosphate rocks was highly significant ($p = 0.01$) at all rates of application (Figure 13), and the Bray P-1 values served as a good indicator of the final cassava root yield (Figure 14). It was observed that 90% of the maximum root yield was obtained with Bray P-1 available P at a level of 7 ppm P. The curvilinear relationships obtained also indicate that although total plant production continued to respond to high levels of available P, the edible root yield failed to respond in the same degree, and that the majority of the

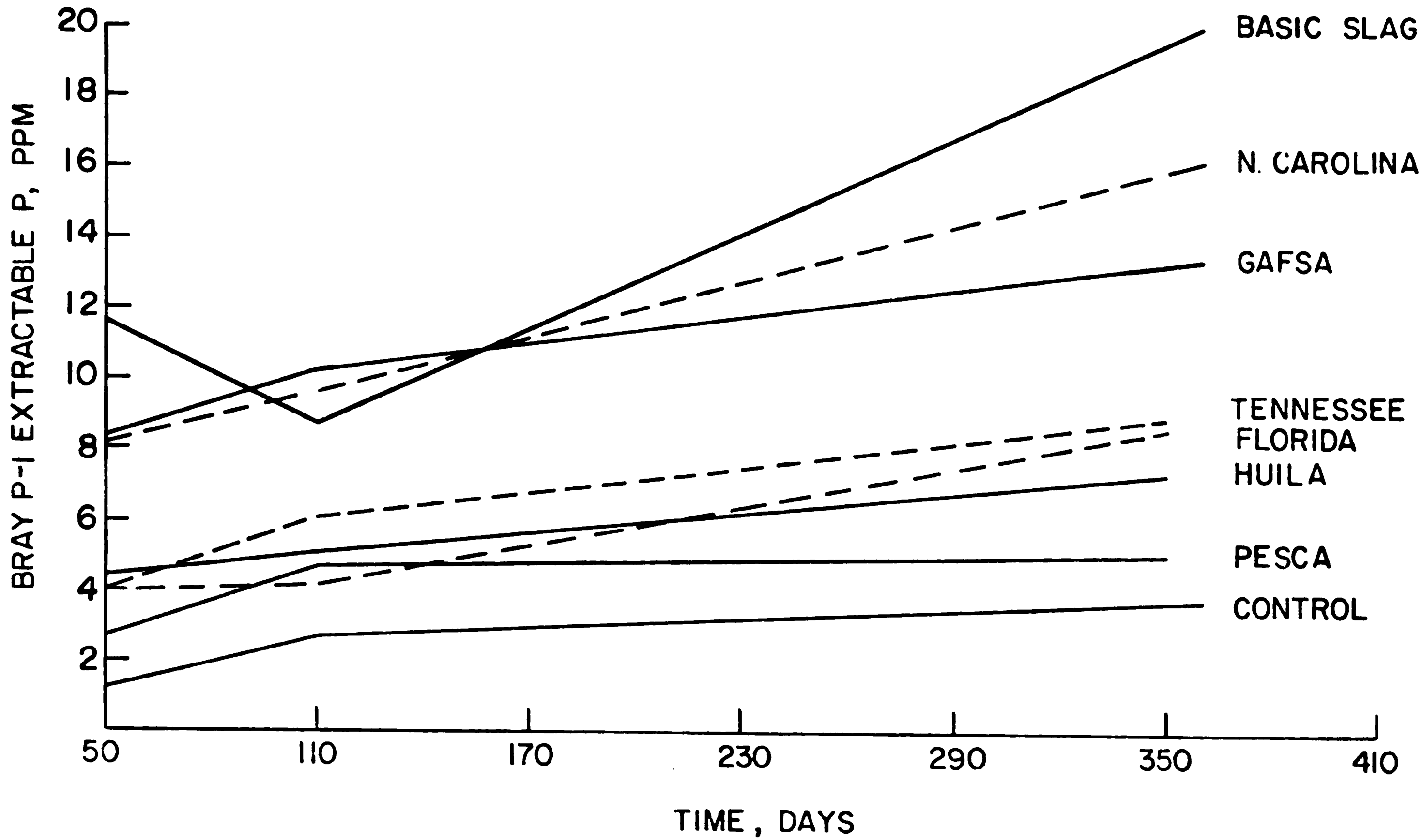

Figure 12.--Bray P-1 extractable P in Carimagua soil as affected by time following application.

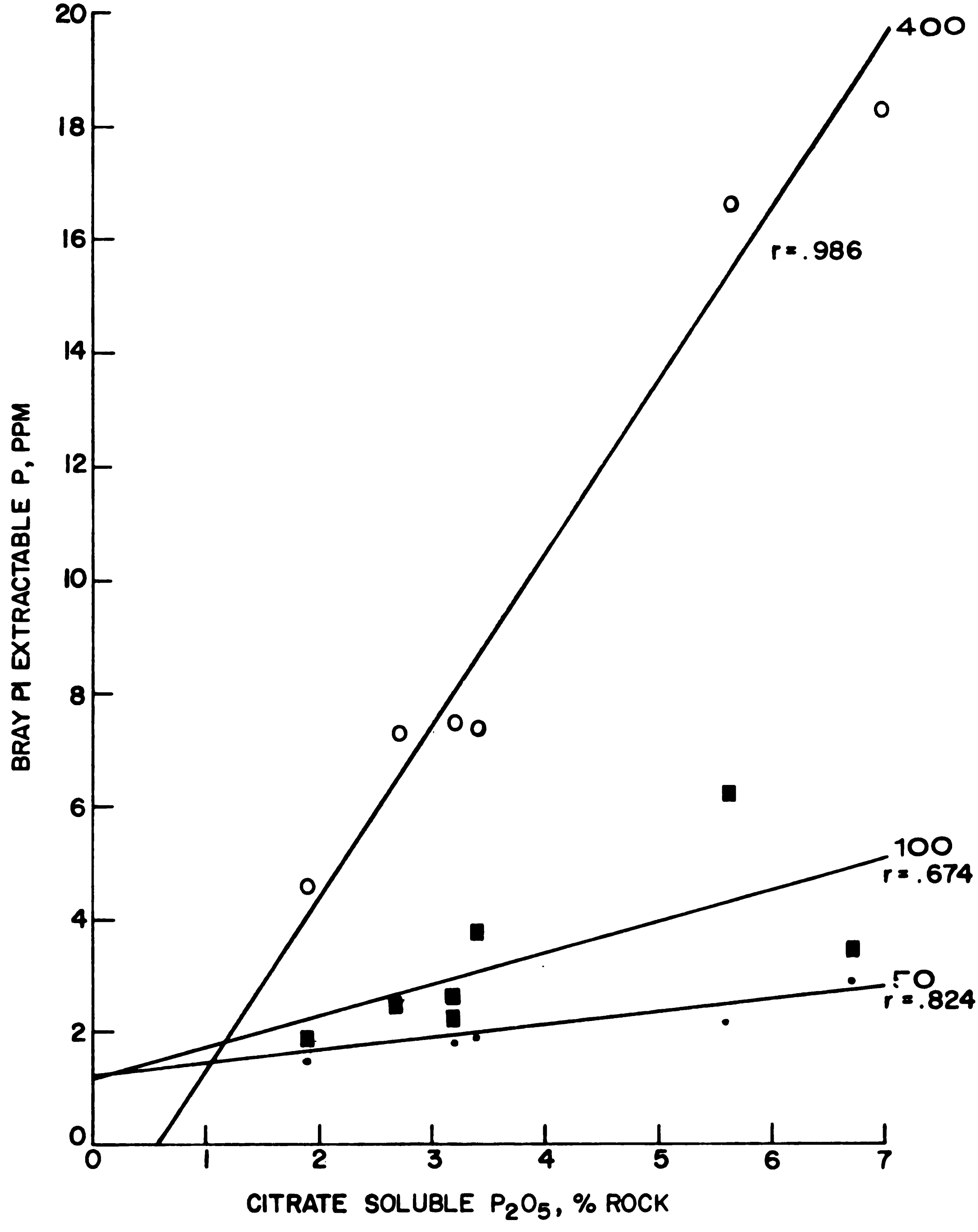

Figure 13.--Relationship between Bray P-1 extractable P in Carimagua soil and citrate soluble P in phosphate rocks.

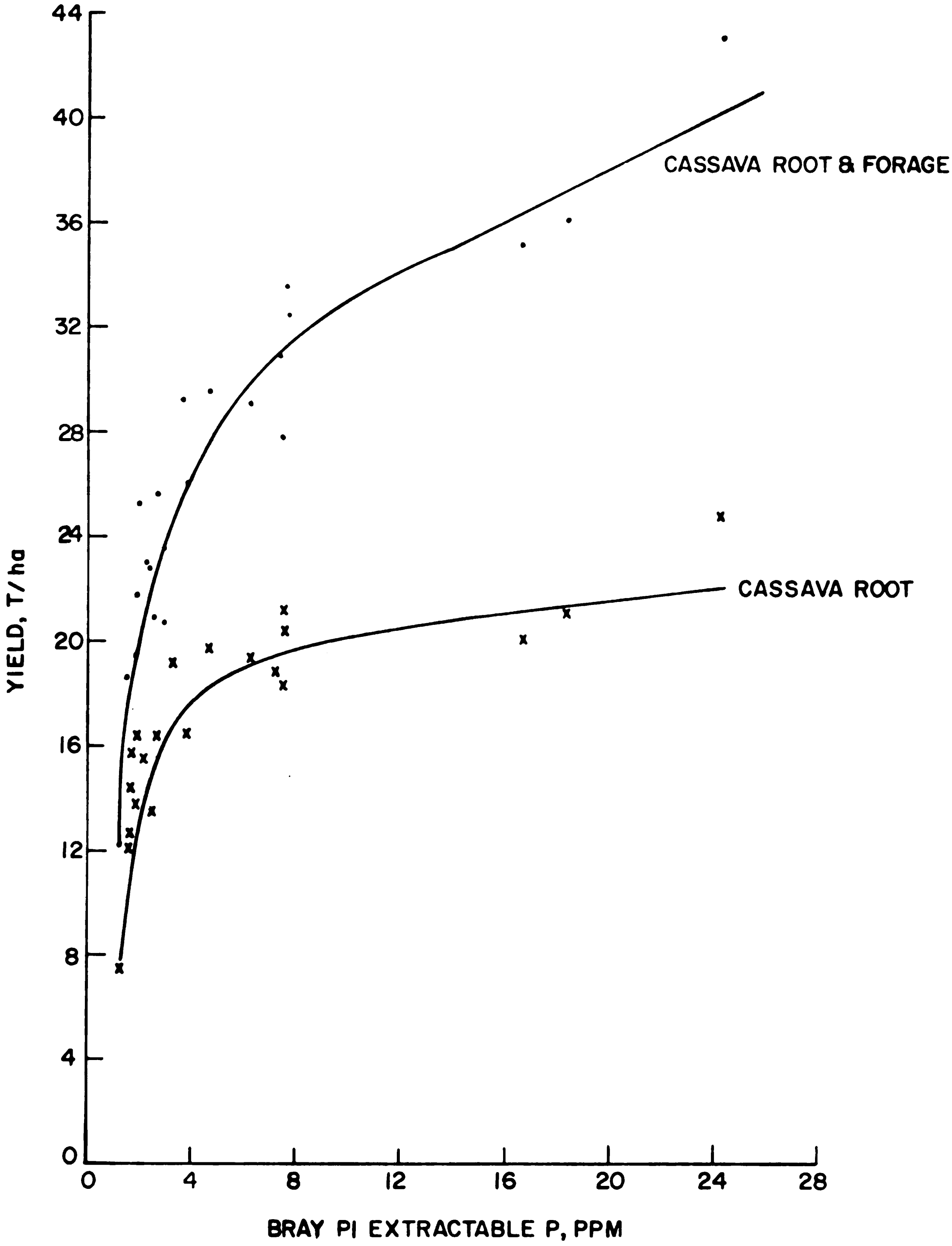

Figure 14.--Relationship between yield of Cassava and Bray P-1 extractable P in the Carimagua soil.

plant response to high levels of P was in the above ground forage production.

Water Soluble P

The amount of water soluble P in the soil was not as good an indicator of cassava yield as the Bray P-1 extractable P (Figure 15), but did follow the same general pattern. When measured 51 days following application, basic slag and the North Carolina, Gafsa, and Tennessee phosphate rocks had statistically higher levels of water soluble P than the Central Florida, Huila, and Pesca rocks (Table 17). In all cases, the amount of water soluble P was extremely low, ranging from 0.004 to 0.028 ppm P.

Soil Acidity

When measured 50 days after application, soil pH in a 1:1 soil/water mixture was significantly increased by all sources except the Central Florida, Tennessee, and Pesca phosphate rocks. Basic slag, with a $CaCO_3$ equivalent of 67%, was the only source which significantly increased the pH at the 50 and 100 kg P_2O_5/ha rates. At the 400 kg P_2O_5/ha rate, the greatest increases for phosphate rocks were with the North Carolina, Gafsa, and Huila sources which raised the pH by 0.27, 0.34, and 0.25 units, respectively (Table 18).

TABLE 17.--Water Soluble P in Field Experiment with Cassava 51 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			Average*
	50	100	400	
	ppm P			
Basic Slag	.013	.013	.020	.015 a
North Carolina PR	.011	.010	.016	.012 a
Gafsa PR	.010	.017	.028	.018 a
Central Florida PR	.012	.009	.010	.010 b
Huila PR	.011	.012	.008	.010 b
Tennessee PR	.009	.014	.014	.012 a
Pesca PR	.004	.008	.017	.010 b
Control				.008

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE 18.--pH of 1:1 Soil-Water Mixture in Field Experiment with Cassava 51 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			Average*
	50	100	400	
	pH			
Basic Slag	4.67	4.70	5.12	4.83 a
North Carolina PR	4.63	4.52	4.80	4.65 bc
Gafsa PR	4.55	4.67	4.87	4.69 ab
Central Florida PR	4.55	4.55	4.55	4.55 bc
Huila PR	4.62	4.67	4.78	4.69 ab
Tennessee PR	4.47	4.58	4.45	4.50 c
Pesca PR	4.62	4.47	4.58	4.56 bc
Control				4.53

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

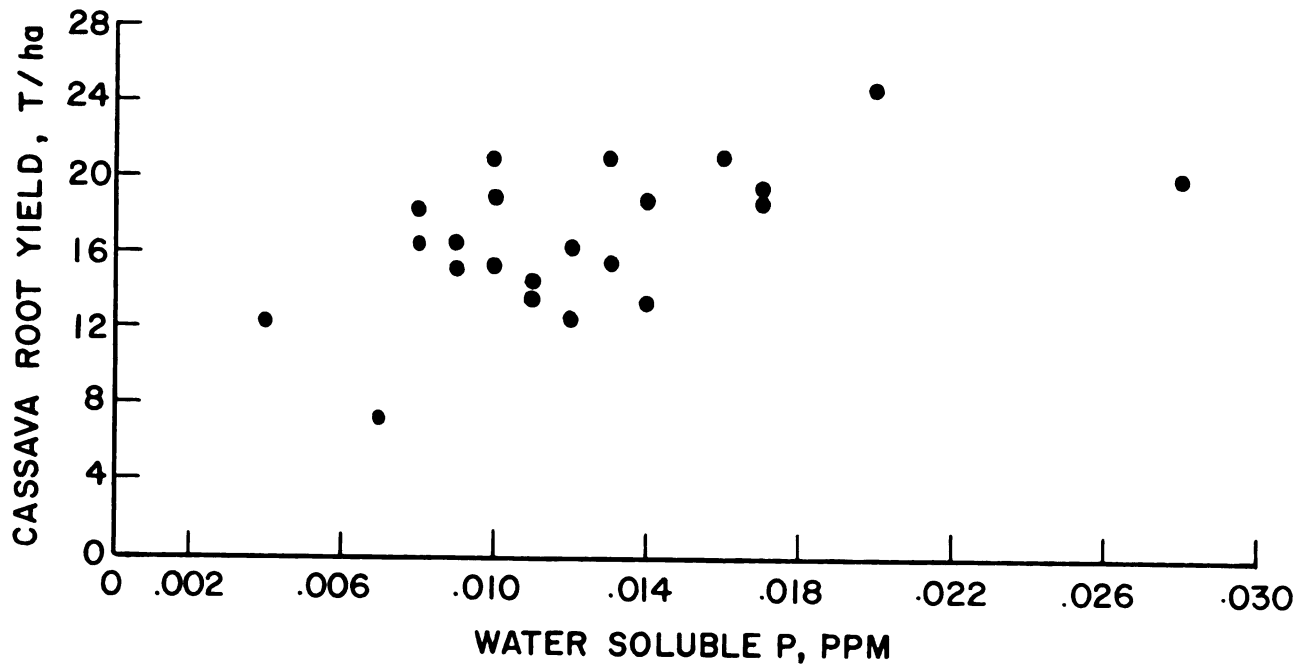

Figure 15.--Relationship between yield of Cassava and water soluble P in the Carimagua soil.

The exchangeable soil Al decreased as the soil pH increased (Figure 16). The decreases in exchangeable Al were as follows: Basic slag > North Carolina PR = Gafsa PR = Huila PR > Central Florida PR = Pesca PR > Tennessee PR (Table 19). The actual change in the amount of exchangeable Al resulting from application of the phosphate sources was small, but the percentage of the effective CEC saturated with Al was markedly decreased (Figure 17). Part of the reduction in Al saturation was due to increased exchangeable Ca which was also related to phosphate rock reactivity.

At harvest, 360 days after P application, Al saturation had been reduced from the level of the control plot by 44% and 39% with the North Carolina and Gafsa phosphate rocks, respectively, at the 400 kg P_2O_5/ha rate of application. The greatest decrease at this rate was 86% with basic slag, while the smallest change was 15% with Pesca phosphate rock. There was no significant reduction in Al saturation at either the 50 or 100 kg P_2O_5/ha rates.

Field Experiment with Beans

The beans were grown on an Andosol which had an initial level of extractable P (Bray P-1) of 2.6 ppm P and an original pH of 4.9. Lime applied at the rate of 4.7 t/ha raised the pH to 5.5 at the time of planting.

TABLE 19.--Exchangeable Al in Field Experiment with Cassava 51 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			Average*
	50	100	400	
	meq/100 gm			
Basic Slag	0.9	0.8	0.4	0.7 a
North Carolina PR	0.9	1.0	0.8	0.9 b
Gafsa PR	0.9	1.0	0.8	0.9 bc
Central Florida PR	1.0	1.0	1.0	1.0 cd
Huila PR	1.0	1.0	0.8	0.9 bc
Tennessee PR	1.1	1.1	1.1	1.1 d
Pesca PR	0.9	1.0	0.9	1.0 bc
Control				1.0

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

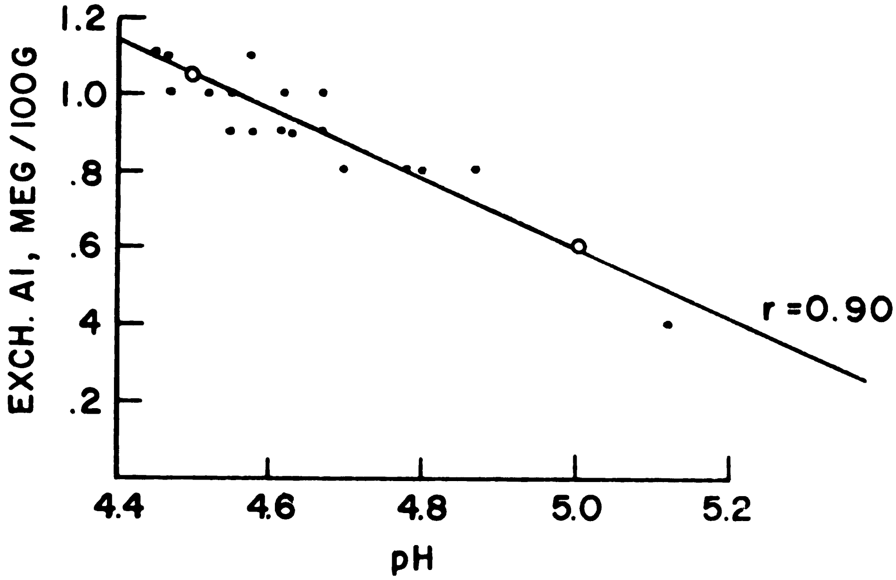

Figure 16.--Relationship between exchangeable Al in the Carimagua soil and soil pH.

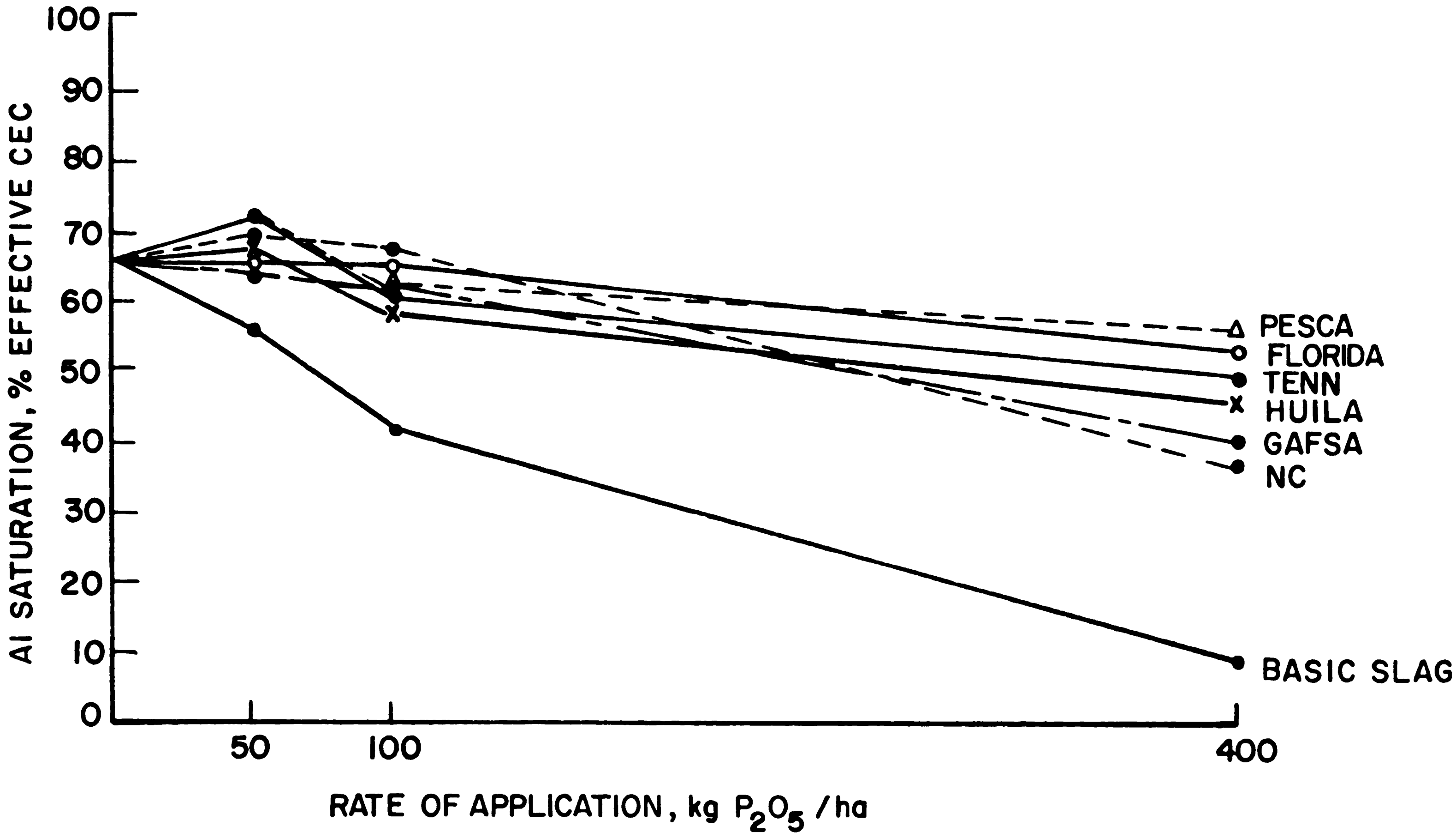

Figure 17.--Aluminum saturation in the Carimagua soil as affected by rate of P application.

Bean Yield Response to
Rate and Source of P

In the first crop of beans following P application, mean yields of all P sources were increased 64%, 76%, 115%, and 138% by applications of 50, 100, 200, and 400 kg P_2O_5/ha, respectively, as compared to the no P treatment (Table 20). Using the mean yields of the TSP treatments as maximum production, 90% of the maximum yield was obtained when 190 kg P_2O_5/ha was applied as TSP, 290 kg P_2O_5 as Gafsa PR and 375 kg P_2O_5 as Sechura PR. Yields obtained with all the other P sources were less than 90% of the maximum yield with TSP.

A statistical comparison of the yields obtained with phosphate rocks shows that the yields using the rocks from North Carolina, Sechura, and Gafsa were highest while those with Tennessee and Pesca were lowest. Yields with the Central Florida and Huila rocks were intermediate. This order is consistent with the results obtained in both of the experiments previously described and as shown in Figure 18, is highly correlated with the citrate solubility of the P in the phosphate rocks at each rate of application.

Following the harvest of the first crop, TSP was reapplied at the original rates to plots which had also received TSP before the first planting. The set of plots which received two applications of TSP produced consistently higher yields during both the first cropping when

TABLE 20.--Yield of First Crop of Beans.

Source	Rate of Application (kg P_2O_5/ha)				Average***
	50	100	200	400	
	kg/ha @ 14% moisture				
Triple superphosphate*	1967	2022	2639	2893	2380 a
Triple superphosphate**	1759	1797	2202	2395	2038 b
North Carolina PR	1624	1719	2102	2297	1935 bc
Sechura PR	1589	1822	2102	2427	1985 bc
Gafsa PR	1750	1883	2256	2596	2121 b
Central Florida PR	1419	1577	1802	1837	1659 de
Tennessee PR	1119	1240	1665	1758	1445 ef
Pesca PR	1204	1109	1237	1611	1290 f
Huila PR	1345	1557	1988	2132	1756 cd
Control					932

*For annual application

**For residual effect evaluation

***Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

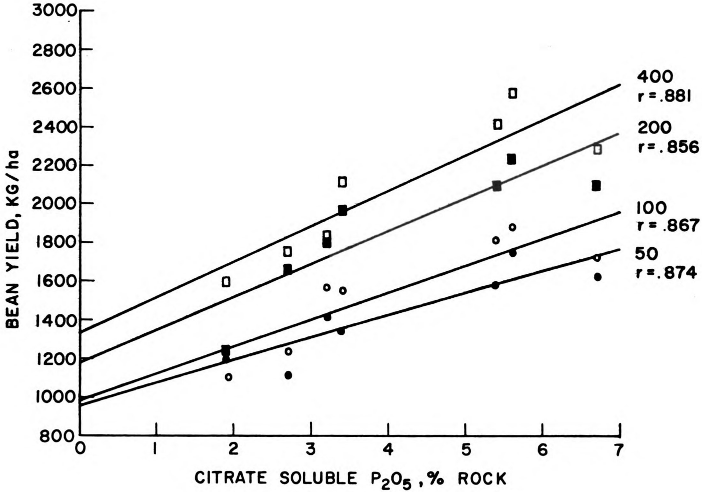

Figure 18.--Relationship between bean yield (1st crop) and citrate soluble P_2O_5 in phosphate rocks.

compared fresh TSP to residual TSP. The difference in yield between these plots was as follows:

	Rate of Application (kg P_2O_5/ha)				
	50	100	200	400	
Yield TSP 1 minus TSP 2, 1st Crop =	208	225	437	498	kg/ha
Yield TSP 1 minus TSP 2, 2nd Crop =	147	672	703	299	kg/ha

Since these large differences were present in both crops, it is probable that reapplication yielded significantly higher only at the 100 and 200 kg P_2O_5/ha rates.

The yields obtained with residual P in the second crop were in the order TSP = North Carolina PR = Sechura PR = Gafsa PR > Huila PR = Central Florida PR > Tennessee PR = Pesca PR (Table 21). The yields averaged over all sources were 33%, 64%, 111%, and 160% higher than the yields from the no P plots.

The Relative Agronomic Effectiveness of the phosphate rocks varied from 28% to 93% in the first crop and from 28% to 72% in the second crop when compared to yields obtained with the freshly applied TSP for each crop (Figure 19). For each source except Huila PR, the yields obtained from the second crop were higher than those obtained in the first crop. Little difference was

TABLE 21.--Yield of Second Crop of Beans.

Source	Rate of Application (kg P_2O_5/ha)				Average***	
	50	100	200	400		
	---------------- kg/ha @ 14% moisture ----------------					
Triple superphosphate*	1740	2414	3064	3316	2634	a
Triple superphosphate**	1593	1742	2361	3017	2178	b
North Carolina PR	1284	1829	2421	3160	2173	b
Sechura PR	1239	1852	2446	2679	2054	b
Gafsa PR	1555	1852	2411	2863	2170	b
Central Florida PR	1320	1542	2038	2479	1845	c
Tennessee PR	1193	1486	1769	2152	1650	c
Pesca PR	1114	1223	1459	2004	1450	d
Huila PR	1200	1458	1825	2255	1685	c
Control					989	

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

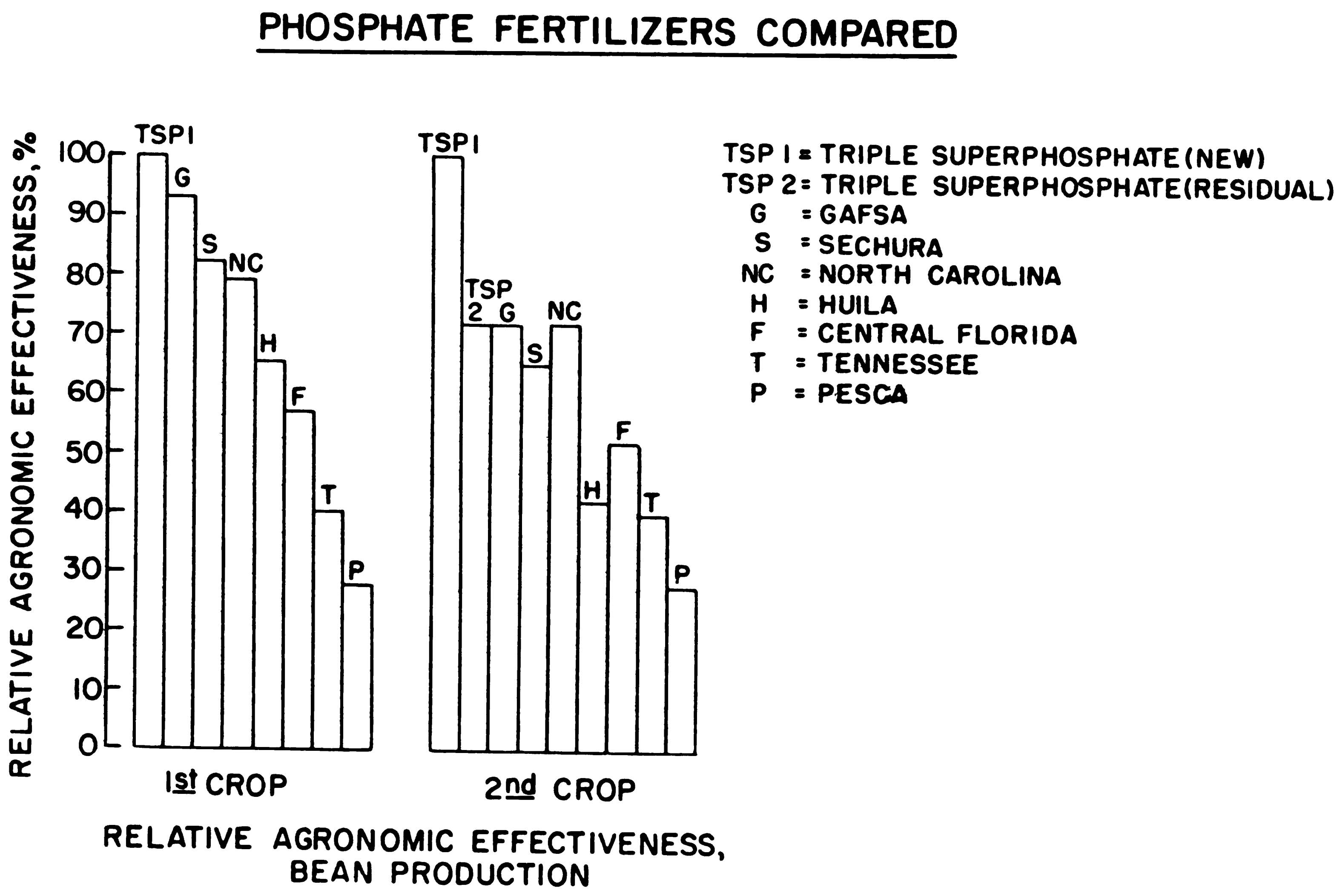

Figure 19.--Relative agronomic effectiveness of phosphate rocks for the first two crops in the field experiment with beans.

was observed between the yields of the no P plots from the first and second crops.

The yield of beans obtained with the phosphate rock treatments were correlated with the citrate soluble P_2O_5 in the rock (Table 22). Only at the 50 kg P_2O_5/ha rate of application in the second crop was the linear correlation coefficient between yield and citrate soluble P_2O_5 in the rock not significant. In all cases, the correlation coefficients were improved by expressing the citrate soluble P_2O_5 as the percent of the rock rather than as the percent of the total P_2O_5 in the rock.

Soil Phosphorus Status

The citrate soluble P_2O_5 in the phosphate rocks was correlated with the extractable soil P (Bray P-1), and the degree of correlation did not increase with increased rates of application (Figure 20). The increase in extractable soil P with increased application of P was much less pronounced than observed in the previously described experiments (Table 23). It is possible that the degree of dissolution of the phosphate rocks is lower in this experiment due to the higher pH resulting from the lime application, reducing the amount of P which can be extracted by Bray P-1 solution. The extractable P measured from treatment with the phosphate rocks was in the order Garfa PR = North Carolina PR > Sechura PR > Central Florida PR = Tennessee PR = Pesca PR = Huila PR.

TABLE 22.--Correlation Coefficients Between Citrate Soluble P_2O_5 in Phosphate Rock and Yield of Beans.

	Rate of Application (kg P_2O_5/ha)			
	50	100	200	400
Citrate Sol. (% of Rock) vs.				
Bean yield, first crop	.894	.867	.856	.881
Bean yield, second crop	.585	.942	.943	.971
Citrate Sol. (% Total P) vs.				
Bean yield, first crop	.828	.798	.812	.876
Bean yield, second crop	.446	.795	.797	.855

TABLE 23.--Extractable P (Bray P-1) in the Field Experiment with Beans 30 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)				Average***
	50	100	200	400	
Triple superphosphate*	4.8	4.7	10.4	13.8	8.4 a
Triple superphosphate**	3.7	5.1	10.8	13.4	8.3 ab
North Carolina PR	3.8	4.6	9.8	8.7	6.7 bc
Sechura PR	3.3	5.4	6.2	8.3	5.8 cd
Gafsa PR	4.0	5.6	10.1	12.3	8.0 ab
Central Florida PR	2.7	3.2	4.9	7.9	4.7 de
Tennessee PR	3.0	4.9	4.8	3.9	4.1 e
Pesca PR	2.1	2.6	5.8	4.4	3.7 e
Huila PR	2.4	3.2	5.2	4.8	3.9 e
Control					2.9

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

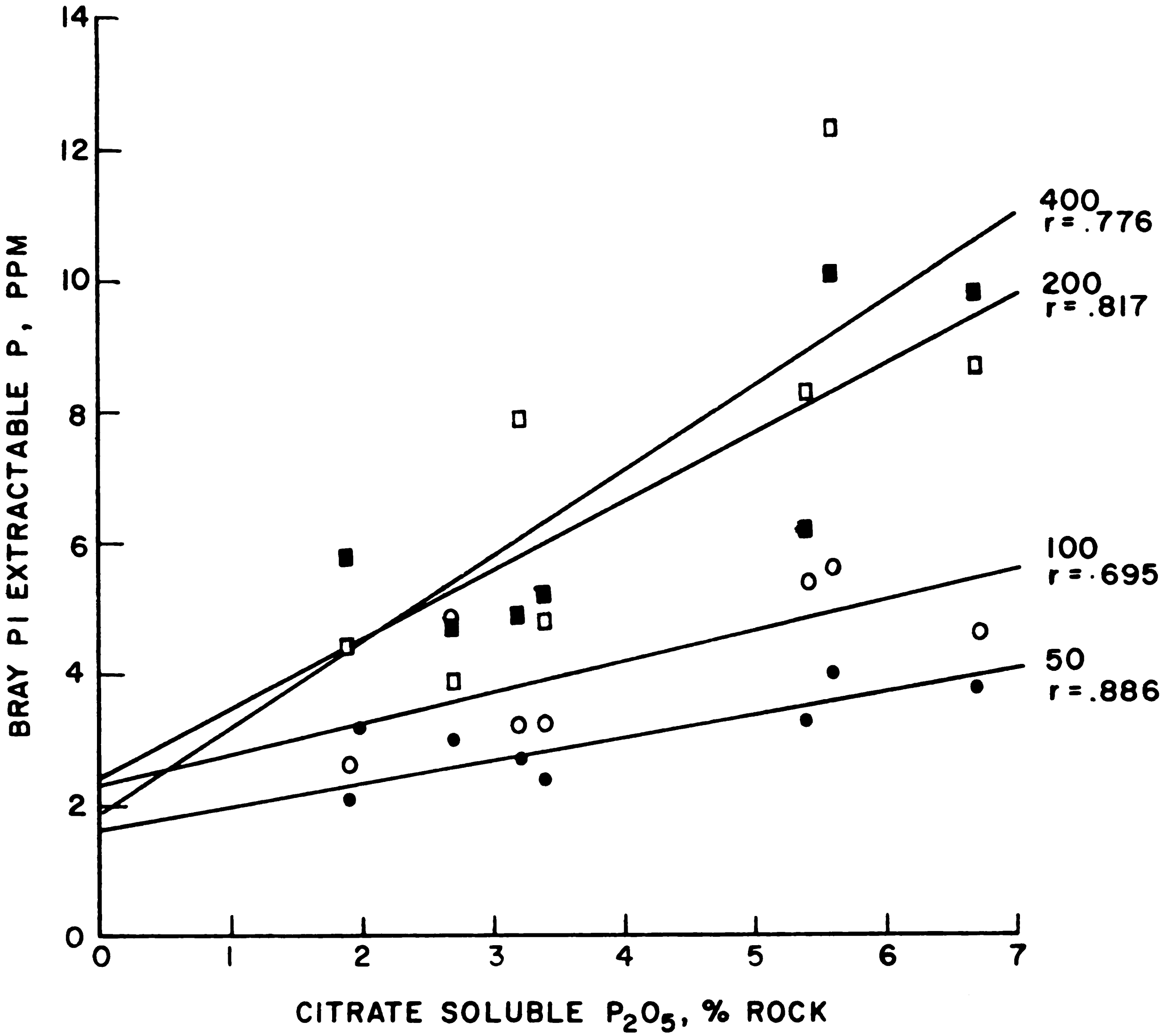

Figure 20.--Relationship between Bray P-1 extractable P in the Popayan soil and citrate soluble P_2O_5 in phosphate rocks.

The Bray P-1 extractable P served well as an indicator of response in both the first and second crops, but water soluble P did not (Appendix Tables C7 to C9). Because of the extremely high P adsorption capacity of this soil and the high Ca status, it is likely that a more accurate approximation of the P in soil solution could be obtained by extraction with 0.01 M $CaCl_2$ for a shorter period of time. This would more closely resemble the salt status of the soil solution and reduce re-adsorption of the P in solution during extraction.

SUMMARY AND CONCLUSIONS

The results obtained in the greenhouse experiment with guinea grass and in the field experiments with cassava and beans show marked crop response to P supplied by direct application of finely ground phosphate rock. In the greenhouse, no yield was obtained from the no P treatment during the three cuttings. With rates of 50, 100, 200, and 400 ppm P, mean yields obtained from the phosphate rock treatments were 1.46, 5.50, 10.61, and 12.91 g/pot, respectively. A positive yield response was also obtained with increasing rates of application with the cassava and two bean crops in the field. The mean percentage of yield increase over the no P treatment obtained with the phosphate rocks in the field was as follows:

	kg P_2O_5/ha			
	50	100	200	400
Cassava	86	125	--	165
Beans, 1st Crop	54	67	102	125
Beans, 2nd Crop	29	62	108	154

The level of crop response to P supplied by a direct application of phosphate rock varies with the source of the rock (Brown and Jacob, 1945; Armiger and Fried, 1957; Bennett, et al., 1957; Shapiro and Armiger, 1958; Ensminger, et al., 1967; Howeler and Woodruff, 1968; Engelstad, et al., 1974; Barnes and Kamprath, 1975). With basic slag as the standard source representing 100% yield in the greenhouse and cassava experiment, and TSP as the standard in the bean experiment, the Relative Agronomic Effectiveness (RAE) of the seven phosphate rocks were as follows:

	Green-house	Cassava	1st Beans	---- 2nd Beans	--- -
North Carolina PR	82	82	79	72*	100**
Gasfa PR	80	84	93	72	99
Sechura PR	94	--	82	65	90
Central Florida PR	53	73	57	52	72
Huila PR	41	70	65	42	59
Tennessee PR	35	66	40	40	56
Pesca PR	27	67	28	28	39

*Fresh TSP = 100.

**Residual TSP = 100.

The yields obtained with the raw phosphate rock never surpassed those obtained with the soluble P fertilizer except in the greenhouse where low Ca and high Al saturation inhibited response to the TSP treatment. Phosphate rock from North Carolina, Gafsa, and Sechura, however, were always at least 80% as effective as the soluble sources when applied on the same data. Tennessee and Pesca rocks were generally ineffective in the greenhouse and bean experiments, while Central Florida and Huila rocks were only moderately effective. All sources were at least two-thirds as effective as soluble P when applied to cassava. Utilization of P from relatively insoluble sources varies with the crop (Russell, 1973; Murdock and Seay, 1955; McLean, 1956). First year yield results indicate that cassava is capable of effective use of P supplied by raw phosphate rock.

An assumption widely accepted when comparing the value of phosphate rock to soluble P fertilizers is that proper evaluation should include the effectiveness of the residual phosphorus from the sources. Many investigations have shown that the initial effect of soluble P is almost always higher than the relatively insoluble forms, but that in two or more years, there is little difference in the RAE between soluble P and phosphate rock, and that over a varying period of time, equivalent total yields will be obtained from both forms (Russell, 1973; Mokwunye, 1977; Cooke and Widdowson, 1959; Barnes and Kamprath, 1975; Arndt and McIntyre, 1963; Cooke, 1956; McLean, 1956; McLachlan, 1959; Armiger and Fried, 1957; Ensminger, et al., 1967).

The RAE of North Carolina and Gafsa PR's was the same as TSP which had been applied at the same time and 72% as effective as TSP which had received fresh applications prior to each planting. Sechura PR was 90% as effective on the second crop. The RAE of all other sources had improved with respect to TSP, but were still only in the range of 39% to 72% as effective as TSP. The field experiments with both cassava and beans are being continued for additional evaluation of residual effect.

The relative availability of P from phosphate rock sources has been shown to be well related to the citrate soluble P content of the material (Armiger and Fried, 1957; Bennett, et al., 1957; Hoffman and Breen, 1964; Engelstad, et al., 1974). In each experiment, the correlation between citrate soluble P in the phosphate rock and yield and P uptake was highly significant and improved as the rate of application increased. It is suggested that the low concentrations of P solubilized from the phosphate rock particles provides a root absorption zone in the soil much smaller and with lower P concentration than that associated with soluble P sources, and therefore, the probability for accurate prediction of crop response as related to rock reactivity increases as the probability for roots to enter the absorption zone increases.

It was found that the citrate soluble P_2O_5 of the phosphate rock was better correlated with yields when expressed as "percent of the rock" rather than "percent of total P_2O_5 in the rock." When expressed as "percent of total P_2O_5 in the rock," it is implied that the quantity of apatite present (grade) controls the amount of citrate soluble P. It has been shown, however, by Lehr and McClellan (1972) that the level of solubility is primarily a function of apatite composition.

Differences in the reactivity of the phosphate rocks were also reflected in the soil test parameters. The citrate soluble P_2O_5 content of the phosphate rocks was well correlated with Bray P-1 extractable P in all of the experiments. In contrast to the correlations between P uptake and citrate solubility, there was no appreciable change in the correlation coefficients obtained in the relationship between citrate soluble P_2O_5 of the rock and Bray P-1 extractable P with changes in the rate of application. It was suggested that the more precise measurement by Bray P-1 was due to the high degree of contact between the extracting solution and the phosphate rock particles.

Larger crop response was observed with the phosphate rocks than with TSP at a given level of Bray P-1 extractable P in the greenhouse as was also found by Barnes and Kamprath (1975). It was suggested that the Bray solution measured all P reaction products from TSP but only a portion of the P from the relatively insoluable phosphate rock. The crop may also have been responding to the calcium supplied by the phosphate rock in addition to the phosphorus (McLean, 1956).

Citrate soluble P in the rock was significantly correlated with the concentration of water soluble P in the soil in the greenhouse experiment at the 200 and 400 ppm P rates of application. At the 50 and 100 ppm P rates, there was no significant correlation. At these low rates of application, the water soluble P ranged from 0.004 to 0.017 ppm P regardless of sources.

Water soluble P or P soluble in a 0.01 M $CaCl_2$ extract approximates the P in the soil solution (Adams, 1971). Phosphorus extracted by these solutions have been shown to be well related to P uptake and plant growth (Khasawneh, 1971; Khasawneh and Copeland, 1973). In the greenhouse experiment, P uptake by guinea grass was linearly correlated with water soluble P and had a correlation coefficient of 4 = 0.918. Dry matter yield was related to water soluble P by one curvilinear relationship for the phosphate rocks and basic slag, and a different curvilinear relationship for TSP. This suggests growth inhibition for the TSP treatment.

In the field experiment with cassava, the same trend was shown in the relationship between water soluble P and yield, but the response curve was not as precise as that obtained from the guinea grass. In the bean experiment, there was no relationship observed between water soluble P and yield. It is suggested that the measurements were influenced by readsorption of P which occurred during the 24-hour extraction period of the water soluble P on the volcanic soil and absorption capacity much higher than with the Oxisol. In addition, 4.7 t/ha of lime had been applied and water may not have been adequately similar to the soil solution which contained a high calcium concentration.

The pH, extractable Al and extractable Ca of the soil were related to the reactivity of the phosphate rock in the greenhouse experiment where no lime had been applied and with the cassava where one-half t/ha had been applied. In the bean experiment, 4.7 t/ha of lime was applied prior to planting and there was no significant difference in the pH, Al, or Ca measurements.

In the greenhouse, pH was significantly increased by all sources of phosphate rock except Tennessee and Pesca. The pH ranged from 0.22 to 0.40 units higher than the no P treatment for the other sources at the 200 and 400 ppm P rates, and from 0.02 to 0.23 at the 50 and 100 ppm P rates. On the Oxisol, in the field experiment with cassava, the pH was raised 0.25 to 0.34 units with 400 kg P_2O_5/ha of North Carolina, Gafsa, and Huila phosphate rocks, but no differences were observed with the other sources or at lower rates.

Both in the greenhouse and in the Oxisol in the field, the Al saturation of the effective CEC was strongly related to the citrate soluble P content of the phosphate rock. As the pH increased, the extractable Al decreased and the extractable Ca increased as follows:

	% Decrease in Al Sat.		Increase in Exch. Ca (meq/100 g)	
	400 ppm P Greenhouse	400 kg/ha P_2O_5 Cassava	400 ppm P Greenhouse	400 kg/ha P_2O_5 Cassava
North Carolina	50	29	2.453	0.442
Gafsa	43	26	2.260	0.579
Sechura	45	-	2.151	-
Central Florida	32	13	1.724	0.369
Huila	30	20	1.797	0.541
Tennessee	15	17	1.099	0.296
Pesca	12	10	0.855	0.195

The importance of these changes was well illustrated in the greenhouse experiments where a stepwise multiple regression with backward elimination showed that uptake of P, Ca, and Zn were all related to the yield of guinea grass at the 5% significance level when all sources (including soluble sources) were involved. Zinc appeared to be included because of the low Zn levels measured at the high rates of applied basic slag. Calcium deficiency and Al toxicity were suggested as the causes of low yields obtained with TSP.

It was also noted that the basic slag utilized contained a high level of Mn, since Mn concentrations in the tissue increased with increased rates of application despite the increase in pH with the increased rates. No other source showed a trend to increase in Mn with increased rates of application.

Based on these results, the following can be concluded:

1. The relative agronomic effectiveness of the phosphate rocks were in the order:

North Carolina		Central Florida		Tennessee
	>		>	
Gafsa		Huila		Pesca
Sechura				

2. The P in the phosphate rock soluble in neutral ammonium citrate is a good measure of the relative reactivity of the rock when expressed as "percent of the rock."

3. Phosphate rock can be described as having high, medium or low reactivity with citrate soluble P_2O_5 in the range of 5.4 to 6.7 for high, 3.2 to 3.4 for medium, and 1.9 to 2.7 for low.

4. Phosphate rock chosen for direct application on the basis of citrate solubility will show erratic and unpredictable crop response unless applied at high rates.

5. Crop response could be influenced by reduced Al saturation and increased exchangeable Ca as well as the level of available P when phosphate rocks are applied to acid soil without added lime.

APPENDICES

APPENDIX A

GREENHOUSE DATA

TABLE A1.--Dry Matter Yield of Guinea Grass from the First Greenhouse Harvest.

Source	Rate of Application (ppm P) 50	100	200	400	Average*
	---- gm/pot ----				
Triple superphosphate	0.12	2.76	5.58	6.53	3.75 c
Basic Slag	2.23	5.73	7.25	8.65	5.97 a
Sechura PR	0.56	4.05	7.07	9.18	5.22 ab
North Carolina PR	0.41	3.49	6.31	9.43	4.91 b
Gafsa PR	0.74	3.58	5.36	8.67	4.59 b
Central Florida PR	0.05	1.88	4.24	5.02	2.80 d
Huila PR	0.01	1.51	3.48	4.00	2.25 de
Tennessee PR	0.03	0.66	1.58	4.12	1.60 ef
Pesca PR	0.01	0.05	0.88	2.36	0.82 f
Control					0.00

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A2.--Dry Matter Yield of Guinea Grass from the Second Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	gm/pot				
Triple superphosphate	0.16	1.00	3.05	3.36	1.89 de
Basic Slag	0.46	2.57	4.16	4.11	2.82 ab
Sechura PR	0.50	1.74	4.06	5.46	2.94 a
North Carolina PR	0.12	1.33	3.62	4.77	2.46 bc
Gafsa PR	0.44	0.51	3.10	4.40	2.11 cd
Central Florida PR	0.20	0.94	2.12	2.94	1.55 e
Huila PR	0.01	0.81	1.34	1.77	0.98 f
Tennessee PR	0.05	0.49	1.35	1.48	0.84 f
Pesca PR	0.09	0.05	0.98	1.03	0.54 f
Control					0.00

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A3.--Dry Matter Yield of Guinea Grass from the Third Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	gm/pot				
Triple superphosphate	1.07	2.18	3.53	2.71	2.37 bc
Basic Slag	1.42	5.20	5.39	4.59	4.15 a
Sechura PR	1.89	3.39	5.46	5.03	3.94 a
North Carolina PR	0.79	2.13	5.17	4.89	3.25 ab
Gafsa PR	2.13	3.26	4.96	4.01	3.59 a
Central Florida PR	1.16	1.96	3.23	3.64	2.50 bc
Huila PR	0.18	2.04	2.59	3.72	2.13 c
Tennessee PR	0.73	2.29	3.84	1.58	2.11 c
Pesca PR	0.10	2.37	3.52	2.31	2.07 c
Control					0.00

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A4.--Available Soil Phosphorus (Bray P-1) in Greenhouse Experiment 30 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm P				
Triple superphosphate	22.3	27.4	81.2	138.5	67.3 a
Basic slag	21.6	32.4	69.1	118.9	60.5 ab
Sechura PR	16.3	19.0	38.6	68.5	35.6 c
North Carolina PR	22.3	39.4	80.0	116.6	64.6 ab
Gafsa PR	23.1	38.6	53.5	99.9	53.8 b
Central Florida PR	12.2	21.3	31.6	55.3	30.1 cd
Huila PR	11.1	16.8	26.1	34.7	22.2 de
Tennessee PR	10.6	15.6	25.9	48.3	25.1 cde
Pesca PR	8.4	11.1	16.9	28.8	16.3 e
Control					1.9

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A5.--Available Soil Phosphorus (Bray P-1) in Greenhouse Experiment 50 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm P				
Triple superphosphate	13.4	23.5	61.7	135.5	58.5 a
Basic Slag	12.9	27.9	50.4	109.6	50.2 b
Sechura PR	11.1	21.7	38.4	62.2	33.4 e
North Carolina PR	11.0	23.3	55.6	92.3	45.6 c
Gafsa PR	11.1	20.8	47.7	67.1	36.7 d
Central Florida PR	8.8	13.1	30.3	44.7	24.2 f
Huila PR	6.4	13.4	18.4	26.8	16.2 g
Tennessee PR	6.9	11.0	21.3	29.8	17.3 g
Pesca PR	4.9	6.4	13.9	19.6	11.2 h
Control					1.6

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE A6.--Available Soil Phosphorus (Bray P-1) in Greenhouse Experiment at Time of Final Harvest (190 Days after Application in Cropped Pots).

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm P				
Triple superphosphate	10.0	19.1	43.5	109.6	45.5 a
Basic Slag	10.9	21.8	48.0	73.1	38.5 b
Sechura PR	10.0	18.7	34.2	63.7	31.6 c
North Carolina PR	9.1	18.4	39.2	77.3	36.0 bc
Gafsa PR	10.0	19.5	41.8	79.3	37.6 b
Central Florida PR	7.7	15.3	32.0	48.4	25.9 d
Huila PR	8.5	18.0	25.7	29.3	20.4 e
Tennessee PR	7.7	11.6	21.3	36.4	19.3 e
Pesca PR	6.6	10.3	19.8	31.7	17.1 e
Control					1.4

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE A7.--Water Soluble Phosphorus in Greenhouse Soil 10 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm P				
Triple superphosphate	.033	.049	.232	.732	.262 a
Basic Slag	.028	.069	.197	.347	.160 b
Sechura PR	.045	.022	.068	.143	.070 cd
North Carolina PR	.009	.061	.158	.325	.138 b
Gafsa PR	.021	.053	.124	.313	.128 bc
Central Florida PR	.015	.015	.055	.096	.045 d
Huila PR	.032	.063	.260	.546	.225 a
Tennessee PR	.021	.064	.174	.216	.119 bc
Pesca PR	.044	.056	.102	.231	.108 bcd
Control					.014

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A8.--Water Soluble Phosphorus in Greenhouse Soil 30 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm P				
Triple superphosphate	.032	.043	.084	.317	.119 a
Basic Slag	.016	.015	.135	.404	.142 a
Sechura PR	.025	.017	.063	.076	.045 cd
North Carolina PR	.017	.022	.055	.208	.076 bc
Gafsa PR	.023	.027	.058	.192	.075 bc
Central Florida PR	.019	.025	.039	.163	.061 bcd
Huila PR	.027	.030	.026	.074	.039 d
Tennessee PR	.025	.036	.041	.221	.081 b
Pesca PR	.023	.023	.033	.050	.032 d
Control					.009

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A9.--Water Soluble Phosphorus in Greenhouse Soil 50 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm P				
Triple superphosphate	.017	.030	.093	.281	.105 b
Basic Slag	.017	.049	.114	.386	.141 a
Sechura PR	.024	.031	.089	.158	.075 c
North Carolina PR	.017	.031	.112	.175	.084 bc
Gafsa PR	.052	.017	.076	.103	.062 cd
Central Florida PR	.023	.021	.048	.095	.047 de
Huila PR	.022	.020	.023	.057	.031 ef
Tennessee PR	.026	.018	.019	.018	.020 f
Pesca PR	.025	.020	.027	.017	.022 f
Control					.009

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE A10.--Water Soluble Phosphorus in Greenhouse Soil at Time of Final Harvest (190 Days after Application).

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm P				
Triple superphosphate	.015	.014	.018	.060	.027 ab
Basic Slag	.014	.021	.024	.071	.032 a
Sechura PR	.021	.011	.038	.037	.027 ab
North Carolina PR	.016	.028	.028	.070	.035 a
Gafsa PR	.015	.019	.022	.072	.032 a
Central Florida PR	.011	.011	.019	.018	.015 bc
Huila PR	.019	.012	.017	.017	.016 bc
Tennessee PR	.018	.018	.010	.012	.014 bc
Pesca PR	.009	.016	.010	.015	.013 c
Control					.011

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A11.--pH in 1:1 Soil-Water Mixture 10 Days After Application in Greenhouse.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	------------	------------ pH	------------	------------	------------
Triple superphosphate	4.63	4.60	4.50	4.55	4.57 f
Basic Slag	4.83	5.02	5.28	5.80	5.23 a
Sechura PR	4.67	4.70	4.78	4.82	4.74 cd
North Carolina PR	4.68	4.80	4.88	4.97	4.83 b
Gafsa PR	4.70	4.67	4.77	4.98	4.78 bc
Central Florida PR	4.65	4.63	4.78	4.73	4.70 de
Huila PR	4.55	4.77	4.80	5.03	4.79 bc
Tennessee PR	4.62	4.68	4.65	4.63	4.65 e
Pesca PR	4.68	4.70	4.60	4.62	4.65 e
Control					4.68

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A12.--pH in 1:1 Soil-Water Mixture 30 Days after Application in Greenhouse.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	pH				
Triple superphosphate	4.93	4.95	4.95	4.90	4.93 d
Basic Slag	5.12	5.47	5.47	6.00	5.51 a
Sechura PR	4.98	5.03	5.07	5.08	5.04 bc
North Carolina PR	5.08	5.03	5.12	5.25	5.12 b
Gafsa PR	4.93	4.98	5.03	5.20	5.04 bc
Central Florida PR	5.03	5.07	5.15	5.13	5.10 b
Huila PR	4.80	4.95	4.98	5.15	4.97 cd
Tennessee PR	4.95	4.95	4.93	5.00	4.96 cd
Pesca PR	4.98	4.92	4.90	4.97	4.94 d
Control					4.98

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A13.--Exchangeable Aluminum in Cropped Greenhouse Soil at Final Harvest 190 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	meq/100 gm				
Triple superphosphate	3.9	3.9	3.5	3.3	3.7 a
Basic Slag	3.1	2.3	0.9	0.2	1.6 f
Sechura PR	3.9	3.3	2.5	1.6	2.8 de
North Carolina PR	3.6	3.5	2.4	1.4	2.8 e
Gafsa PR	3.4	3.4	2.8	1.8	2.9 de
Central Florida PR	3.6	3.6	3.3	2.4	3.2 bc
Huila PR	3.5	3.4	3.0	2.3	3.0 cd
Tennessee PR	3.5	3.5	3.4	3.2	3.4 b
Pesca PR	3.5	3.5	3.5	3.2	3.4 ab
Control					3.4

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A14.--Exchangeable Aluminum in Uncropped Greenhouse Soil 190 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	------------------ meq/100 gm				
Triple superphosphate	4.1	4.1	3.9	3.8	4.0 a
Basic Slag	3.4	3.1	1.8	0.2	2.1 e
Sechura PR	3.9	3.8	3.5	2.6	3.5 b
North Carolina PR	3.8	3.7	3.2	2.1	3.2 cd
Gafsa PR	3.7	3.4	3.1	2.2	3.1 d
Central Florida PR	3.8	3.8	3.4	3.1	3.5 b
Huila PR	3.5	3.6	3.4	2.9	3.4 bc
Tennessee PR	3.7	3.6	3.5	3.4	3.6 b
Pesca PR	3.5	3.7	3.6	3.4	3.5 b
Control					3.5

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A15.--Exchangeable Calcium in Greenhouse Soil 90 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	---------- meq/100 gm ----------				
Triple superphosphate	0.369	0.545	0.837	1.230	0.745 g
Basic Slag	1.134	2.003	4.500	6.083	3.430 a
Sechura PR	0.737	1.074	1.694	2.298	1.450 c
North Carolina PR	0.797	1.122	2.043	2.917	1.720 b
Gafsa PR	0.801	1.166	1.868	2.750	1.646 b
Central Florida PR	0.617	0.841	1.058	1.720	1.059 e
Huila PR	0.697	1.022	1.284	2.083	1.272 d
Tennessee PR	0.533	0.697	1.034	1.122	0.846 f
Pesca PR	0.461	0.561	0.793	1.008	0.706 g
Control					0.270

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A16.--Exchangeable Calcium in Uncropped Greenhouse Soil 190 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	meq/100 gm				
Triple superphosphate	0.474	0.526	0.843	1.281	0.781 e
Basic Slag	1.208	2.093	2.596	3.025	2.231 a
Sechura PR	0.651	1.130	1.648	2.859	1.572 c
North Carolina PR	0.801	1.265	2.077	3.410	1.889 b
Gafsa PR	0.833	1.177	1.984	3.171	1.791 b
Central Florida PR	0.619	0.922	1.479	2.198	1.304 d
Huila PR	0.625	0.979	1.567	2.201	1.343 d
Tennessee PR	0.619	0.744	0.984	1.364	0.928 e
Pesca PR	0.542	0.734	0.822	1.208	0.826 e
Control					0.333

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A17.--Exchangeable Magnesium in Greenhouse Soil 90 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	meq/100 gm				
Triple superphosphate	.119	.124	.143	.158	.136 b
Basic Slag	.126	.145	.179	.219	.168 a
Sechura PR	.126	.125	.139	.160	.138 b
North Carolina PR	.126	.127	.132	.154	.136 b
Gafsa PR	.119	.124	.128	.150	.130 bc
Central Florida PR	.129	.121	.124	.126	.125 cd
Huila PR	.132	.121	.120	.124	.124 cd
Tennessee PR	.121	.115	.124	.119	.120 d
Pesca PR	.116	.114	.120	.118	.117 d
Control					.142

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A18.--Exchangeable Magnesium in Cropped Greenhouse Soil at Final Harvest 190 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	meq/100 gm				
Triple superphosphate	.129	.103	.075	.070	.094 bcd
Basic Slag	.103	.058	.052	.074	.072 e
Sechura PR	.133	.084	.076	.053	.086 de
North Carolina PR	.121	.081	.056	.052	.078 de
Gafsa PR	.125	.107	.065	.057	.089 cde
Central Florida PR	.122	.102	.064	.049	.084 de
Huila PR	.177	.114	.106	.065	.116 a
Tennessee PR	.122	.124	.110	.071	.106 abc
Pesca PR	.118	.121	.104	.105	.112 ab
Control					.164

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A19.--Exchangeable Magnesium in Uncropped Greenhouse Soil 190 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	meq/100 gm				
Triple superphosphate	.136	.151	.197	.196	.170 c
Basic Slag	.169	.201	.224	.248	.211 a
Sechura PR	.139	.173	.214	.239	.191 ab
North Carolina PR	.167	.172	.166	.209	.176 bc
Gafsa PR	.158	.142	.160	.195	.164 c
Central Florida PR	.153	.153	.176	.170	.163 c
Huila PR	.145	.125	.142	.146	.140 d
Tennessee PR	.147	.134	.133	.139	.138 d
Pesca PR	.147	.147	.130	.140	.141 d
Control					.137

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A20.--Exchangeable Potassium in Cropped Greenhouse Soil at Final Harvest 190 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	------------------- meq/100 gm -------------------				
Triple superphosphate	.090	.036	.032	.032	.047 bcd
Basic Slag	.032	.032	.036	.047	.037 ef
Sechura PR	.038	.027	.032	.036	.033 f
North Carolina PR	.076	.029	.038	.038	.045 cd
Gafsa PR	.053	.034	.036	.038	.040 def
Central Florida PR	.081	.027	.032	.036	.044 cde
Huila PR	.106	.032	.034	.030	.050 bc
Tennessee PR	.112	.038	.036	.036	.056 b
Pesca PR	.111	.081	.032	.033	.064 a
Control					.121

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE A21.--Exchangeable Potassium in Uncropped Greenhouse Soil 190 Days after Application.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	meq/100 gm				
Triple superphosphate	.115	.123	.128	.142	.127 abc
Basic Slag	.138	.138	.130	.119	.131 a
Sechura PR	.112	.115	.117	.117	.115 bc
North Carolina PR	.123	.115	.124	.121	.121 abc
Gafsa PR	.126	.134	.130	.139	.132 a
Central Florida PR	.126	.132	.128	.117	.126 abc
Huila PR	.115	.115	.113	.115	.114 c
Tennessee PR	.123	.121	.132	.134	.128 ab
Pesca PR	.119	.124	.115	.128	.121 abc
Control					.135

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A22.--Phosphorus Content of Guinea Grass from the First Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% P				
Triple superphosphate	.107	.148	.152	.378	.226 a
Basic Slag	.100	.098	.190	.285	.191 ab
Sechura PR	.148	.105	.152	.155	.137 c
North Carolina PR	.143	.098	.123	.218	.147 c
Gafsa PR	.141	.115	.117	.228	.153 bc
Central Florida PR	.135	.153	.157	.172	.161 bc
Huila PR	.094	.127	.112	.150	.129 c
Tennessee PR	.076	.128	.183	.170	.161 bc
Pesca PR	-	.140	.158	.148	.149 c
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A23.--Phosphorus Content of Guinea Grass from the Second Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% P				
Triple superphosphate	.078	.093	.136	.332	.187 ab
Basic Slag	.095	.106	.167	.330	.201 a
Sechura PR	.073	.100	.157	.213	.157 bc
North Carolina PR	.060	.090	.159	.395	.214 a
Gafsa PR	.067	.105	.132	.233	.157 bc
Central Florida PR	.057	.088	.210	.165	.125 cd
Huila PR	-	.081	.112	.133	.109 d
Tennessee PR	.063	.074	.102	.160	.112 d
Pesca PR	.098	.095	.098	.100	.098 d
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A24.--Phosphorus Content of Guinea Grass from the Third Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% P				
Triple superphosphate	.064	.119	.157	.575	.284 a
Basic Slag	.063	.098	.207	.525	.277 a
Sechura PR	.075	.116	.170	.279	.188 bc
North Carolina PR	.074	.092	.167	.424	.228 ab
Gafsa PR	.066	.098	.157	.264	.173 bcd
Central Florida PR	.071	.085	.129	.229	.147 cde
Huila PR	.062	.062	.148	.198	.136 cde
Tennessee PR	.069	.065	.109	.157	.110 de
Pesca PR	-	.089	.080	.100	.090 e
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE A25.--Calcium Content of Guinea Grass from the First Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% Ca				
Triple superphosphate	.239	.331	.393	.401	0.375 f
Basic Slag	.414	.720	1.067	1.491	1.093 a
Sechura PR	.479	.488	.633	.613	0.578 cd
North Carolina PR	.422	.508	.882	.856	0.749 b
Gafsa PR	.435	.480	.717	.859	0.685 bc
Central Florida PR	.427	.366	.481	.791	0.546 de
Huila PR	.454	.453	.566	.856	0.625 cd
Tennessee PR	.312	.374	.407	.573	0.451 ef
Pesca PR	-	.262	.374	.446	0.361 f
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A26.--Calcium Content of Guinea Grass from the Second Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% Ca				
Triple superphosphate	0.189	0.332	0.642	0.720	0.565 d
Basic Slag	0.671	1.262	1.483	2.135	1.627 a
Sechura PR	0.392	0.817	1.025	1.063	0.968 bc
North Carolina PR	0.220	0.817	1.072	1.389	1.093 b
Gafsa PR	0.280	0.747	1.110	1.190	1.016 b
Central Florida PR	0.385	0.475	0.887	1.122	0.828 c
Huila PR	-	0.409	0.791	1.296	0.832 c
Tennessee PR	0.220	0.252	0.499	0.712	0.488 d
Pesca PR	0.268	0.444	0.280	0.552	0.425 d
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A27.--Calcium Content of Guinea Grass from the Third Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	-----------------------		% Ca		-----------------------
Triple superphosphate	0.188	0.469	0.812	0.889	0.723 e
Basic Slag	0.563	1.295	1.451	2.371	1.706 a
Sechura PR	0.302	0.952	1.246	1.492	1.230 b
North Carolina PR	0.424	0.846	1.297	1.672	1.272 b
Gafsa PR	0.996	0.792	1.265	1.390	1.149 bc
Central Florida PR	0.260	0.502	0.937	1.335	0.925 d
Huila PR	0.319	0.522	1.223	1.492	1.079 c
Tennessee PR	0.269	0.345	0.724	1.052	0.707 e
Pesca PR	-	0.379	0.445	0.786	0.536 f
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A28.--Potassium Content of Guinea Grass from the First Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% K				
Triple superphosphate	4.02	3.37	1.52	1.24	2.04 de
Basic Slag	3.58	1.54	1.18	0.77	1.16 f
Sechura PR	4.30	1.96	1.17	0.92	1.35 ef
North Carolina PR	3.34	2.40	1.29	0.81	1.50 ef
Gafsa PR	3.54	2.59	1.83	1.13	1.85 ef
Central Florida PR	3.51	3.89	2.61	1.46	2.66 cd
Huila PR	3.06	3.67	2.71	2.23	2.87 bc
Tennessee PR	2.63	3.88	4.42	2.18	3.49 b
Pesca PR	-	5.10	4.27	3.41	4.26 a
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A29.--Potassium Content of Guinea Grass from the Second Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% K				
Triple superphosphate	3.34	1.70	0.60	0.71	1.00 c
Basic Slag	1.92	0.75	0.57	0.47	0.60 c
Sechura PR	2.97	1.07	0.52	0.42	0.67 c
North Carolina PR	3.11	1.09	0.60	0.57	0.75 c
Gafsa PR	3.09	1.26	0.71	0.59	0.85 c
Central Florida PR	2.59	2.54	1.22	0.70	1.49 b
Huila PR	-	2.69	1.46	0.78	1.64 b
Tennessee PR	3.00	3.45	2.67	0.97	2.36 a
Pesca PR	3.39	2.44	2.99	1.48	2.30 a
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A-30.--Potassium Content of Guinea Grass from the Third Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% K				
Triple superphosphate	2.81	0.47	0.43	0.55	0.48 de
Basic Slag	1.03	0.36	0.30	0.42	0.36 e
Sechura PR	2.23	0.36	0.28	0.30	0.31 e
North Carolina PR	2.06	0.65	0.29	0.32	0.42 de
Gafsa PR	1.05	0.48	0.28	0.39	0.39 e
Central Florida PR	2.78	0.93	0.91	0.38	0.74 c
Huila PR	2.89	0.76	0.58	0.52	0.62 cd
Tennessee PR	2.93	1.71	0.66	0.70	1.02 b
Pesca PR	-	2.38	0.92	0.48	1.26 a
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A31.--Magnesium Content of Guinea Grass from the First Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% Mg				
Triple superphosphate	.330	.301	.293	.341	.312 c
Basic Slag	.308	.357	.568	.607	.511 a
Sechura PR	.327	.381	.272	.336	.330 bc
North Carolina PR	.396	.378	.349	.357	.361 bc
Gafsa PR	.311	.351	.371	.406	.376 b
Central Florida PR	.310	.343	.302	.341	.329 bc
Huila PR	.415	.279	.338	.446	.354 bc
Tennessee PR	.354	.308	.338	.348	.331 bc
Pesca PR	-	.319	.328	.378	.342 bc
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE A32.--Magnesium Content of Guinea Grass from the Second Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% Mg				
Triple superphosphate	.241	.300	.305	.312	.306 ab
Basic Slag	.330	.361	.265	.321	.316 ab
Sechura PR	.308	.376	.209	.212	.266 b
North Carolina PR	.255	.354	.278	.236	.289 b
Gafsa PR	.303	.422	.312	.230	.321 ab
Central Florida PR	.288	.337	.334	.274	.315 ab
Huila PR	-	.297	.372	.398	.356 a
Tennessee PR	.307	.286	.301	.334	.307 ab
Pesca PR	.247	.247	.287	.407	.314 ab
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE A33.--Magnesium Content of Guinea Grass from the Third Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	% Mg				
Triple superphosphate	.247	.379	.231	.387	.332 a
Basic Slag	.316	.286	.126	.234	.215 c
Sechura PR	.264	.398	.219	.141	.253 bc
North Carolina PR	.272	.387	.202	.182	.257 bc
Gafsa PR	.181	.366	.209	.224	.266 bc
Central Florida PR	.256	.349	.339	.184	.291 ab
Huila PR	.278	.278	.320	.339	.312 ab
Tennessee PR	.267	.266	.327	.332	.308 ab
Pesca PR	-	.291	.246	.385	.307 ab
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE A34.--Manganese Content of Guinea Grass from the First Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm Mn				
Triple superphosphate	-	140	124	147	137 d
Basic Slag	185	193	427	534	385 a
Sechura PR	160	125	112	129	122 d
North Carolina PR	161	158	125	124	136 d
Gafsa PR	317	152	146	161	153 cd
Central Florida PR	-	224	175	149	183 c
Huila PR	-	180	174	177	177 c
Tennessee PR	-	205	220	223	216 b
Pesca PR	-	-	187	188	-
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$). Means are calculated over the three highest rates of application.

TABLE A35.--Manganese Content of Guinea Grass from the Second Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm Mn				
Triple superphosphate	-	183	230	252	222 c
Basic Slag	186	340	540	631	503 a
Sechura PR	218	205	191	187	194 c
North Carolina PR	-	179	211	198	196 c
Gafsa PR	217	229	190	169	196 c
Central Florida PR	-	190	206	193	196 c
Huila PR	-	202	223	199	208 c
Tennessee PR	-	298	244	350	297 b
Pesca PR	-	-	226	209	-
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$). Means are calculated over the three highest rates of application.

TABLE A36.--Manganese Content of Guinea Grass from the Third Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm Mn				
Triple superphosphate	203	178	242	362	261 b
Basic Slag	207	440	515	639	531 a
Sechura PR	178	250	161	-	206 d
North Carolina PR	141	191	192	178	187 d
Gafsa PR	174	193	189	181	188 d
Central Florida PR	183	158	194	208	186 d
Huila PR	-	128	203	234	188 d
Tennessee PR	-	189	214	316	239 c
Pesca PR	-	163	148	196	-
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$). Means are calculated over the three highest rates of application.

TABLE A37.--Zinc Content of Guinea Grass from the First Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm Zn				
Triple superphosphate	-	26	23	23	24 cd
Basic Slag	28	20	25	14	20 d
Sechura PR	36	25	23	24	24 cd
North Carolina PR	30	29	23	24	26 bc
Gafsa PR	39	31	28	30	30 ab
Central Florida PR	-	30	26	22	26 bc
Huila PR	-	37	27	26	30 ab
Tennessee PR	-	28	36	30	31 a
Pesca PR	-	-	35	36	-
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05). Means are calculated over the three highest rates of application.

TABLE A38.--Zinc Content of Guinea Grass from the Second Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm Zn				
Triple superphosphate	-	28	25	28	27 bc
Basic Slag	16	23	20	11	18 d
Sechura PR	25	26	24	21	23 c
North Carolina PR	-	28	28	27	28 b
Gafsa PR	33	42	29	29	33 a
Central Florida PR	-	27	30	25	28 b
Huila PR	-	25	25	25	25 bc
Tennessee PR	-	28	26	30	28 b
Pesca PR	-	-	28	31	-
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Test ($p = .05$). Means are calculated over the three highest rates of application.

TABLE A39.--Zinc Content of Guinea Grass from the Third Greenhouse Harvest.

Source	Rate of Application (ppm P)				Average*
	50	100	200	400	
	ppm Zn				
Triple superphosphate	41	29	25	28	27 ab
Basic Slag	26	21	17	8	15 c
Sechura PR	28	33	21	-	27 ab
North Carolina PR	25	28	24	31	28 ab
Gafsa PR	25	34	26	25	28 ab
Central Florida PR	27	23	24	24	24 b
Huila PR	-	23	29	29	27 ab
Tennessee PR	-	27	26	35	29 a
Pesca PR	-	-	28	44	-
Control					-

*Means with the same letter are not significantly different with Duncan's Multiple Test ($p = .05$). Means are calculated over the three highest rates of application.

APPENDIX B

CASSAVA DATA

TABLE B1.--Yield of Above-Ground Cassava Forage.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average***
	ton/ha			
Triple superphosphate*	8.2	11.6	16.4	12.1 a
Triple superphosphate**	7.2	10.5	15.6	11.1 b
Basic slag	8.0	12.1	18.3	12.8 a
North Carolina PR	6.9	10.1	15.0	10.7 b
Gafsa PR	7.5	9.8	15.1	10.8 b
Central Florida PR	6.9	9.2	12.4	9.5 c
Huila PR	7.3	9.5	9.5	8.8 cd
Tennessee PR	7.5	7.4	12.1	9.0 cd
Pesca PR	6.4	8.8	9.9	8.4 d
Control				4.9

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE B2.--Available Phosphorus (Bray P-1) in Field Experiment with Cassava 110 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	---------------- ppm P ----------------			
Basic Slag	3.7	5.5	16.9	8.7 ab
North Carolina PR	4.1	7.2	17.6	9.6 a
Gafsa PR	4.1	7.1	19.5	10.2 a
Central Florida PR	3.7	4.0	5.1	4.2 c
Huila PR	3.0	4.2	7.9	5.1 c
Tennessee PR	2.4	4.1	11.6	6.0 bc
Pesca PR	3.3	3.9	6.5	4.6 c
Control				2.7

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE B3.--Available Phosphorus (Bray P-1) at Time of Harvest 360 Days after Application in Field Experiment with Cassava.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	---- ppm P ----			
Basic Slag	5.4	12.5	42.2	20.0 a
North Carolina PR	2.8	7.9	37.9	16.2 ab
Gafsa PR	2.7	7.0	30.5	13.4 bc
Central Florida PR	4.5	4.8	16.5	8.6 cd
Huila PR	2.9	5.2	13.8	7.3 cd
Tennessee PR	3.5	7.3	15.4	8.7 cd
Pesca PR	2.4	4.1	8.1	4.9 d
Control				3.7

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE B4.--pH of 1:1 Soil-Water Mixture in Field Experiment with Cassava at Harvest 360 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	----------	pH	----------	
Basic Slag	5.00	5.23	5.67	5.30 a
North Carolina PR	4.97	5.07	5.33	5.12 b
Gafsa PR	5.00	5.17	5.20	5.12 b
Central Florida PR	4.97	4.97	5.17	5.03 b
Huila PR	5.00	5.00	5.20	5.07 b
Tennessee PR	4.97	4.97	5.17	5.03 b
Pesca PR	4.90	5.03	5.03	4.99 b
Control				4.86

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE B5.--pH of 0.01 M $CaCl_2$-Soil Mixture in Field Experiment with Cassava 51 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	pH			
Basic Slag	4.07	4.25	4.65	4.32 a
North Carolina PR	4.08	4.08	4.23	4.13 b
Gafsa PR	4.08	4.08	4.23	4.13 b
Central Florida PR	4.02	4.07	4.10	4.06 bc
Huila PR	4.10	4.10	4.22	4.14 b
Tennessee PR	4.00	4.10	4.03	4.04 c
Pesca PR	4.05	4.02	4.08	4.05 c
Control				4.03

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE B6.--pH of 0.01 M $CaCl_2$-Soil Mixture in Field Experiment with Cassava at Harvest 360 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	pH			
Basic Slag	4.33	4.53	5.03	4.63 a
North Carolina PR	4.20	4.20	4.57	4.32 b
Gafsa PR	4.20	4.27	4.47	4.31 bc
Central Florida PR	4.23	4.27	4.33	4.28 bc
Huila PR	4.27	4.30	4.47	4.34 b
Tennessee PR	4.20	4.27	4.37	4.28 bc
Pesca PR	4.17	4.23	4.27	4.22 c
Control				4.20

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE B7.--Exchangeable Aluminum in Soil from Field Experiment with Cassava 51 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	-------------- meq/100 gm --------------			
Basic Slag	0.9	0.8	0.4	0.7 a
North Carolina PR	0.9	1.0	0.8	0.9 b
Gafsa PR	0.9	1.0	0.8	0.9 bc
Central Florida PR	1.0	1.0	1.0	1.0 cd
Huila PR	1.0	1.0	0.8	0.9 bc
Tennessee PR	1.1	1.1	1.1	1.1 d
Pesca PR	0.9	1.0	0.9	1.0 bc
Control				1.0

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE B8.--Exchangeable Aluminum in Soil from Field Experiment with Cassava at Harvest 360 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	meq/100 gm			
Basic Slag	0.9	0.7	0.2	0.6 a
North Carolina PR	1.0	1.1	0.5	0.9 b
Gafsa PR	1.0	1.1	0.7	0.9 bc
Central Florida PR	0.9	1.0	0.9	0.9 bc
Huila PR	1.0	0.9	0.8	0.9 bc
Tennessee PR	1.1	1.0	0.8	1.0 bc
Pesca PR	1.1	1.0	0.9	1.0 c
Control				1.0

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE B9.--Exchangeable Calcium in Soil from Field Experiment with Cassava 51 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	meq/100 gm			
Basic Slag	.368	.861	1.746	.992 a
North Carolina PR	.307	.387	.696	.463 b
Gafsa PR	.333	.518	.711	.521 b
Central Florida PR	.212	.283	.399	.298 c
Huila PR	.273	.427	.642	.447 b
Tennessee PR	.233	.368	.337	.313 c
Pesca PR	.220	.222	.393	.278 c
Control				.199

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE B10.--Exchangeable Calcium in Soil from Field Experiment with Cassava at Harvest 360 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	meq/100 gm			
Basic Slag	.514	.760	1.714	.996 a
North Carolina PR	.260	.340	.651	.417 bc
Gafsa PR	.320	.346	.788	.485 b
Central Florida PR	.292	.338	.572	.401 bc
Huila PR	.288	.413	.750	.484 b
Tennessee PR	.248	.331	.505	.361 bc
Pesca PR	.236	.309	.404	.317 c
Control				.209

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE B11.--Exchangeable Magnesium in Soil from Field Experiment with Cassava 51 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	---------------- meq/100 gm -------------			
Basic Slag	.247	.354	.354	.318 a
North Carolina PR	.273	.298	.269	.280 a
Gafsa PR	.340	.415	.261	.338 a
Central Florida PR	.251	.259	.239	.249 a
Huila PR	.279	.327	.271	.292 a
Tennessee PR	.256	.389	.219	.288 a
Pesca PR	.259	.227	.310	.265 a
Control				.246

*Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE B12.--Exchangeable Magnesium in Soil from Field Experiment with Cassava at Harvest 360 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	---------- meq/100 gm ----------			
Basic Slag	.092	.109	.096	.099 a
North Carolina PR	.087	.085	.107	.093 a
Gafsa PR	.101	.089	.091	.094 a
Central Florida PR	.082	.097	.094	.091 a
Huila PR	.099	.116	.087	.101 a
Tennessee PR	.090	.102	.101	.098 a
Pesca PR	.089	.097	.103	.097 a
Control				.087

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE B13.--Exchangeable Potassium in Soil from Field Experiment with Cassava at Harvest 360 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)			
	50	100	400	Average*
	----------------	meq/100 gm	-------------	
Basic Slag	.111	.114	.106	.110 b
North Carolina PR	.111	.124	.088	.107 b
Gafsa PR	.148	.200	.157	.168 a
Central Florida PR	.110	.102	.133	.115 b
Huila PR	.109	.127	.101	.113 b
Tennessee PR	.094	.231	.213	.179 a
Pesca PR	.111	.196	.192	.166 a
Control				.218

*Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

APPENDIX C

FIELD BEAN DATA

TABLE C1.--Dry Weight Production of Bean Plants 30 Days after Planting.

Source	Rate of Application (kg P_2O_5/ha)				Average***
	50	100	200	400	
	gm/plant				
Triple superphosphate*	0.97	1.51	1.80	3.41	1.92 a
Triple superphosphate**	0.99	1.21	1.69	2.77	1.67 a
North Carolina PR	1.01	1.05	1.27	1.87	1.30 b
Sechura PR	0.73	1.05	0.99	1.51	1.07 bc
Gafsa PR	0.93	1.13	1.27	1.51	1.21 b
Central Florida PR	0.72	0.78	0.89	1.12	0.88 c
Tennessee PR	0.57	0.67	0.71	0.98	0.73 d
Pesca PR	0.63	0.61	0.71	0.85	0.70 d
Huila PR	0.79	0.79	0.91	1.01	0.87 c
Control					0.53

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C2.--Phosphorus Uptake by Field Beans 30 Days after Planting.

Source	Rate of Applicagion (kg P_2O_5/ha)				Average***
	50	100	200	400	
	gm/plant				
Triple superphosphate*	0.36	0.52	0.65	1.22	0.69 a
Triple superphosphate**	0.34	0.48	0.81	1.27	0.73 a
North Carolina PR	0.33	0.45	0.51	0.83	0.53 b
Sechura PR	0.30	0.30	0.35	0.52	0.41 bc
Gafsa PR	0.38	0.57	0.40	0.66	0.50 b
Central Florida PR	0.23	0.30	0.28	0.44	0.32 cd
Tennessee PR	0.18	0.22	0.25	0.36	0.25 cd
Pesca PR	0.29	0.29	0.25	0.33	0.28 cd
Huila PR	0.32	0.20	0.30	0.32	0.28 d
Control					0.18

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C3.--Dry Weight Production of Bean Plants 65 Days after Planting.

Source	Rate of Applicagion (kg P_2O_5/ha)				Average***
	50	100	200	400	
	gm/plant				
Triple superphosphate*	4.84	7.25	7.88	12.81	8.20 a
Triple superphosphate**	5.53	9.76	6.10	9.11	7.63 a
North Carolina PR	3.55	3.93	5.77	6.48	4.93 bc
Sechura PR	3.19	4.60	4.50	8.61	5.22 bc
Gafsa PR	5.07	4.01	7.21	7.94	6.06 b
Central Florida PR	4.30	3.78	5.80	5.20	4.77 bc
Tennessee PR	2.53	3.28	4.93	5.54	4.07 cd
Pesca PR	2.34	2.34	2.83	4.66	3.04 d
Huila PR	2.81	3.80	4.85	5.93	4.35 cd
Control					2.69

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C4.--Phosphorus Uptake by Field Beans 65 Days after Planting.

Source	Rate of Application (kg P_2O_5/ha)				Average***
	50	100	200	400	
	gm/plant				
Triple superphosphate*	3.16	4.35	4.95	9.50	5.49 a
Triple superphosphate**	3.03	5.73	4.88	8.76	5.60 a
North Carolina PR	1.90	2.77	3.97	5.74	3.60 bc
Sechura PR	1.35	2.74	2.89	5.18	3.04 bcd
Gafsa PR	2.97	2.77	4.80	5.78	4.08 b
Central Florida PR	2.52	2.73	3.54	3.22	3.00 cd
Tennessee PR	1.10	1.81	2.88	3.55	2.34 de
Pesca PR	1.20	1.21	1.54	2.62	1.64 e
Huila PR	1.55	2.47	2.57	3.18	2.44 de
Control					1.16

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE C5.--Available Phosphorus as Measured by Bray P-1 65 Days after Application in the Field Experiment with Beans.

Source	Rate of Application (kg P_2O_5/ha)				Average***
	50	100	200	400	
	ppm P				
Triple superphosphate*	2.3	3.5	4.3	9.4	4.9 b
Triple superphosphate**	2.3	4.1	6.8	11.4	6.3 a
North Carolina PR	2.9	3.2	5.4	7.7	4.8 b
Sechura PR	2.2	2.4	3.6	3.9	3.0 c
Gafsa PR	3.5	3.8	4.5	7.0	4.7 b
Central Florida PR	2.1	2.4	2.9	4.4	3.0 c
Tennessee PR	2.1	1.7	2.3	2.8	2.2 c
Pesca PR	2.0	1.9	2.8	2.8	2.4 c
Huila PR	2.2	2.7	2.9	4.5	3.1 c
Control					1.6

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE C6.--Available Phosphorus as Measured by Bray P-1 at Bean Harvest 120 Days after Application.

Source	Rate of Application (kg P_2O_5/ha)				Average***
	50	100	200	400	
	ppm P				
Triple superphosphate*	3.4	4.8	3.0	6.4	4.4 ab
Triple superphosphate**	4.0	3.5	3.0	4.0	3.6 b
North Carolina PR	4.4	2.6	2.9	5.9	4.0 ab
Sechura PR	5.0	5.2	2.8	5.4	4.6 ab
Gafsa PR	3.4	4.3	3.2	4.5	3.8 b
Central Florida PR	5.7	2.5	2.6	3.4	3.5 b
Tennessee PR	4.2	3.2	2.8	5.0	3.8 b
Pesca PR	3.3	4.3	3.1	4.6	3.8 b
Huila PR	7.1	4.3	3.0	5.8	5.0 a
Control					3.8

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE C7.--Water Soluble Phosphorus 30 Days after Application in the Field Experiment with Beans.

Source	Rate of Application (kg P_2O_5/ha)				Average***
	50	100	200	400	
	ppm P				
Triple superphosphate*	.007	.019	.016	.009	.013 a
Triple superphosphate**	.011	.004	.004	.012	.008 a
North Carolina PR	.008	.007	.015	.003	.008 a
Sechura PR	.005	.016	.014	.004	.010 a
Gafsa PR	.009	.007	.014	.002	.008 a
Central Florida PR	.002	.018	.009	.004	.008 a
Tennessee PR	.004	.008	.017	.010	.010 a
Pesca PR	.008	.011	.003	.011	.008 a
Huila PR	.002	.013	.012	.003	.007 a
Control					.004

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE C8.--Water Soluble Phosphorus 65 Days after Application in the Field Experiment with Beans.

Source	Rate of Application (kg P_2O_5/ha)				Average**
	50	100	200	400	
	ppm P				
Triple superphosphate*	.029	.020	.014	.032	.024 a
Triple superphosphate**	.020	.015	.020	.037	.023 a
North Carolina PR	.021	.025	.042	.030	.030 a
Sechura PR	.015	.023	.034	.028	.025 a
Gafsa PR	.023	.020	.027	.029	.025 a
Central Florida PR	.036	.012	.017	.018	.021 a
Tennessee PR	.016	.037	.021	.030	.026 a
Pesca PR	.022	.020	.026	.019	.022 a
Huila PR	.027	.011	.021	.019	.020 a
Control					.028

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C9.--Water Soluble Phosphorus at Time of Bean Harvest 120 Days after Application.

Source	Rate of Application (kg P_2O_g/ha)				Average***
	50	100	200	400	
	ppm P				
Triple superphosphate*	.023	.042	.015	.017	.024 bc
Triple superphosphate**	.021	.023	.025	.020	.022 bc
North Carolina PR	.028	.020	.021	.030	.025 bc
Sechura PR	.024	.030	.019	.026	.026 bc
Gafsa PR	.035	.029	.028	.034	.031 a
Central Florida PR	.016	.009	.034	.026	.021 c
Tennessee PR	.026	.022	.034	.030	.028 ab
Pesca PR	.006	.029	.025	.016	.022 c
Huila PR	.021	.004	.021	.019	.019 c
Control					.018

*For annual application.

**For residual effect evaluation.

**Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE C10.--pH (1:1 Soil-Water) 30 Days after Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	pH				
Triple superphosphate*	4.92	4.72	4.95	4.85	4.86 a
Triple superphosphate**	4.86	4.84	4.74	4.86	4.82 a
North Carolina PR	4.81	4.84	4.92	4.92	4.87 a
Sechura PR	4.89	4.84	4.90	5.00	4.91 a
Gafsa PR	4.87	4.79	5.00	4.93	4.90 a
Central Florida PR	4.81	4.79	4.90	4.80	4.83 a
Tennessee PR	4.92	4.79	4.89	4.78	4.85 a
Pesca PR	4.81	4.92	4.85	4.79	4.84 a
Huila PR	4.85	4.73	4.87	4.83	4.82 a
Control					4.87

*For Annual application.

**For residual effect evaluation.

**Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C11.--pH (1:1 Soil-Water) 65 Days after Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	----------	----------	pH	----------	----------
Triple superphosphate*	5.12	5.03	5.12	5.12	5.10 ab
Triple superphosphate**	5.10	5.30	5.10	5.17	5.17 ab
North Carolina PR	5.15	5.23	5.20	5.17	5.19 a
Sechura PR	5.15	5.08	5.17	5.20	5.15 ab
Gafsa PR	5.17	5.07	5.18	5.23	5.16 ab
Central Florida PR	5.10	5.07	5.17	5.13	5.12 ab
Tennessee PR	5.07	5.03	5.07	5.10	5.07 b
Pesca PR	5.00	5.22	5.30	5.07	5.15 ab
Huila PR	5.07	5.12	5.15	5.18	5.13 ab
Control					5.00

*For annual application.

**For residual effect evaluation.

**Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C12.--pH (1:1 Soil-Water) at Time of Bean Harvest 120 Days after Application.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	pH				
Triple superphosphate*	4.70	4.74	4.70	4.80	4.74 ab
Triple superphosphate**	4.78	4.79	4.69	4.80	4.76 a
North Carolina PR	4.71	4.79	4.76	4.80	4.77 a
Sechura PR	4.70	4.71	4.70	4.76	4.72 ab
Gafsa PR	4.67	4.81	4.72	4.72	4.73 ab
Central Florida PR	4.71	4.68	4.64	4.77	4.70 b
Tennessee PR	4.80	4.74	4.79	4.72	4.76 a
Pesca PR	4.70	4.77	4.75	4.79	4.76 a
Huila PR	4.77	4.68	4.73	4.75	4.73 ab
Control					4.73

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE C13.--pH in a 1:1 Soil-Solution Mixture with 0.01 M $CaCl_2$ 65 Days after Treatment Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	----------	----------	pH	----------	----------
Triple superphosphate*	4.67	4.53	4.67	4.73	4.65 a
Triple superphosphate**	4.70	4.73	4.70	4.73	4.72 a
North Carolina PR	4.67	4.63	4.77	4.77	4.71 a
Sechura PR	4.77	4.67	4.73	4.80	4.74 a
Gafsa PR	4.73	4.63	4.73	4.83	4.73 a
Central Florida PR	4.67	4.67	4.70	4.70	4.68 a
Tennessee PR	4.70	4.70	4.67	4.63	4.68 a
Pesca PR	4.60	4.67	4.73	4.67	4.67 a
Huila PR	4.67	4.70	4.67	4.73	4.69 a
Control					4.63

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C14.--pH in a 1:1 Soil-Solution Mixture with 0.01 M $CaCl_2$ at Time of Bean Harvest 120 Days after Treatment Application.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	pH				
Triple superphosphate*	4.39	4.38	4.34	4.42	4.38 a
Triple superphosphate**	4.41	4.45	4.33	4.44	4.41 a
North Carolina PR	4.37	4.37	4.39	4.45	4.40 a
Sechura PR	4.38	4.33	4.37	4.41	4.37 a
Gafsa PR	4.32	4.48	4.40	4.38	4.40 a
Central Florida PR	4.33	4.39	4.37	4.41	4.37 a
Tennessee PR	4.42	4.36	4.42	4.35	4.39 a
Pesca PR	4.35	4.41	4.38	4.43	4.39 a
Huila PR	4.44	4.37	4.35	4.37	4.38 a
Control					4.36

*For annual application.

**For residual effect evaluation.

**Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C15.--Exchangeable Aluminum 30 Days after Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	meq/100 gm				
Triple superphosphate*	0.9	1.3	0.8	1.0	1.0 a
Triple superphosphate**	1.1	1.1	1.3	1.0	1.1 a
North Carolina PR	1.1	1.0	0.8	0.8	0.9 a
Sechura PR	1.0	1.0	0.9	0.8	0.9 a
Gafsa PR	1.0	1.1	0.7	0.8	0.9 a
Central Florida PR	1.0	1.1	1.0	1.3	1.1 a
Tennessee PR	1.1	1.0	1.1	1.3	1.1 a
Pesca PR	1.2	1.0	0.9	1.1	1.0 a
Huila PR	1.1	1.4	1.0	1.1	1.2 a
Control					1.1

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C16.--Exchangeable Aluminum 65 Days after Treatment Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	------------------ meq/100 gm				
Triple superphosphate*	1.3	1.7	1.3	1.2	1.4 a
Triple superphosphate**	1.2	1.2	1.3	1.1	1.2 a
North Carolina PR	1.1	1.4	0.9	1.1	1.1 a
Sechura PR	1.0	1.2	1.2	1.0	1.1 a
Gafsa PR	1.2	1.3	1.1	0.9	1.1 a
Central Florida PR	1.1	1.4	1.2	1.2	1.2 a
Tennessee PR	1.2	1.2	1.4	1.4	1.3 a
Pesca PR	1.4	1.5	1.1	1.3	1.3 a
Huila PR	1.4	1.2	1.2	1.1	1.2 a
Control					1.4

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C17.--Exchangeable Aluminum at Time of Bean Harvest 120 Days after Treatment Application.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	meq/100 gm				
Triple superphosphate*	1.3	1.2	1.4	1.3	1.3 a
Triple superphosphate**	1.2	1.2	1.4	1.3	1.3 a
North Carolina PR	1.5	1.3	1.2	1.1	1.3 a
Sechura PR	1.3	1.4	1.5	1.1	1.3 a
Gafsa PR	1.5	1.1	1.3	1.3	1.3 a
Central Florida PR	1.4	1.2	1.4	1.2	1.3 a
Tennessee PR	1.1	1.3	1.0	1.4	1.2 a
Pesca PR	1.4	1.2	1.3	1.2	1.3 a
Huila PR	1.1	1.3	1.4	1.2	1.3 a
Control					1.3

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C18.--Exchangeable Calcium 30 Days after Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	meq/100 gm				
Triple superphosphate*	4.247	2.967	6.187	4.357	4.439 ab
Triple superphosphate**	4.760	3.367	4.193	3.600	3.980 b
North Carolina PR	4.867	4.360	5.240	4.763	4.808 a
Sechura PR	5.053	4.707	5.647	5.163	5.143 a
Gafsa PR	4.450	4.020	6.023	4.687	4.795 a
Central Florida PR	4.367	4.393	5.260	3.673	4.423 ab
Tennessee PR	4.747	3.770	5.397	3.347	4.315 b
Pesca PR	3.323	4.320	5.353	3.740	4.184 b
Huila PR	3.937	3.393	5.060	3.763	4.038 b
Control					4.359

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C19.--Exchangeable Calcium 65 Days after Treatment Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	meq/100 gm				
Triple superphosphate*	2.737	2.543	3.278	3.170	2.930 a
Triple superphosphate**	3.020	3.697	3.640	3.900	3.564 a
North Carolina PR	3.337	2.750	4.273	3.773	3.533 a
Sechura PR	3.657	2.890	4.437	3.503	3.622 a
Gafsa PR	3.020	3.080	2.887	3.627	3.153 a
Central Florida PR	3.900	3.053	3.603	3.287	3.461 a
Tennessee PR	3.597	3.123	3.493	2.660	3.218 a
Pesca PR	2.570	2.233	4.107	2.870	2.945 a
Huila PR	3.390	3.093	3.320	3.053	3.214 a
Control					2.765

*For annual application

**For residual effect evaluation.

**Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C20.--Exchangeable Calcium at Time of Bean Harvest 120 Days after Treatment Application.

Score	Rate of Application (ppm P)				Average***
	50	100	200	400	
	meq/100 gm				
Triple superphosphate*	4.117	4.920	4.033	4.197	4.317 a
Triple superphosphate**	4.887	4.943	4.927	4.897	4.913 a
North Carolina PR	4.923	4.940	4.927	4.210	4.750 a
Sechura PR	4.940	4.190	4.050	4.890	4.518 a
Gafsa PR	4.093	4.890	4.203	4.160	4.337 a
Central Florida PR	3.873	4.927	4.920	4.157	4.719 a
Tennessee PR	4.910	3.477	4.920	4.140	4.362 a
Pesca PR	4.147	4.890	4.193	4.903	4.533 a
Huila PR	4.153	4.890	3.980	4.907	4.483 a
Control					4.550

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE C21.--Exchangeable Magnesium 30 Days after Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	meq/100 gm				
Triple superphosphate*	2.133	1.750	2.733	2.243	2.215 ab
Triple superphosphate**	2.643	1.413	2.607	1.993	2.164 b
North Carolina PR	2.853	2.140	2.990	2.027	2.503 a
Sechura PR	2.410	1.920	2.290	2.183	2.201 ab
Gafsa PR	2.263	2.147	2.713	2.083	2.302 a
Central Florida PR	2.287	2.197	2.450	2.117	2.263 a
Tennessee PR	2.683	1.923	2.393	1.857	2.214 ab
Pesca PR	1.757	1.987	2.440	2.150	2.083 bc
Huila PR	1.813	1.660	2.060	1.907	1.860 c
Control					2.081

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE C22.--Exchangeable Magnesium 65 Days after Treatment Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	meq/100 gm				
Triple superphosphate*	1.387	1.430	1.287	1.297	1.350 abc
Triple superphosphate**	1.437	1.360	1.043	1.510	1.338 abc
North Carolina PR	1.977	1.300	1.413	1.503	1.548 ab
Sechura PR	1.710	1.543	1.037	1.290	1.395 abc
Gafsa PR	1.710	1.250	0.927	1.260	1.282 abc
Central Florida PR	1.643	1.333	1.603	1.723	1.576 a
Tennessee PR	1.357	1.357	0.987	1.290	1.248 bc
Pesca PR	1.480	0.873	1.053	1.377	1.196 c
Huila PR	1.570	1.530	1.177	1.547	1.456 abc
Control					1.274

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C23.--Exchangeable Magnesium at Time of Bean Harvest 120 Days after Treatment Application.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	meq/100 gm				
Triple superphosphate*	0.957	0.883	0.943	0.813	0.899 a
Triple superphosphate**	0.990	1.083	0.947	1.050	1.018 a
North Carolina PR	0.820	0.930	1.237	0.937	0.981 a
Sechura PR	0.923	1.010	0.930	0.913	0.944 a
Gafsa PR	0.800	0.923	0.977	0.957	0.914 a
Central Florida PR	0.997	0.897	0.873	0.947	0.928 a
Tennessee PR	0.883	0.843	1.010	0.927	0.916 a
Pesca PR	0.760	1.030	0.983	0.877	0.913 a
Huila PR	0.830	0.947	0.867	1.073	0.929 a
Control					0.903

*For annual application.

**For residual effect evaluation.

**Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C24.--Exchangeable Potassium 30 Days after Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	------------------- meq/100 gm			-------------------	
Triple superphosphate*	.640	.610	.640	.597	.622 a
Triple superphosphate**	.637	.543	.763	.613	.639 a
North Carolina PR	.723	.630	.783	.597	.683 a
Sechura PR	.600	.550	.637	.613	.600 a
Gafsa PR	.687	.623	.707	.583	.650 a
Central Florida PR	.690	.610	.657	.643	.650 a
Tennessee PR	.730	.660	.650	.633	.668 a
Pesca PR	.643	.627	.630	.627	.632 a
Huila PR	.597	.597	.590	.630	.603 a
Control					.592

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C25.--Exchangeable Potassium 65 Days after Treatment Application in the Field Experiment with Beans.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	meq/100 gm				
Triple superphosphate*	.516	.497	.456	.513	.496 a
Triple superphosphate**	.540	.417	.559	.532	.512 a
North Carolina PR	.572	.475	.525	.526	.525 a
Sechura PR	.532	.462	.571	.511	.519 a
Gafsa PR	.591	.489	.526	.537	.536 a
Central Florida PR	.566	.468	.516	.607	.539 a
Tennessee PR	.585	.556	.415	.537	.523 a
Pesca PR	.575	.547	.508	.458	.522 a
Huila PR	.479	.450	.460	.566	.489 a
Control					.515

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C26.--Exchangeable Potassium at Time of Bean Harvest 120 Days after Treatment Application.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	meq/100 gm				
Triple superphosphate*	.567	.484	.509	.578	.535 a
Triple superphosphate**	.594	.511	.581	.654	.585 a
North Carolina PR	.569	.600	.617	.559	.586 a
Sechura PR	.484	.521	.578	.546	.532 a
Gafsa PR	.540	.540	.583	.605	.567 a
Central Florida PR	.569	.559	.530	.634	.573 a
Tennessee PR	.569	.506	.578	.556	.552 a
Pesca PR	.528	.556	.473	.554	.528 a
Huila PR	.521	.539	.539	.572	.543 a
Control					.568

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C27.--Phosphorus Content of the Bean Plants 30 Days after Planting of First Crop.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	% P				
Triple superphosphate*	.152	.147	.157	.162	.155 ab
Triple superphosphate**	.149	.181	.176	.148	.163 a
North Carolina PR	.127	.155	.165	.156	.151 b
Sechura PR	.175	.167	.140	.154	.159 ab
Gafsa PR	.194	.170	.134	.180	.169 a
Central Florida PR	.118	.122	.130	.159	.132 c
Tennessee PR	.124	.137	.151	.150	.141 bc
Pesca PR	.172	.151	.150	.153	.157 ab
Huila PR	.146	.084	.141	.147	.130 c
Control					.149

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C28.--Phosphorus Content of the Bean Plants 65 Days after Planting of First Crop.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	% P				
Triple superphosphate*	.250	.257	.287	.350	.286 a
Triple superphosphate**	.220	.313	.277	.330	.285 a
North Carolina PR	.213	.253	.273	.317	.264 abc
Sechura PR	.183	.237	.250	.270	.235 bcd
Gafsa PR	.267	.243	.287	.297	.273 ab
Central Florida PR	.220	.233	.263	.237	.238 bcd
Tennessee PR	.180	.233	.267	.240	.230 cd
Pesca PR	.220	.183	.240	.230	.213 d
Huila PR	.203	.220	.233	.253	.228 cd
Control					.204

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test ($p = .05$).

TABLE C29.--Calcium Content of the Bean Plants 65 Days after Planting of First Crop.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	% Ca				
Triple superphosphate*	1.64	1.81	1.68	1.69	1.70 a
Triple superphosphate**	1.57	1.99	1.73	1.71	1.75 a
North Carolina PR	1.70	1.89	1.90	1.71	1.80 a
Sechura PR	1.56	1.89	1.73	1.77	1.74 a
Gafsa PR	1.60	1.86	1.86	1.72	1.76 a
Central Florida PR	1.71	1.63	1.58	1.63	1.64 a
Tennessee PR	1.57	1.72	1.83	1.66	1.69 a
Pesca PR	1.54	1.59	1.87	1.57	1.64 a
Huila PR	1.57	1.77	1.77	1.64	1.69 a
Control					1.64

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C30.--Magnesium Content of the Bean Plants 65 Days after Planting of First Crop.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	% Mg				
Triple superphosphate*	.35	.36	.34	.36	.35 ab
Triple superphosphate**	.31	.36	.35	.37	.35 ab
North Carolina PR	.33	.38	.39	.34	.36 a
Sechura PR	.33	.38	.33	.35	.35 ab
Gafsa PR	.37	.40	.35	.35	.37 a
Central Florida PR	.35	.34	.34	.33	.34 ab
Tennessee PR	.32	.34	.36	.35	.34 ab
Pesca PR	.31	.31	.35	.32	.32 b
Huila PR	.32	.34	.36	.35	.34 ab
Control					.30

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan's Multiple Range Test (p = .05).

TABLE C-31.--Potassium Content of the Bean Plants 65 Days after Planting of First Crop.

Source	Rate of Application (ppm P)				Average***
	50	100	200	400	
	% K				
Triple superphosphate*	2.99	3.04	3.01	2.88	2.98 a
Triple superphosphate**	2.86	2.87	2.88	2.95	2.89 a
North Carolina PR	2.99	2.59	3.37	3.13	3.02 a
Sechura PR	2.96	3.03	2.91	3.12	3.01 a
Gafsa PR	3.13	2.97	3.22	2.99	3.08 a
Central Florida PR	3.19	3.13	3.11	2.80	3.06 a
Tennessee PR	3.12	3.12	3.44	2.99	3.17 a
Pesca PR	3.18	3.12	3.06	2.82	3.05 a
Huila PR	2.58	3.11	3.35	3.01	3.01 a
Control					3.15

*For annual application.

**For residual effect evaluation.

***Means with the same letter are not significantly different with Duncan;s Multiple Range Test (p = .05).

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