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UTILIZATION OF PHOSPHATE ROCK IN TROPICAL SOILS OF LATIN AMERICA

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The direct use of phosphate rock (PR) as a phosphorus (P) fertilizer is not a new concept in either the temperate or tropical areas of the world The great majority of the PR experiments, however, have been conducted in temperate climates on soils with pH valves of 5 5 or above The voluminous amount of literature would indicate in general that a direct relationship exists between fineness of particle size and yield response Most of these experiments were usually conducted from a soil fertility standpoint whereby a particular PR was applied to a particular soil, and yield responses were noted It has been pointed out that this empirical approach had various limitations not only because of the tremendous variability between soils but also the large variabilities between PRs As a consequence, the experimental results varied markedly from experiment to experiment, thus making the predictibility of PR effectiveness as a P fertilizer almost impossible to ascertain In addition, the residual value of PR was not in most instances determined as most of the experiments were designed for only one to two years

In recent years, however, laboratory studies have been made with the objective of characterizing PRs from a P

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availability standpoint (12, 28, 35) Also long-term experiments have been set up in tropical Latin America to determine the residual value of the rock sources This, combined with a thorough and meaningful soil analysis should help to clarify the PR effectiveness from a generalized fertilizer recommendation standpoint

The objectives of this paper will be to review the soils and phosphorus fertilizer problems in the acid Oxisols, Ultisols and Inceptisols (target area) of tropical Latin America, selectively review the literature, state the research objectives and attempt to layout a research program to meet those objectives

SOILS AND PHOSPHORUS PROBLEMS IN TROPICAL LATIN AMERICA

The soils in the target area of tropical Latin America are primarily Oxisols and Ultisols (Fig 1) These soils are generally medium to fine textured, present an acid reaction of from 4 0 to 5 5, and contain only about 200 to 600 ppm total P Available P is also very low in these soils, ranging only from about 1 to 5 ppm, regardless of extractant used It is quite obvious that without additions of P neither arable nor forage crops can be grown effectively Due to the extremely acid conditions, these soils are also high in free iron and aluminum oxides and hydroxides which tend to rapidly fix large amounts of P when it is applied in soluble forms such as single (SSP) or triple superphosphate (TSP) Although P is generally the most limiting element, other nutrient deficiencies of nitrogen, potassium, sulfur, calcium and magnesium are common (12, Fig 2) In addition to these nutrient management problems, there is also the problem of aluminum and manganese toxicity

From a physical standpoint, the soils which have potential for arable and forage crop production, in general, possess excellent structure, good infiltration capacities and are well drained According to Sánchez (45), "the excellent structure of these soils is caused by primary particles being aggregated in very stable sand-sized granules Their high stability is associated with high clay content and cementing or coating of amorphous iron and aluminum oxides" He further states that the organic matter content is also directly associated with the aggregate stability It is clear that the physical properties of these tropical Latin American soils will not present major problems in most crop production schemes

One of the main limiting factors in increasing crop production in tropical Latin America would appear to be the high cost of fertilizers, especially those containing high amounts of available P This is primarily due to the high cost of manufacturing which results from the high input costs of sulfuric and/or phosphoric acid used in the acidulation process Transportation costs are also high Given the fact that high rates of these P fertilizers are required to be effective, it is easy to see why immediately available forms of P fertilizers are not used on most arable or forage crops, except those of high monetary value such as potatoes and other vegetable crops

The direct use of PR or some of its low-input altered products would seem to present a logical approach to take in overcoming the monetary and soil chemical constraints in crop production which have been mentioned previously. Over the years many hundreds of PR trials have been conducted to increase crop production. These experiments lend credibility to the idea that PR or its low-cost altered products could be used to increase crop production both from short- and long-term viewpoints. Given the amounts of exchangeable and nonexchangeable acidity in these tropical soils, it would seem natural that PR could and should be used in some form to make increased arable and forage crop production an economically feasible reality.

REVIEW OF THE LITERATURE

The authors recognize and have reviewed much of the literature pertaining to the use of PR as a source of P for crops in the temperate areas of the world. Most of the literature cited here, however, will be from research conducted in tropical Latin America as our proposed research will be focused in this area.

General Phosphorus and Soils Review

In a review chapter on P, Kamprath (34) states, "the highly weathered soils, Oxisols and Ultisols of the tropics along with Andosols, are generally very deficient in phosphorus. Many of the soils fix large quantities of added phosphorus. Therefore, without the application of phosphorus, sustained crop production at high yields is not possible". After a rather exhaustive review of crop responses to phosphate fertilization in the tropics, Kamprath (34) further indicates that, "Rates of phosphorus on deficient soils generally giving optimum yields were 100 to 150 kg P_2O_5/ha for corn, soybeans, sugarcane and forages, 120 to 240 kg P_2O_5/ha for wheat, 120 to 180 kg P_2O_5/ha for potatoes, and 60 kg P_2O_5/ha for rice"

Fassbender et al (24) in a greenhouse study with tomatoes as the test crop on 110 different soils of Central America showed that most of the soils studied (66%) were extremely deficient in P and only 15% contained an adequate supply In another greenhouse study with tomatoes, Fassbender (25) showed that 96% of the applied monocalcium phosphate (MCP) was transformed into iron and aluminum forms after 8 weeks with a P-deficient Inceptisol, in the Colorado series (pH KCl 4 6)

In characterizing some of the main Oxisols and Ultisols at the Quilichao and Carimagua experiment stations, in Colombia, and at the Cerrado Center station, in Brazil, León and Sánchez (12) found soil pH values from 4 1 to 4 9 and percent aluminum saturation ranges from 64 to 82 (Table 1) The available P (Bray II) levels were extremely low, showing values from only trace amounts to 1 8 ppm in both surface and sub-samples Also, using a Quilichao soil in a greenhouse missing element trial with Centrosema plumieri, Gualdrón, León and Sánchez (12) found this soil to be severely deficient in P as well as sulfur, ooron, and to some extent calcium (Fig 2) In further studies these investigators indicated that a soil test of about 3 ppm P (Bray II) was a critical level for achieving 80% of maximum yield with both Panicum maximum and a Centrosema hybrid (Fig 3) It was also suggested that a rate of about 240 kg P_2O_5/ha would be needed to satisfy this requirement

In order to characterize the P fixation capacity of the Brasilia, Quilichao and Carimagua experiment station soils, León and Sánchez (12) ran P fixation isotherms (Fig 4) Using a 0 2 ppm P in solution as a critical level, it took 620 to 750 ppm P for Quilichao and Brasilia and about 350 ppm for Carimagua to achieve this, thus indicating the extremely high fixation capacity of these soils

Direct Application of Phosphate Rock to Soils

The direct application of PR to temperate soil conditions is well documented in the literature It is also well recognized that much of the research and the resulting contributions to the understanding and use of PR as a P source for plants, was conducted in Europe, the United States, and other parts of the world (3,4,5,7,13,18,19,21,22,29,33,42,44,49)

In tropical Latin America the information on direct application of PR is more limited, nevertheless, important and applicable studies have been and are being conducted in several of the countries This section will be devoted primarily to these investigations

Characterizing Phosphate Rocks

Over the years it has been well understood that fineness of particle size of the PR and soil reactivity were extremely important in predicting the value of PRs (3, 13, 19, 33) Since it was generally and erroneously assumed that most were fluorapatite, variable agronomic responses in field and greenhouse studies were usually attributed to particle size of the rock and/or different soil characteristics Lehr and McClellan (35) state that, "new insight into the composition of phosphate rocks was obtained recently from characterization studies which showed that the compositions of their apatitic phosphate minerals varied markedly With few exceptions, the apatites were not fluorapatite, but belonged to the series of carbonate apatites in which PO_4 is replaced by CO_3 and F, and Ca is replaced by Na and Mg in the fluorapatite structure Chemical reactivity of the apatite increased as the degree of substitution increased" Based on this the citrate solubility was redefined on an absolute basis This "Absolute Citrate Solubility" (ACS) index for any given rock was defined as the ratio of its citrate-soluble P_2O_5 to the theoretical P_2O_5 content of its particular apatite composition (35) Working with 50 representative PRs, Lehr and McClellan showed that the ACS index "Correctly associated P_2O_5 solubility with the kind of apatite supplying the P_2O_5, and not merely the amount of apatite, or P_2O_5 grade of the phosphate rock" They further showed a high degree or correlation between the ACS indices of the rocks and agronomic response to their P in greenhouse studies More recently, Hammond and León (12) have shown that the relative availability of P from PR sources correlates well with the citrate-soluble P content of the material when expressed as "percent of the rock" rather than "percent of total P_2O_5 in the rock" In a greenhouse study with Panicum maximum, the researchers also concluded that the degree of correlation was higher when higher rates of the various PRs were applied (Fig 5)

The characterization of the PRs has really illucidated many of the here-to-fore erratic appearing research results with the many different rocks Even more importantly, the relative agronomic effectiveness (RAE) can be predicted for the various PRs For example Gafsa (Morocco), Sechura (Perú), and North Carolina (USA) rocks are considered highly reactive, Huila (Colombia) and Florida (USA) medium reactivity, and Pesca (Colombia) and Tennessee (USA) are of low reactivity Hammond and León (11,12) have confirmed this predictibility with citrate soluble P in the total rock with both greenhouse and field studies (Table 2)

Greenhouse and Field Investigations with Phosphate Rock

A number of experiments have been conducted in tropical Latin America using the direct application of PR Although many of the results have been quite variable, recent works in Brazil and Perú by North Carolina State University (40), and in Colombia by the International Fertilizer Development Center (IFDC) and CIAT (9,10,11,12,28) have shown very encouraging results

Alvarez et al (1), in several experiments with sugarcane on acid soils in Sao Paulo, Brazil, using various sources and rates of P showed that four naturally occurring PRs gave 10 to 28 percent yield increases while other more available phosphate fertilizers gave 35 to 49 percent yield increases In another series of experiments in Sao Paulo with corn, Miranda et al (41) showed that three PRs from Brazil gave yield increases of from 37 to 71 percent of that attained with ordinary superphosphate over a two year period

In 1969 significant experiments with PR were also initiated by León et al (37) in several geographic areas of Colombia on Oxisols, Ultisols, and some inceptisols Varying rates of PR, basic slag, and SSP and TSP were compared using oats for forage, several forage grasses, peanut, corn, rice, and onions as the test crops On selected treatments of 200 kg P_2O_5/ha for TSP, Turmeque (Pesca-like) rock and Florida rock, with 3 cuttings of Penisetum clandestinum, the researchers found that all forms of P gave significant yield increases over the check and that TSP was slightly inferior to both forms of PR Similar broadcast treatments at two other locations with different grasses showed no significant yield increases after 5 to 7 cuttings, regardless of the source of P At other locations with Dactylis glomerata, L only slight yield increases with TSP were noted When oats (2 crops) was the test crop 200 kg P_2O_5/ha gave significant yield increases with TSP and Turmeque rock In this same experiment no increases were realized with Florida rock With onions, applications of 100 to 200 kg P_2O_5/ha either broadcast or row applied gave significant yield increases regardless of the P source

In the Llanos Orientales region of Colombia with corn, the response to P was highly significant (Fig 6) Although the results varied the first year, in the second and third years, Turmeque and Florida PRs were equal to and in some cases superior to TSP León et al (36,37) concluded that in the highly acidic P deficient soils of Colombia, almost all crops showed some degree of response to applications of PR

In the Cerrado of Brazil, North Carolina State University and Cornell (43) initiated a long-term experiment with various phosphate carriers on pastures to determine the effect of using cheaper sources of P Initially the two highly soluble PRs, Gafsa (Morocco) and North Carolina, performed about as well as SSP The low reactive Araxá PR from Brazil was ineffective at first, however, after two years the availability was increased significantly and yields were comparable to other P carriers, indicating it may be economically competitive with time (Fig 7) Rates of P_2O_5 used were 86, 345 and 1380 kg/ha In the Amazon Jungle of Perú, North Carolina State University (43,47) in another series of pasture experiments also showed that Gafsa, Florida, North Carolina and Fosbayovar (Perú) PRs were comparable to SSP in forage production with Panicum maximum These experiments in Brazil and Perú will be continued to assess the residual values of the P carriers

In the highlands of Perú, Davelouis and Cano (14) conducted a series of P experiments with potatoes and wheat over a two year period In comparing Sechura rock, Gafsa rock, SSP, and combinations of rock plus super, these researchers reported that marginal money returns were better for the PRs than SSP The best economic returns were noted with potatoes when 160 kg P_2O_5/ha of Sechura PR and 80 of SSP were applied (Fig 8) Although the results with wheat were not very encouraging using PR, the residual effect the following year with potatoes showed promise

In Colombia, Howeler (9) on an acid,low P soil reported that 200 kg P_2O_5/ha as TSP increased bean yields from 0 7 to 1 8 tons/ha while only slight responses were noted with Huila and Turmeque PRs In another bean experiment on an acid,low P Andept, Howeler, Hammond and León (11) * state that, "a positive response to application rates as high as 400 kg P_2O_5/ha was obtained Although TSP produced the best response, relatively soluble rock phosphates from Gafsa (Morocco), North Carolina (USA), Sechura (Perú) and Huila (Colombia) also gave good responses Yields with more insoluble rock phosphates from Tennessee and Florida (USA) were lower but still significantly better than the control The agronomic effectiveness of the sources followed closely their solubility in N ammonium citrate, a commonly used measure of available phosphate" (Fig 9) These same researchers found similar results using the same P carriers in a Carimagua Oxisol with cassava Yields ranged from 18 to 25 ton/ha with 400 kg P_2O_5/ha down to 8 ton/ha on the check Rates of 100 kg P_2O_5/ha also appeared very encouraging, especially with the more soluble sources of PR

* International Fertilizer Development Center cooperating

Hammond (12, 28), in a greenhouse experiment with Panicum maximum grown on a Carimagua Oxisol, reported that the high reactivity PRs, Sechura and North Carolina, were superior to application rates of TSP ranging from 50 to 400 ppm P (Fig 10) Huila and Pesca PRs were less effective than TSP but significantly better than the checks Using a Relative Agronomic Effectiveness scale with basic slag equal to 100, Sechura, North Carolina, TSP, Huila and Pesca were scaled at 94, 82, 62, 41, and 27, respectively (Fig 10) In a long-term field experiment at Carimagua using Brachiaria decumbens and comparing six PR sources with TSP at P_2O_5 rates varying from 0 to 400 kg/ha, Hammond and León (12) conclude that, "triple superphosphate was only superior to rock phosphates during the first cut, afterwards all rock phosphate sources increased their effectiveness with time approaching or surpassing the yields of superphosphate during the third and fourth cuts (Fig 11) The overall results during the first 16 months show the high reactivity rocks, Gafsa and Sechura, were 105 and 99% as effective as superphosphate, the medium reactivity Huila rock was 91% as effective, and the low reactivity rocks, Tennessee and Pesca were 87 and 88% as effective as triple superphosphate" This experiment will be continued to further evaluate the residual effects of the PRs, but already there appears to be opportunity for the use of the low cost, low reactivity rocks on the acid soils for pasture production

Greenhouse and Field Investigations with Partially Acidulated Phosphate Rock

The use of partially acidulated PR may present an attractive alternative to the use of either PR or superphosphate alone or in combination in the acid,P deficient soils of tropical Latin America

McLean and Wheeler (40) conducted a growth chamber study with German millet and alfalfa in which finely ground Florida PR was acidulated with phosphoric acid to the following degrees 0, 10, 20, 50, 100% Two Ohio soils were limed to pH levels of about 6 0 and 6 5 and P was added at a rate of 90 pp2m

The P was applied both in bands and broadcast These researchers concluded that, "in general, German millet and alfalfa yielded about as much and contained as much P in the tissue from 10% acidulated phosphate as from 100% acidulated" "The comparative favorable plant response to the partially acidulated material and the economy of its production make partial acidulation appear to have very promising practical applications"

Terman and Allen (48) acidulated Florida PR with phosphoric acid to levels of 0, 10, 25, 50, 75, and 100%, and then granulated the resulting materials to -6+9 and -35 mesh Two experiments were conducted with corn on soils with pH values of 6 5 and 5 6 and P was applied at rates of 40, 80 and 160 lb/a P The authors concluded that dry matter yields were directly related to the amount of P applied and the content of water-soluble P They further noted that the conclusion from these studies differ markedly from the works of McLean et al (40) and suggest that the reason may be that these researchers used ungranulated materials applied at only one rate

In Colombia, McCormick and Galeano (38) acidulated Turmeque PR with sulfuric acid to levels of 0, 25, 50, 75 and 100% Four pot experiments were conducted with soils from the Sabana of Bogotá and the eastern plains of Colombia with barley as the test crop The rate of phosphorus applied was 200 kg P_2O_5/ha Yield results showed that in general all levels of acidulation were superior to unacidulated PR and there were no differences between levels of acidulation from 25 to 100%

Howeler (10) in a bean experiment on an acid,P deficient Andept soil near Popayán, Colombia, reported that Huila PR acidulated to a level of 20% with sulfuric acid improved its efficiency to that of TSP at rates of up to 400 kg P_2O_5/ha (Fig 12) In another experiment a 5 1 mixture of Huila PR sulfur gave cassava yields which were equal to those of TSP at rates of up to 400 kg P_2O_5/ha (Fig 13)

In other experiments in Colombia, however, when elemental sulfur or ammonium sulfate were added to PR and applied to the soil, no yield responses were noted and in some cases yield depressions occurred (10,27,30)

Greenhouse and Field Investigations with Thermally Altered Phosphate Rock

Rhenania phosphates These phosphate fertilizers are made by heating PR, sodium carbonate and silica to temperatures of

1200 to 1400°C. The P in the resulting material is almost completely citrate - and water-soluble (16)

After reviewing the pertinent literature from Europe and the United States on the Rhenania phosphates, Doll (16) indicated that under a wide range of soil conditions they appear to be nearly equal to superphosphate as a source of P for long-season crops when the material is finely ground, broadcast, and thoroughly mixed with the soil He further indicated that they are not suitable as a P source when banded in the soil In general, however, the reviewing author did indicate that the Rhenania phosphates would appear to be quite effective on the more acid soils

León (12) conducted a greenhouse experiment on a Carimagua Oxisol, in Colombia, with Stylosanthes guyanensis (2 cuttings) and showed that Rhenania phosphate was superior to TSP but inferior when magnesium oxide and calcium silicate were incorporated with the TSP (Fig 14) This would indicate that there was a magnesium deficiency in the soil in addition to P

Fused Magnesium Phosphates (FMP) These phosphate fertilizers are made by fusing PR, serpentine or olivine, and silica at about 1250°C This phosphate, depending upon the composition and ratio of materials used will usually contain about 29-33% CaO, 17-19% MgO, 19-21% P_2O_5, 22-26% SiO_2, plus small percentages of Fe and Al oxides, all of which are almost completely soluble in 2% citric acid (2)

Early investigations by Walthall and Bridger (50) in a

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pot experiment with two soils, pH 4 9 and 5 3, using sudangrass (2 cuttings) as the test crop, found that the FMP was equally effective as a P source as both TSP and SSP The application rate of P_2O_5 for all P carriers was 40 pp2m

In Brazil, where a Japanese manufactured FMP is commonly used for certain crops, research results have been most favorable Alvarez et al (1) conducted five experiments with sugarcane on three different soil types with varying rates of phosphate in the State of San Paulo They showed that thermophosphate was substantially better than any other P carrier used The average of the five experiments, with three rates of P_2O_5 (50, 100 and 150 kg/ha) included, gave percentage yield increases of 49 for the FMP and only 35 for SSP In another series of experiments with corn in the State of San Paulo, Miranda et al (41) showed similar results using the FMP In three experiments with P_2O_5 rates of 60 and 120 kg/ha, these researchers found that the thermophosphate fertilizer outperformed SSP, on a relative scale, by 127 to 100

In Colombia, León (12) conducted a greenhouse experiment on an acid Carimagua Oxisol with *Stylosanthes guyanensis*, and showed that the Japanese FMP was superior to TSP at all levels of application (Fig 14) When MgO and SiO_2 were incorporated with the TSP, the FMP and TSP give similar results In another experiment on a Colombian Andept, Howeler (10) concluded that FMP was not significantly different from TSP as a P source on yields of beans

RESEARCH PROPOSAL

Objectives of the Research Proposal

The objectives are

1 - To evaluate the effectiveness of sources and methods of application of phosphate fertilizers on soils of tropical Latin America

2 - To determine the forms and availability of the reaction products of these fertilizers in soils as related to their initial and residual effectiveness

3 - To establish criteria for applying the results of the first two objectives to different soils and crops at various locations by conducting field experiments on selected soils throughout tropical Latin America

Currently it is planned that research will be conducted in Colombia, Brazil, Perú, Ecuador and other countries as may be appropriate

It is hoped that these objectives can be accomplished through interrelated and pertinent laboratory, incubation, greenhouse, and field experiments In the following discussion, the authors will attempt to be succinct but thorough in their reasoning and justification for the proposed research

Situation Statement

Given the facts that the acid Oxisols, Ultisols, and Inceptisols in tropical Latin America are not only low in both available and total P but also fix large quantities of P, it becomes obvious that proper soil management of P fertilizers is extremely important It is also apparent that the use of traditional sources of phosphate fertilizers such as SSP or TSP may not be acceptable sources for most crops because of their relatively high costs and because high rates are necessary even when they are banded (12) The direct application of ground phosphate rock (PR) alone is probably not a suitable alternative either due to its initial rate of release of P and cost of transportation The authors realize that certain crops such as cassava, and some legume and grass forages are capable of foraging for P quite effectively, from even the medium or low reactivity rocks, but nevertheless this situation is not true for most crops It is also understood that some of the PRs are high in reactivity but due to geographic distribution and infrastructural problems, the direct application of these rocks is probably limited to certain areas

Although the use of combinations of broadcast PR with banded TSP or SSP have shown promise as overall sources of immediately and residual forms of P, once again the previously discussed restrictions still apply Furthermore, a normal practice of banding TSP is probably not feasible in either a pasture or forage production scheme which is so important in tropical Latin America

The use of other altered PR products, however, may have some advantages over the previously mentioned P carriers In the few trials which have been conducted, for example, with partially acidulated PR and FMP, the responses have been generally equal to or superior to TSP (Figs 12, 13, 14). There would also appear to be some economic advantages in using these forms In addition, it is feasible to granulate these products thus overcoming the handling problems normally associated with PR The potential merits of these altered products will be discussed in more detail later

Phosphate Materials to be tested

Currently there are three long-term field experiments being conducted in Colombia on rates and sources of several PRs, TSP, and basic slag The residual value of the phosphate carriers are being ascertained with test crops of cassava, beans and *Brachiaria decumbens* These experiments, which were set up by a previous investigator*, will be continued Also, several other PR experiments, which have been reported on, were conducted in Colombia, by IFDC In addition another experiment was set up by Drs Sánchez and León this past year in which 3 PRs (Pesca, Huila and Gafsa) are being compared with TSP at six different rates of P Various combinations of the PRs and TSP are also included The test crops are *Panicum maximum* and *Andropogon gayanus*, each interseeded with *Centrosema* 1733 Forage production,and uptake and removal of P will be determined in this long-term residual study Based on the studies that have been and are currently being conducted with PR and TSP, it is the opinion of the authors that emphasis should now be directed towards the use of partially acidulated PR and

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thermophosphates Phosphate rock and TSP will be used for comparative purposes

Partially Acidulated Phosphate Rocks

Since the soils in the target area fix large quantities of P (12, Fig 4), it would seem reasonable that applying a P material that contains a large percentage of its P in a relatively unfixable form would have some advantages Once this partially acidulated material is applied to the soil the monocalcium phosphate is converted to dicalcium phosphate and phosphoric acid It is hoped that the PR and the acidulated materials would remain in intimate enough contact in the soil, so that at least a portion of the phosphoric acid would then react with the PR, thus making it available for plant uptake In addition the acidic nature of the soils themselves should also help to solubilize the remaining PR Since the P is probably becoming available over a period of time, thus providing a continuous supply to the plants, perhaps the adverse common ion effect of the iron and aluminum can be somewhat overcome

McLean and Wheeler (40) state that, "the smaller quantity of soluble P in the partially acidulated material compared to the triple superphosphate (100% acidulated) might then cause less H_3PO_4 to form, and, if part of that formed were dissipated on the rock phosphate, then less Al and Fe would be activated to revert the P to unavailable forms" They further indicate that, "the soluble P in the partially acidulated material might stimulate the plant initially, so that they can make more efficient use of the unreacted rock phosphate when the soluble P accessible to the roots has been exhausted"

Another potential advantage to the partially acidulated PR is that of granulation Past attempts at granulating PR have not been successful because of decreasing the effective surface area of the PR in contact with the soil It may now be possible through the "minigranulation" process*(Tyler-50+200 mesh) with the partially acidulated PR to have a P fertilizer that is both effective as a P source and easy to handle from a physical standpoint

There are also indications that surface applications of soluble forms of phosphate may be effective in stimulating vegetative growth on existing savannas (43) In some areas of Brazil aerial applications of SSP are fairly commonplace in native forage production (Personnal communications with Clinton Shock, IRI Brazil) The "minigranulated" partially acidulated PR might also lend itself to this type of application

The economics of producing the partially acidulated PR should be quite favorable because of the smaller amounts of the sulfuric or phosphoric acids being used This is especially true in tropical Latin America where the costs of these acids are very high

Greenhouse and field experiments are being planned and initiated in 1978 using varying levels of partially acidulated PR These materials will be made using sulfuric acid and rocks

* New granulation concept developed by the International Fertilizer Development Center, Muscle Shoals

of low, medium, and high reactivity Whenever possible, local sources of PR will be used The experiments will also include rate studies, methods of application, and granulated versus un-granulated materials Efficiency of the test materials will be compared to TSP and ground PR Several different test crops will be studied for uptake and removal of P The cropping philosophy will be discussed in more detail later

Thermophosphates

The use of thermophosphates especially fused magnesium phosphates (FMP) also appear to have good potential as a phosphate fertilizer in tropical Latin America It has been previously shown (1,38,41) that this material is generally superior when compared with TSP (Figs 14,15) The implications of this are not clear, however, León in preliminary studies indicates that both soil and plant calcium and magnesium contents are somewhat higher when FMP is used versus TSP In addition the P content also appears to be marginally higher There is also the possibility that the available soil silicates may be involved, either directly or indirectly, but the experiments were not designed to sort this out Fox et al (26), for example, increased sugar yields by 12 ton / ha through the use of a calcium silicate slag

There is also a marked difference in solubilities of P in TSP and FMP The TSP is mostly all water-soluble whereas the FMP is citrate-but not water-soluble Although both forms of P are generally considered available to plants, perhaps the P in the FMP is not as vulnerable to fixation by Al and Fe in the soil.

At this point in time it is difficult to know if the FMPs would have an economic advantage over other P sources such as TSP or SSP because of the high energy inputs in fusing the materials In future years, however, FMPs may become very competitive economically when the hydroelectric potentials of the Latin American countries are realized Since large known reserves of PR (36, Fig 16) and serpentine/olivine (8,20,23,32) are also present in these countries, the essential raw material are there for making FMP

It is interesting to note that FMPs may become a manufactured product in Colombia in the near future In 1974 the Colombian government commissioned a Japanese Consulting firm to make a feasibility study on PR uses and specifications for a FMP plant (31,32) The results of the study were quite favorable for its production

Greenhouse experiments will be designed to try and determine why plants in general respond better to FMP than TSP Treatments of FMP will also be an integral part of the greenhouse and field studies proposed under the previous section on partially acidulated PR

Other Materials

Although the partially acidulated PRs and FMPs have been highlighted in this paper, other combinations of PR and sulfur, and PR and silica, for example, will be experimented with in greenhouse trials If any of these appear promising field experiments at representative sites will also be conducted

Other Laboratory, Incubation, and Greenhouse Studies

Another aspect of the proposal is chemical and mineralogical characterization of the acid Oxisols, Ultisols, and Inceptisols in the target area It is extremely important to be able to predict the behaviour of different P carriers under the varying soil conditions It was noted earlier (12), for example, that P fixation capacities of 350 to 750 ppm are quite common in these soils (Fig 4) These sorts of ranges would significantly alter both the P carrier used and amounts of phosphate to apply In order to further quantify the spectrum of soils in tropical Latin America, representative soils will be collected, for analysis and study, from several areas in Colombia

Phosphorus fractionation of these soils will be included in the initial laboratory analyses Subsequently, the proposed P carriers will be incubated with the soils and time studies on available, fixed, and labile forms of P will be determined Greenhouse trials, with several crops will also be conducted in conjunction with these studies to correlate plant P uptake and removal values with the results obtained in the laboratory and incubation studies

These sorts of investigations will be important in giving a better understanding and direction when establishing other greenhouse and field experiments in this overall project

Cropping and Management Strategy

The Phosphorus Project has responsibility for testing a number of potential P fertilizers on a variety of different crops In general these crops will include cassava, beans, rice, and both grass and leguminous forages Other test crops could include corn, soybeans, peanut, sesame, sugarcane,and cowpeas Although this seems like a confusing number of crops it must be remembered that experiments will be conducted on several different soils under varying climes Furthermore, the authors feel that using test crops which are normally grown in a given area is very important

Because of the importance of the beef industry in tropical Latin America, a considerable effort will be devoted to improving forage production through P fertilization Although P fertility trials will be conducted on direct pasture fertilization and forage production, the concept of a crop sequence appears to have added merit

Since the cost of P fertilizers is relatively high, it is not reasonable in many instances for a farmer or rancher to plow up existing savanna, incorporate fertilizer and immediately replant a forage In order for the farmer to realize an immediate monetary return from the fertilizer investment, it is suggested that high value arable crops be planted for one or more seasons before going into forage production This allows for defraying some of the immediate input costs and increasing forage production in the long run

From a research standpoint this cropping scheme offers the opportunity to gain results from the immediately available P as well as residual effects of the P fertilizers It also lends itself to working with a variety of crops to the extent that their P requirements from the various fertilizers can be ascertained

If the requirements of the different crops are known it seems feasible that a tailored P fertilizer and management program could be packaged to include the arable and forage crop sequence scheme In order to make P fertilizer recommendations crop specific, the behaviour of the P carriers, the plant requirements, and the soil chemical characteristics must be well understood

Length of Project

The very nature and scope of the proposed phosphorus fertility research program dictates a minimum period of 7 to 10 years to accomplish the objectives of this IFDC project proposal

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Table 1 Characteristics of the main soils at Quilichao, Carimagua and Cerrado Center Stations

Horizon (cm)	Clay %	Sand %	pH (H_2O)	Org C %	Exchangeable cations (meg/100g) Al	Ca	Mg	K	CEC	Al satn %	Avail P* (ppm)	Avail. H_2O (%,vol)
CIAT - Quilichao Ultisol (Orthoxic Palehumult, clayey, kaolinitic, isohyperthermic).												
0- 20	71	4	4 1	4 1	2 7	65	49	36	4 2	64	1 8	16
20- 35	77	5	4 0	2 3	2 7	31	04	13	3 2	83	1 1	13
35- 62	84	2	4 3	1 1	3 2	24	02	09	3.6	88	0 9	16
62- 91	88	1	4 4	0 4	1 1	15	02	06	1 4	77	0 9	9
91-150	90	1	4 4	0 3	2 0	22	01	04	2 3	85	1 2	14
CARIMAGUA Oxisol (Tropeptic Haplustox, fine-clayey, mixed, isohyperthermic)												
0- 20	37	6	4 9	3 1	2 8	2	2	10	3 4	82	0 9	9
20- 51	39	5	5 0	1 5	2 0	1	1	10	2 3	85	0 4	7
51- 82	40	5	4 8	0 8	1 9	1	1	10	2 2	84	0 9	5
82-117	40	5	5 4	0 6	1 1	1	1	10	1 6	69	0 4	5
117-132	48	5	5 8	0 4	-	2	2	30	0 8	-	0 4	6
132-152	52	4	5 9	0 3	-	2	2	30	0 7	-	0 4	7
CERRADO CENTER Oxisol (Typic Haplustox, fine, kaolinitic, isohyperthermic - LVE)												
0- 10	45	36	4 9	1 8	1 9	0 4		10	2 4	79	tr	11
10- 35	48	33	4 8	1 2	2 0	0 2		05	2 2	89	tr	11
35- 70	47	35	4 9	0 9	1 6	0 2		03	1 8	88	tr	9
70-150	47	35	5 0	0.7	1.5	0 2		01	1 7	88	tr	9
150-260	42	39	4 6	0.3	0 7	0 2		02	0 9	76	tr	9

* Bray II extraction method

Source CIAT, 1977 Annual Report

Table 2 Percentage Relative Agronomic Effectiveness of Various Phosphorus Carriers as Compared to Basic Slag and/or Triple Superphosphate

Source	Panicum Maximum	Cassava	Beans 1	Beans 2
	R A E (%)			
TSP	62	100	100	72 *
Basic Slag	100	100	-	-
Sechura	94	-	82	65
N Carolina	82	82	79	72
Gafsa	80	84	93	72
C Florida	53	73	57	52
Huila	41	70	65	42
Tennessee	35	66	40	40
Pesca	27	67	28	28

* Residual

Source Hammond, 1977

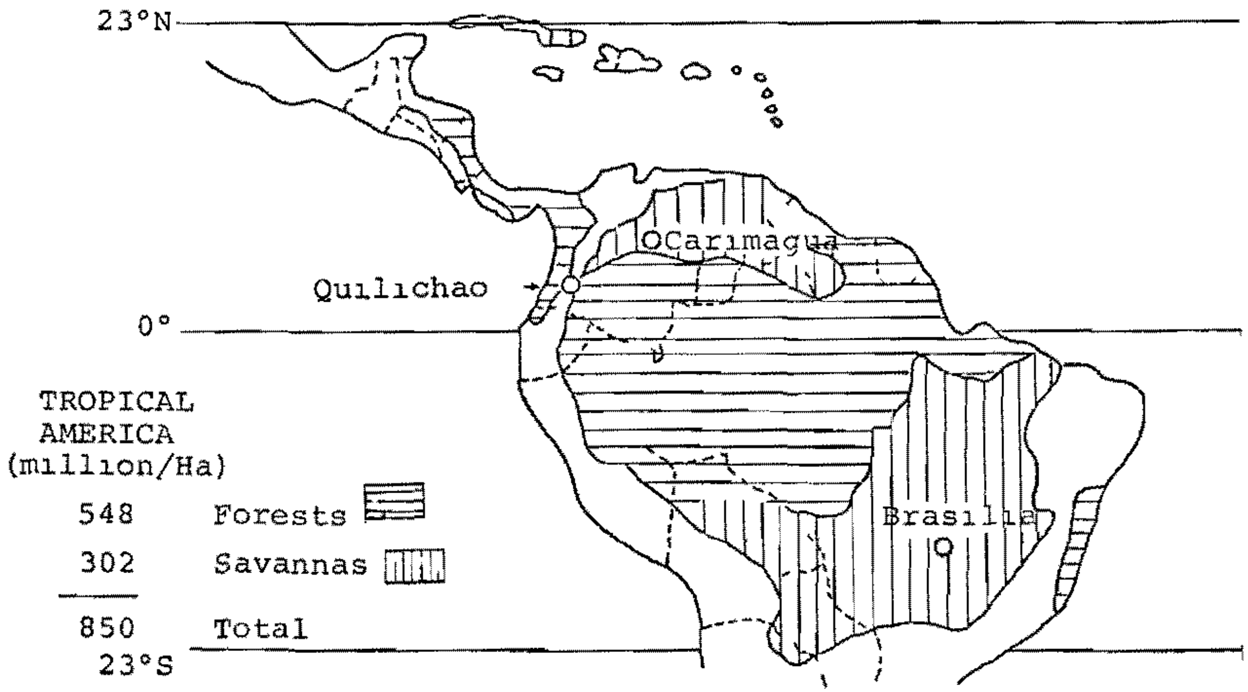

Figure 1 Geographical distribution of Oxisols and Ultisols in tropical Latin America
Source CIAT, 1977 Annual Report

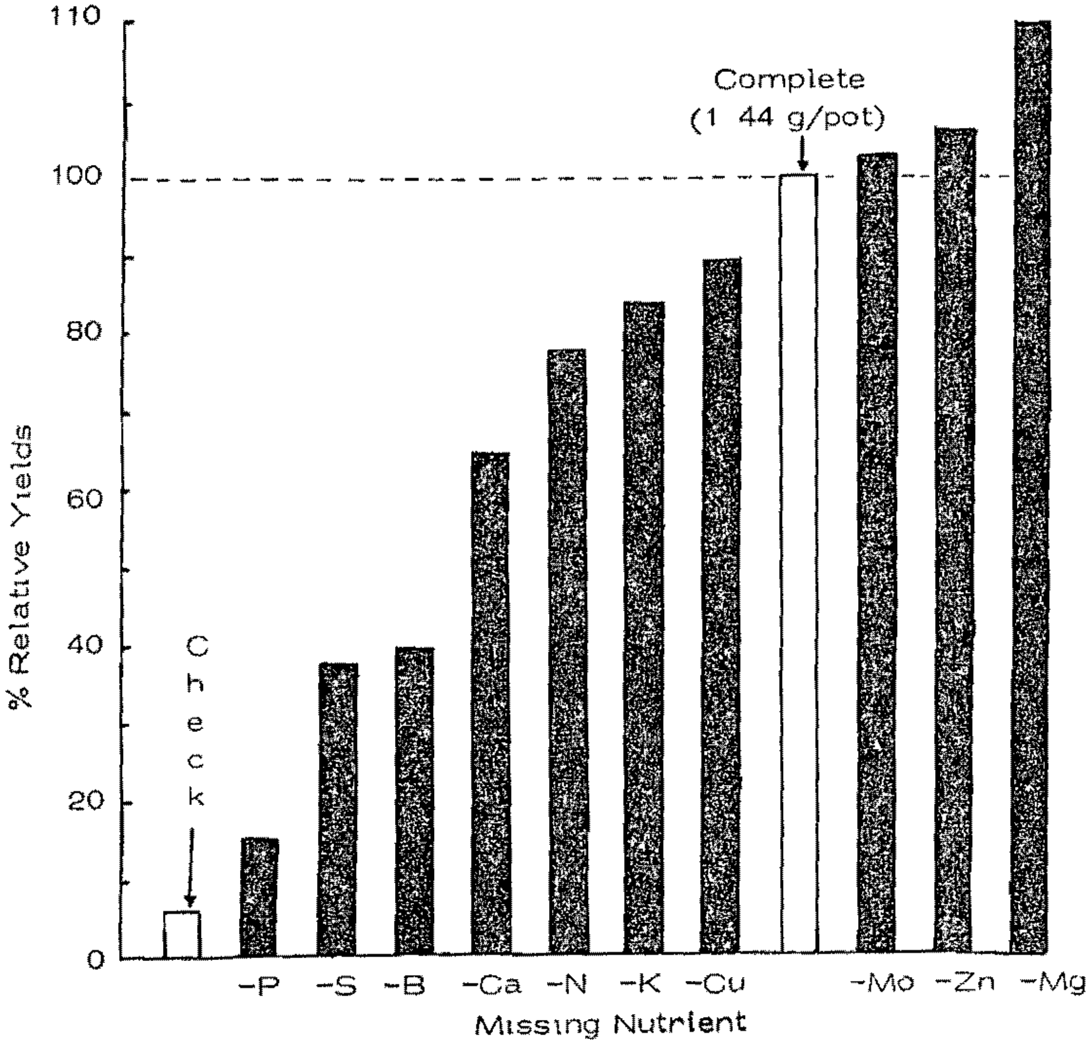

Figure 2 Response of Centrosema plumieri to missing nutrient elements in the Quilichao Ultisol Dry matter production, first cut Mean of four replications Source CIAT, 1977 Annual Report

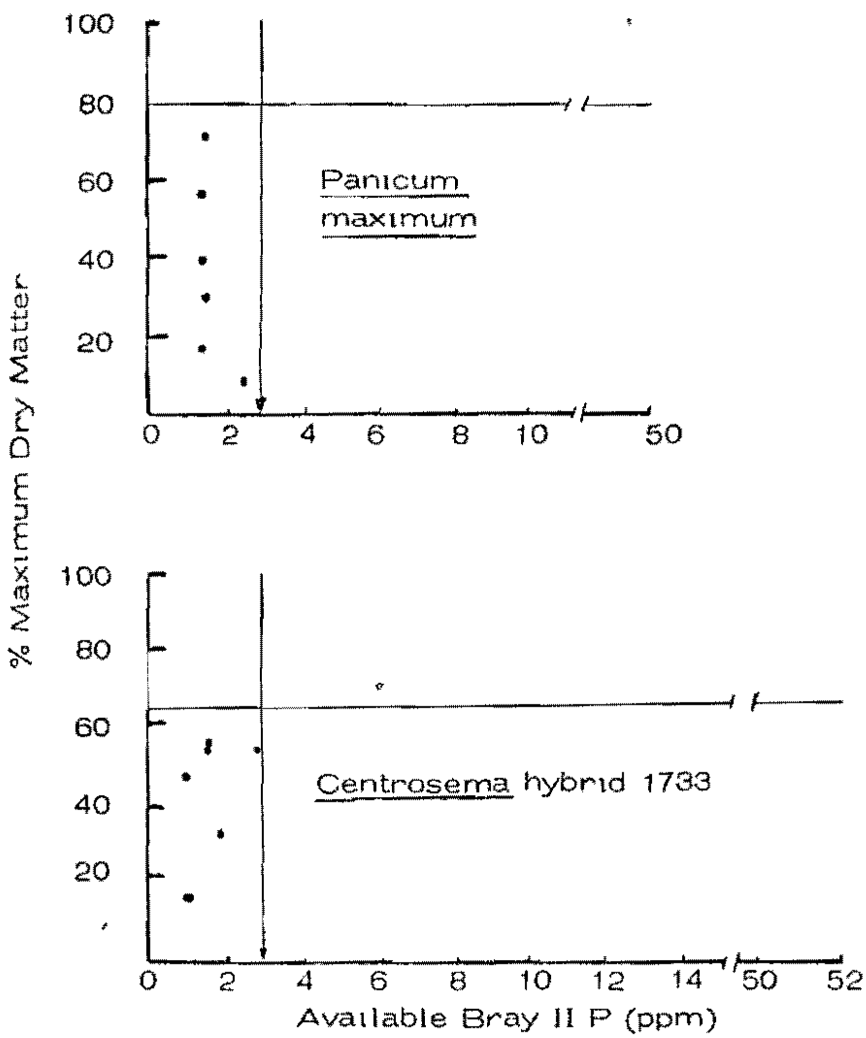

Figure 3 Estimation of the critical phosphorus levels in the Quilichao Ultisol under greenhouse conditions Sum of two cuts and mean of four replications
Source CIAT, 1977 Annual Report

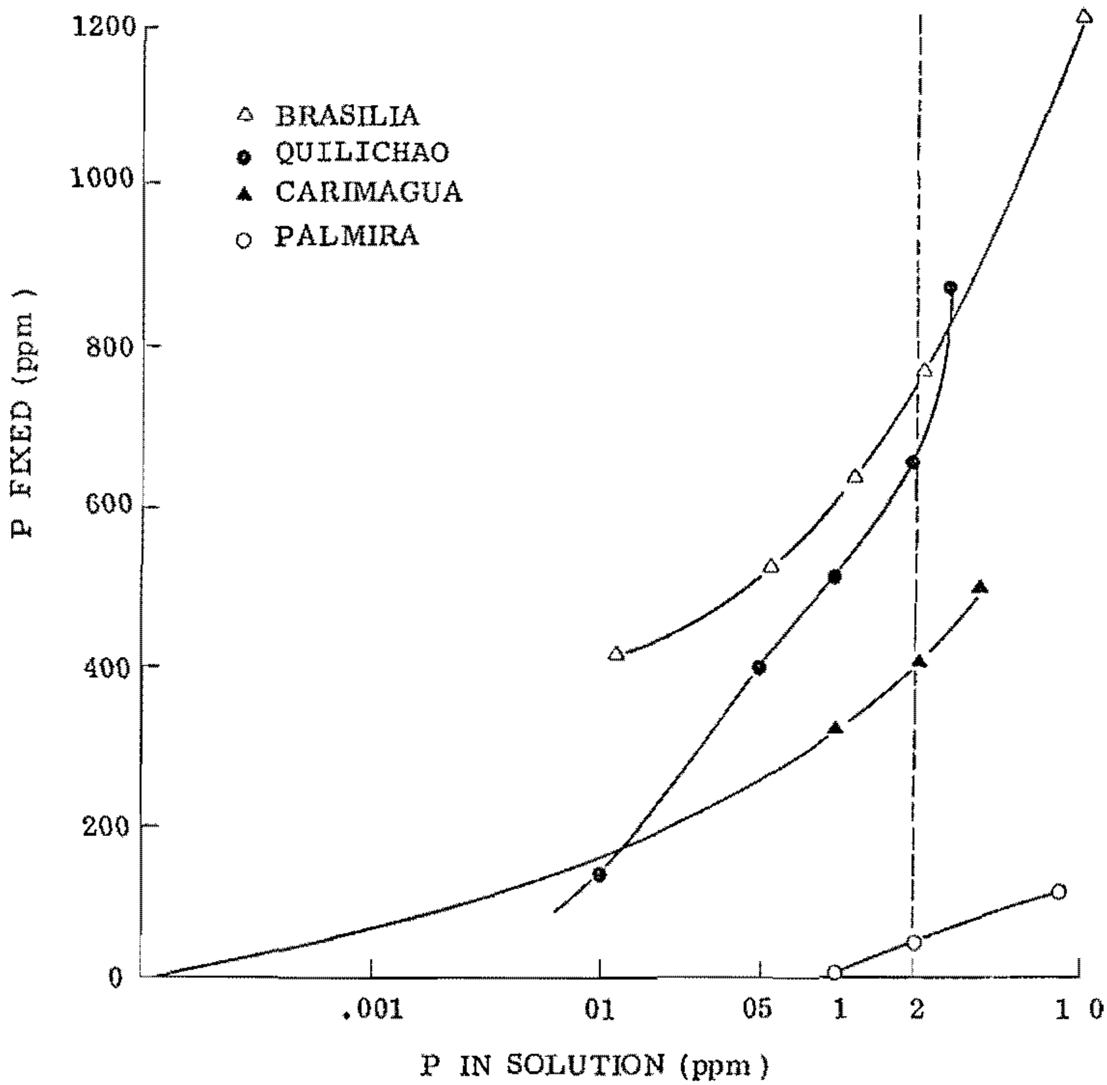

Fıgure 4 Phosphorus fıxatıon ısotherms of CPAC (Brasılıa), CIAT-Quılıchao, CNIA-Carımagua and CIAT-Palmıra
Source CIAT, 1977 Annual Report

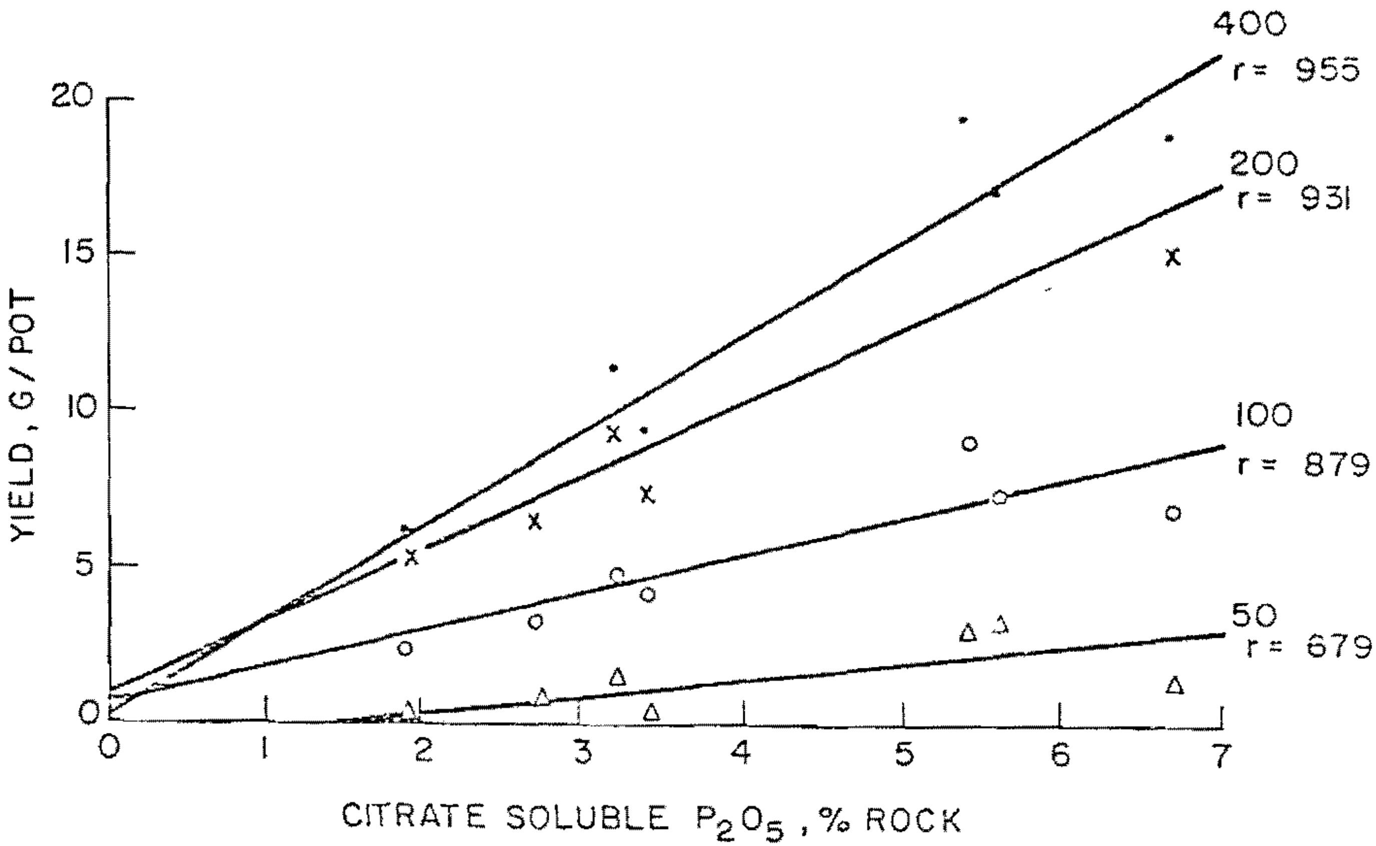

Figure 5 Relationship between yield of three cuttings of guinea grass grown on a Carimagua Oxisol, and citrate-soluble phosphorus in phosphate rocks

Source Hammond, 1977

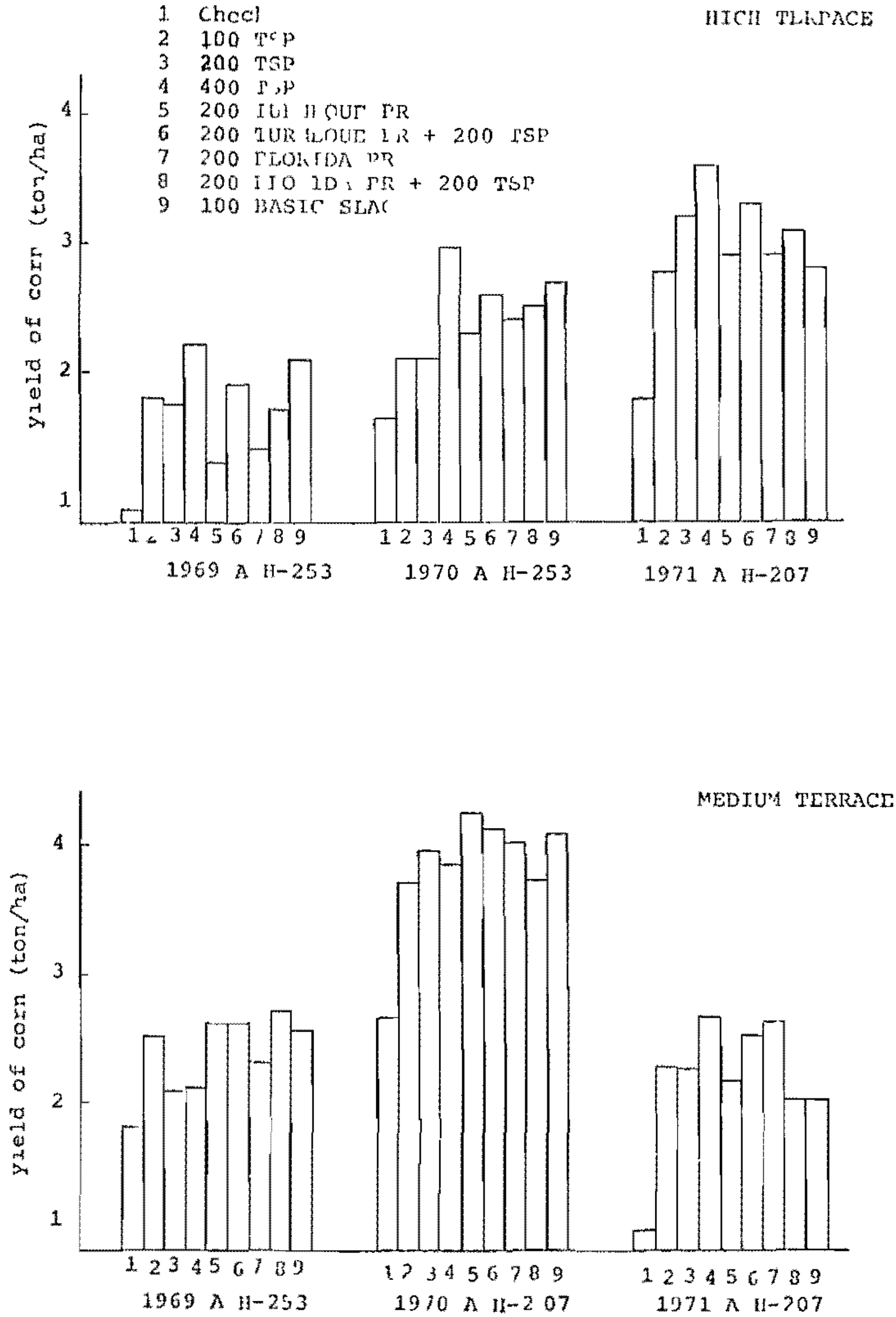

Figure 6 Effect of broadcast application of different forms and rates of phosphorus to corn grown on the high and medium terraces of the Eastern Plains of Colombia (La Libertad Experiment Station) Source León et al , 1976

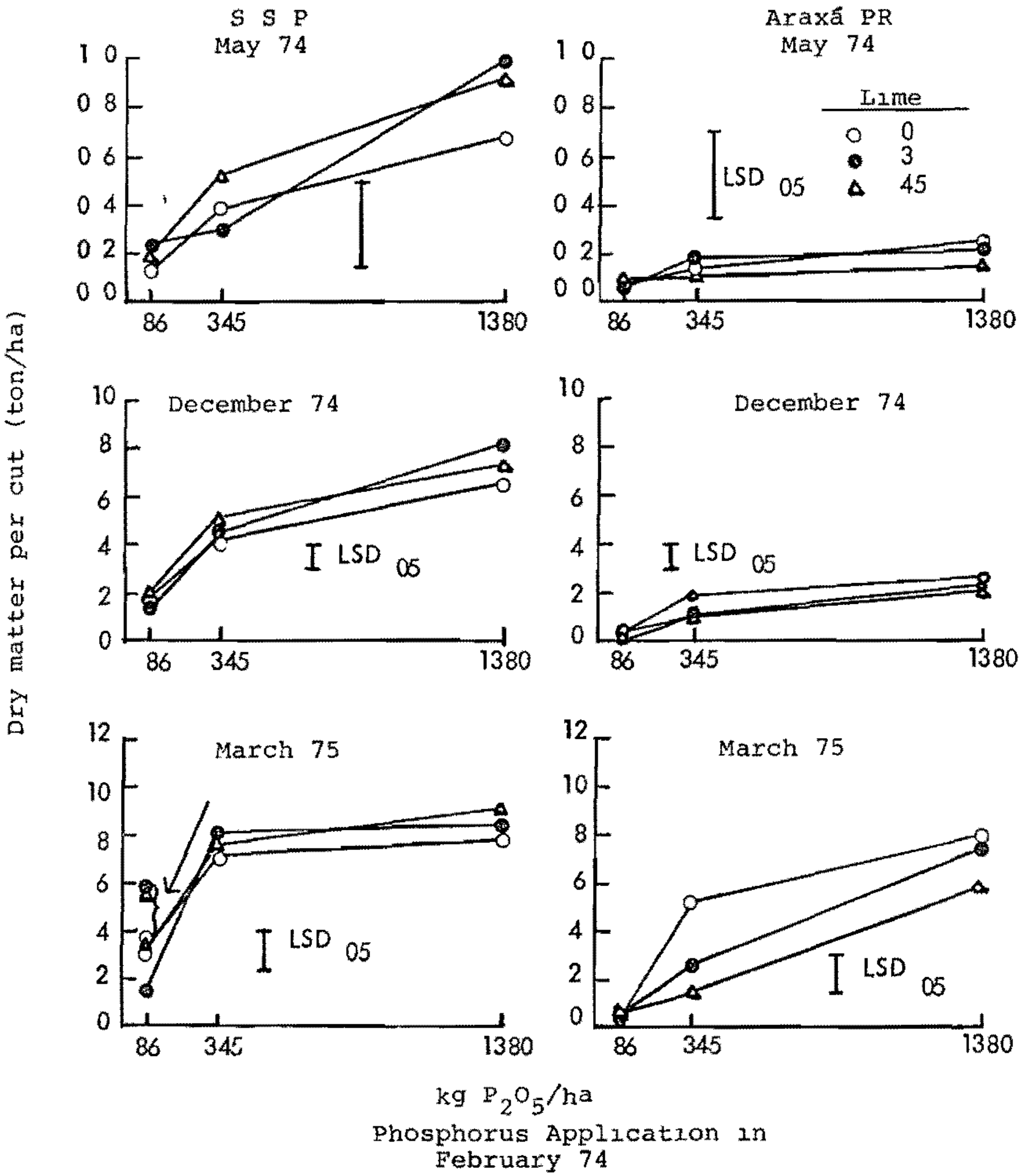

Figure 7 Availability of Araxá PR with time using *Brachiaria decumbens*, grown on an Oxisol in the Cerrado of Brazil
Source North Carolina State University, 1975 Annual Report

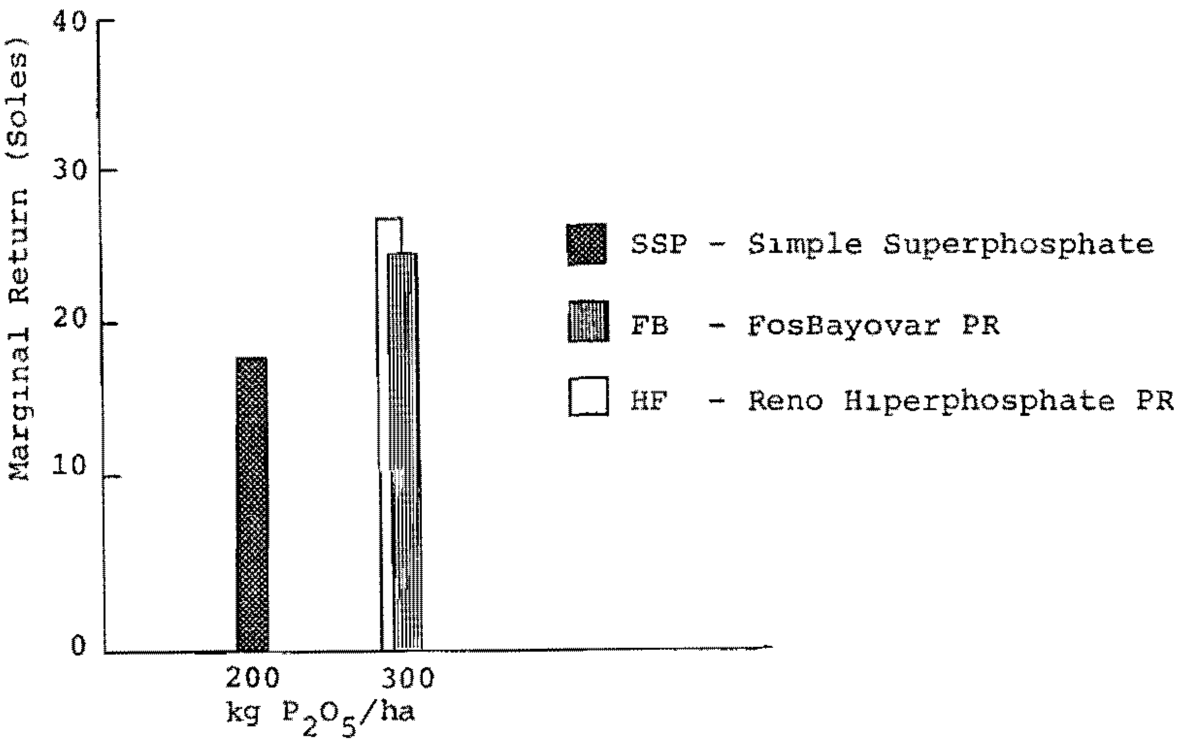

Figure 8 Comparison of marginal monetary returns with simple superphosphate and two phosphate rocks with potatoes in the highlands of Perú

Source Davelouis et al , 1976

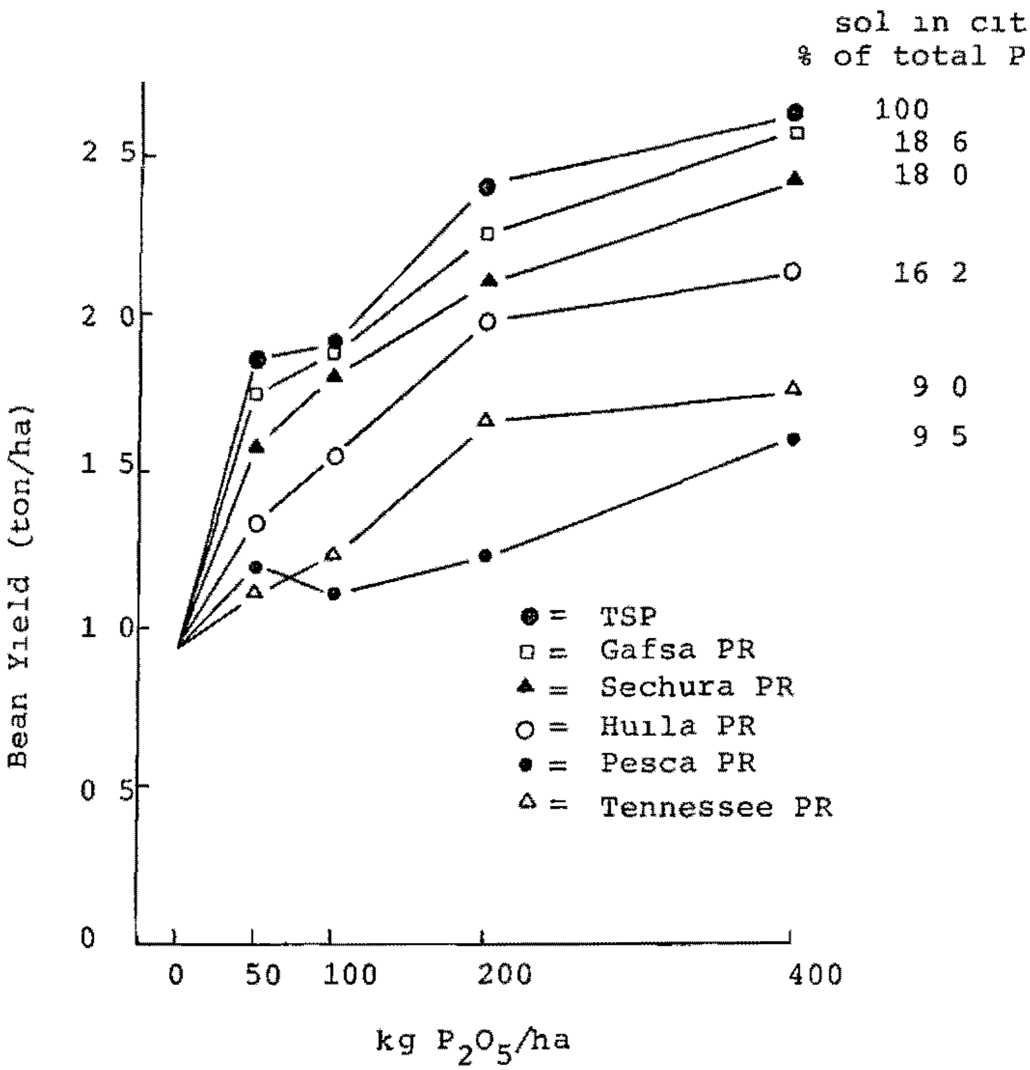

Fıgure 9 Response of Huasanó beans to forms and rates of phosphorus on an Andosol from Popayán, Colombıa

Source CIAT, 1976 Annual Report

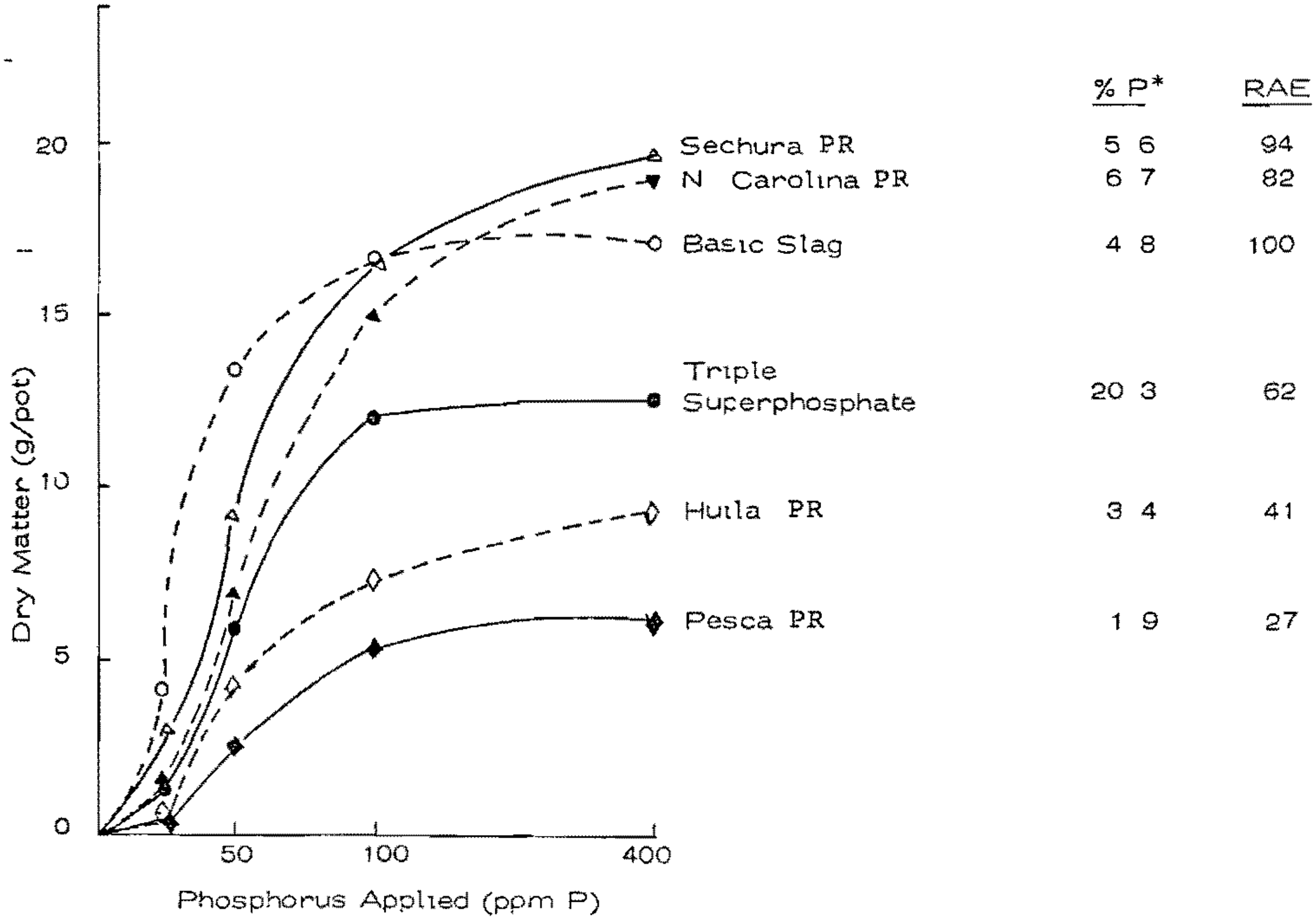

Figure 10 Effect of sources of phosphorus on _Panicum maximum_ dry matter production (sum of 3 cuts) grown on a Carimagua Oxisol without liming, in the greenhouse

% P = citrate-soluble P of entire material

RAE = relative agronomic effectiveness

Source CIAT, 1977 Annual Report

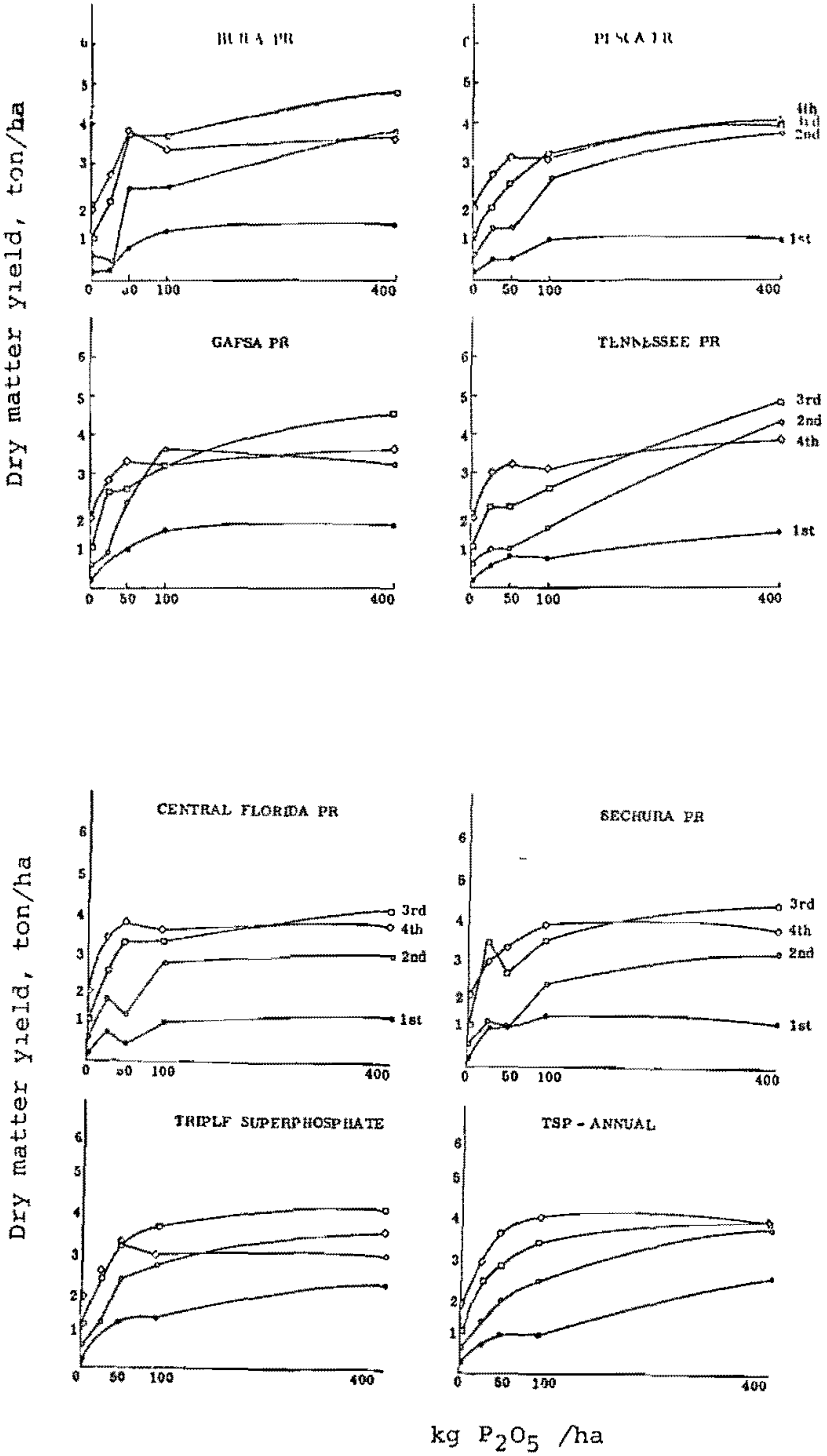

Figure 11 Dry matter yield of four cuttings of Brachiaria decumbens, grown on a Carimagua Oxisol, as affected by rate and source of phosphorus
Source CIAT, 1977 Annual Report

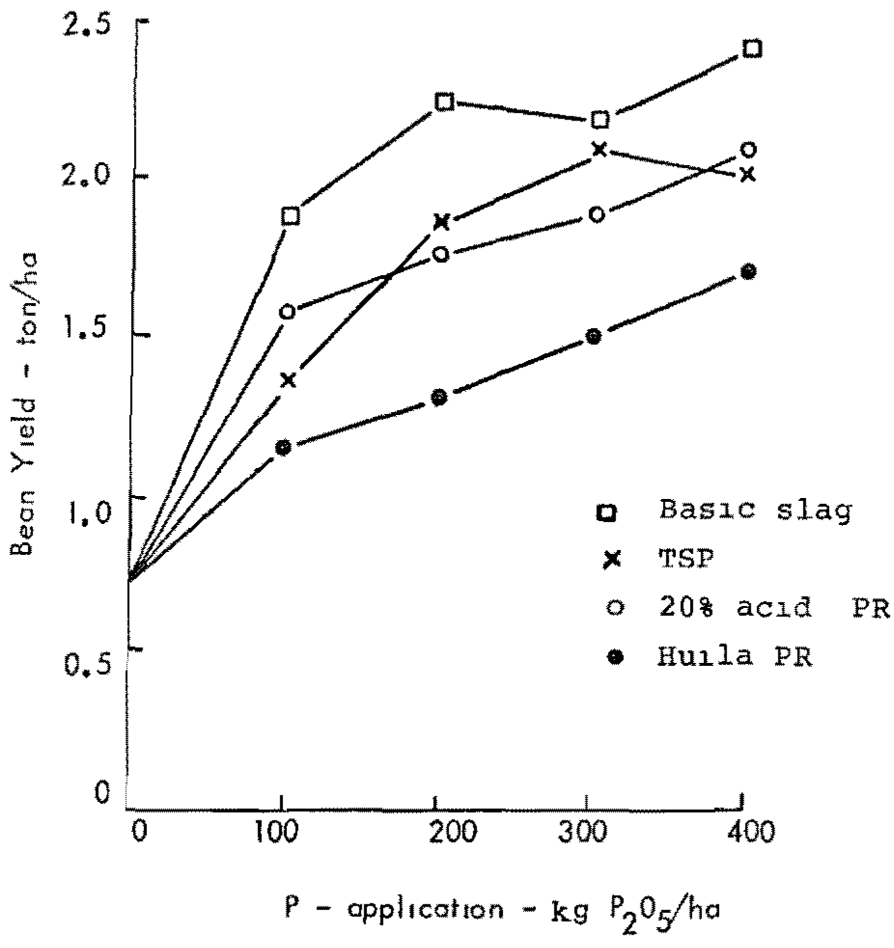

Figure 12 Response of beans to forms and rates of P grown, on an Andosol near Popayán
Source CIAT, 1975 Annual Report

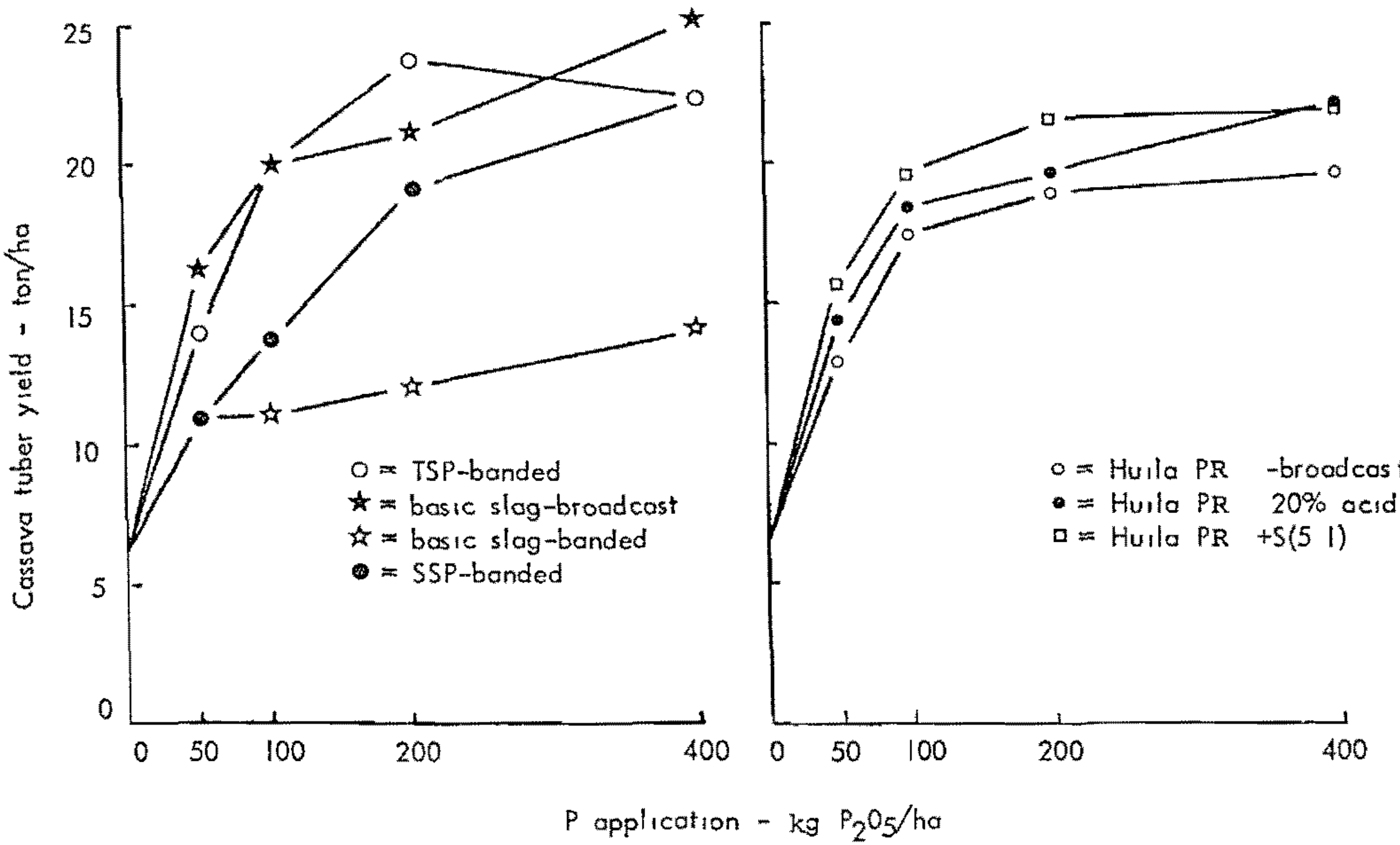

Figure 13 Response of Cassava to forms and rates of P on an Oxisol from Carimagua
Source CIAT, 1976 Annual Report

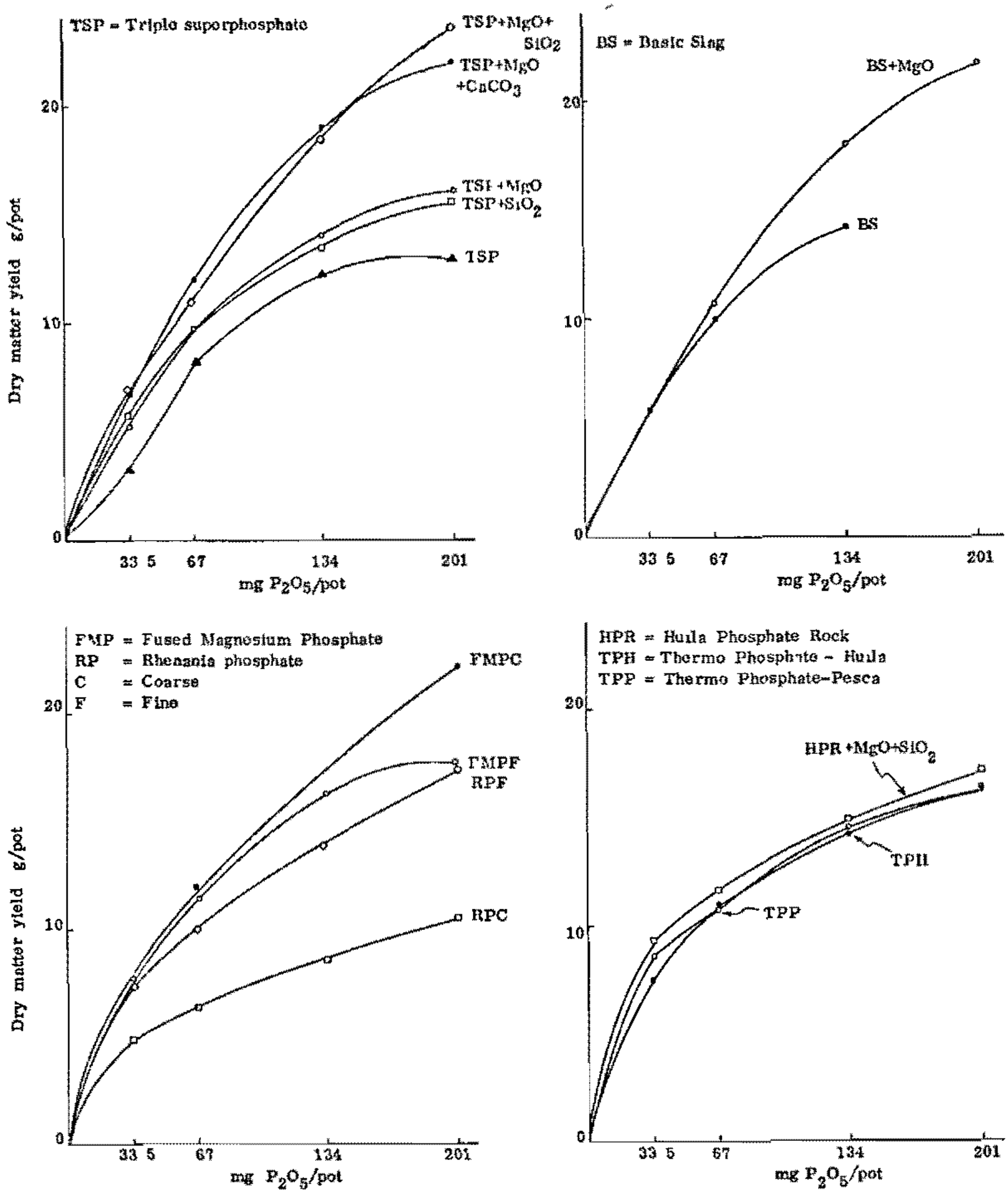

Figure 14 Dry matter yield of two cuttings of Stylosanthes guyanensis 136, in a greenhouse experiment on a Carimagua Oxisol, as affected by rate of phosphorus with MgO, $CaCO_3$ and SiO_2 and by different thermophosphates Source CIAT, 1977 Annual Report

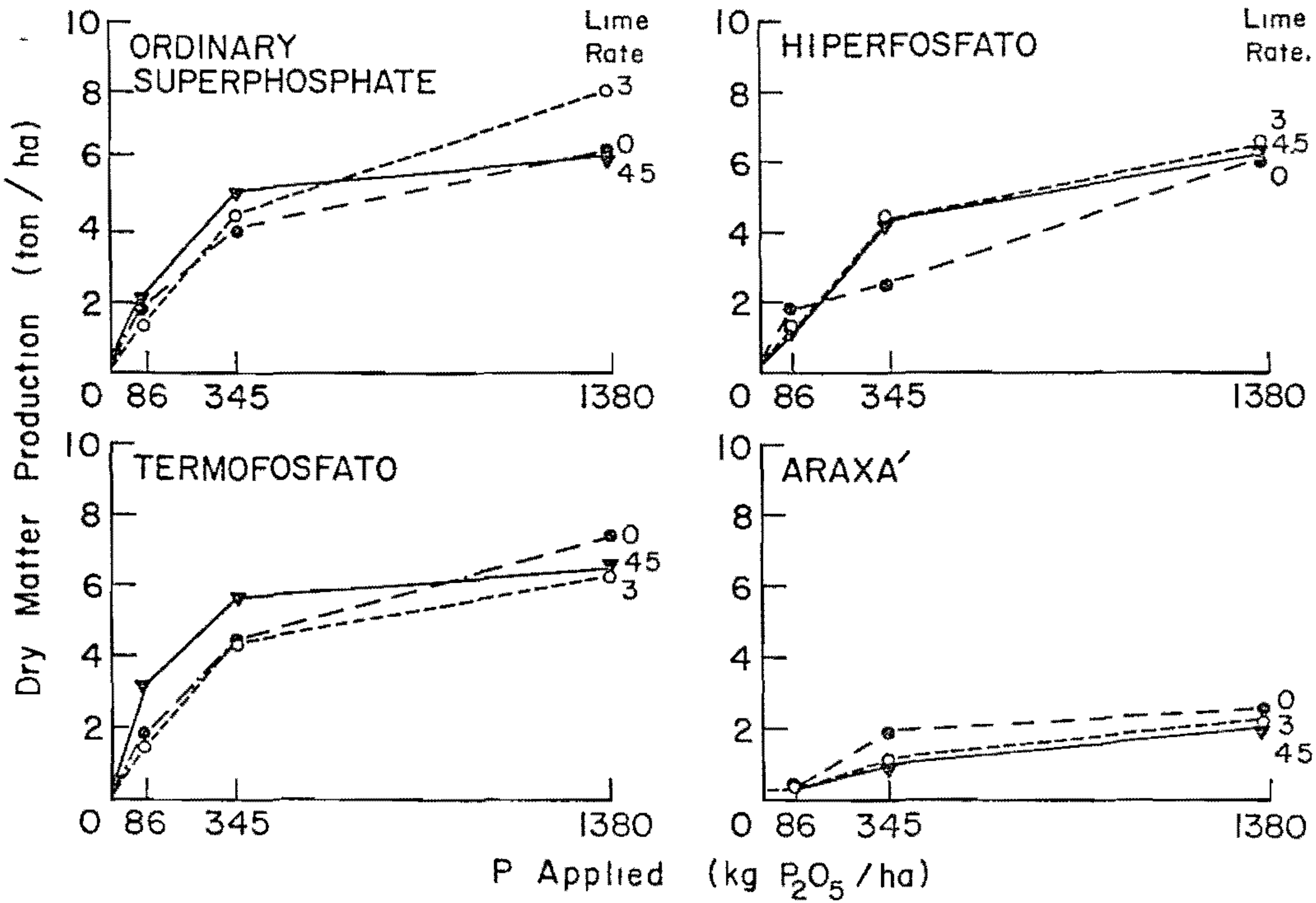

Fig 15 Growth of *Brachiaria decumbens* (second cut) as affected by phosphorus sources, rates and liming, in the Cerrado of Brazil

Source North Carolina State University, 1974 Annual Report

Figure 16 Rock phosphate deposits in tropical South America, Source León, 1977