PN-ABT-060
ISN 91012

USE OF INDIGENOUS PHOSPHATE ROCKS FOR ALUMINUM-TOLERANT CULTIVARS IN HUMID TROPICAL SOILS

FINAL REPORT

Grant No. DAN-5053-G-00-1047
HBCU Research Grant Program No. 936-5053

Department of Plant and Soil Science
Alabama A&M University
Normal, Alabama 35762

Investigators:
R. W. Taylor, Professor/PI
S. H. Chien, Adjunct Professor/CO-PI
K. R. Sistani, Research Assistant Professor

February 1994

Contents

	Page
Summary	3
Project Goals and Objectives	6
Incubation Study	
Introduction	7
Materials and Methods	7
Results	8
Field Studies	
Experiment 1, 1992	22
Experiment 2, 1992	23
Experiment 1, 1993	28
Experiment 2, 1993	29
Experiment 3, 1993	32

SUMMARY

The research work was carried out at two locations. Laboratory soil incubation was carried out at Alabama A&M University in Huntsville, Alabama, USA, and the field work was carried out in Colombia, South America during 1992 and 1993.

1. Laboratory Soil Incubation Study

The direct application of indigenous Phosphate Rock (PR) is an economically feasible alternative to the use of more expensive water soluble P fertilizers in some developing countries especially in the humid tropical regions. The objective of this incubation study which was a prelude to greenhouse and field studies was to evaluate the chemical changes in relation to the effectiveness of three PRs (Pesca, Huila and Sechua) from humid tropic regions relative to water-soluble Triple Super Phosphate (TSP) in three soil types, two Colombia South American soils (Oxisol and Inceptisol) and one soil from USA (Hartselle soil). Three P rates of 100, 200 and 400 mg kg^{-1} were mixed with 100g soil of each type. Samples were taken for analysis at four incubation times up to 10 weeks in duplicate. pH, available P, exchangeable Ca, Al, and CEC were determined. In general, the pH of the soils increased after one week of incubation, then generally decreased gradually especially by week six. Aluminum decreased significantly through the six weeks and at the same time Ca increased significantly; this is in agreement with the previous reported work that the direct application of PR will increase the pH and Ca, and at the same time reduce exchangeable Al. Available P increased by the first week then gradually decreased. In general, the reduction in Al and increase in pH and Ca should give a possible beneficial effects due to the direct application of PR for crop production on acid tropical soils .

2. Field Study

During the August to December 1992, two field trials were carried out by the researchers of the Institute Colombiano Agropecurio (ICA), Colombia. Sources of P were two PRs indigenous to Colombia (Huila and Pesca) and a commercial-grade triple superphosphate (TSP). Rates of P applied were 0, 50, 100, and 150 kg P/ha. In 10 treatments, the soil was limed with 1,500 kg/ha of dolomitic lime. In the remaining 3 treatments, which included check, Huila PR, and TSP at only one P rate (150 kg P/ha), the soil was not limed. An Al-tolerant soybean cultivar locally available (ICA variety-Soyica Araria) was used. The P fertilizers were broadcasted and incorporated using a garden rake. The soybean seeds were placed in rows 40 cm apart. Before planting (August 27-28), the seeds were inoculated with rhizobium inoculant (ICAJOL). All treatments received constant applications of 20 kg N/ha as urea and 90 kg K_2O/ha as KCl. Three replicates were made for each treatment. Soybean plants were grown to maturity and harvested on December 17.

The relative agronomic effectiveness on the limed soil, the (RAE) values of Huila PR were from 43% to 58% and the values of Pesca PR were from 34% to 52%. The higher RAE values for Huila PR than for Pesca PR were due to the fact that Huila PR is more reactive than Pesca PR. The citrate solubility of Huila PR is 1.5%, whereas the citrate solubility of Pesca PR is only 0.8%. Although the two indigenous PRs were less effective than the imported TSP in producing soybean yield, it should be pointed out that the cost of PRs is also less than that of TSP. If the cost of PR is less than one-third that of TSP, it would be more cost-effective for the resource-poor farmers in Colombia to use PRs. Without liming, soybean yields were very low for check, Huila PR, or TSP. Although the ICA variety is Al-tolerant, apparently the variety could not grow well on the Oxisol with Al-saturation at 70%. However, the RAE value of Huila PR with respect to TSP was increased from 57% with liming to 70% without liming. In other words, in the absence of liming the potential use of PR with respect to TSP increases. This tends to support our hypothesis which resulted in a research project 1993, when three field experiments were conducted to study the initial and residual effects of two indigenous PRs (Huila and Pesca) against imported TSP in producing soybean grain yield on two acid soils (Oxisol and Ultisol) in Colombia. Three local soybean varieties (two more Al tolerant—Soyica Ariari and Lita 9; one less Al tolerant—Soyica P-34) were grown on the two soils with or without liming. The results are summarized as follows.

1. On both soils without liming, the Soyica Ariari variety, which is more Al tolerant, was unable to grow well because of very high Al saturation levels (74%-84%) of the unlimed acid soil. Consequently, it was not possible to test the proposed hypothesis that the use of indigenous PR would be more attractive for the Al-tolerant soybean cultivars grown on tropical acid soils without liming. However, it was also observed that factors other than Al saturation may also influence the effect of soybean variety on soybean grain yield obtained with various P sources.

2. TSP was more effective than PRs in producing soybean grain yields on limed acid soils both for initial and residual effects. However, PRs should be more cost effective for fertilization if the cost of PR is only one-third to one-half of TSP on a per kilogram P_2O_5 basis.

3. The relative effectiveness of PRs with respect to TSP was increased from the initial effect to the residual effect. The average RAE values for two PRs are 48% and 68%, respectively, in the initial and residual effects on the limed Oxisol. Chemical reactivity of PR also was found to be less important in the residual effect than in the initial effect.

4. The effect of soybean variety on the grain yield varied with (1) absolute yield or net increase yield over the control, (2) sources of P fertilizer, (3) rates of P applied, and (4) types of soil. All these need to be considered when we try to optimize the economic benefit of using P fertilizers for soybean production on acid soils.

Project Goals and Objectives

The primary goal of this project was to present an innovative research program of developing low-cost yet agronomically effective strategies for growing soybean crops in humid tropical regions with soil characteristics of strong acidity, high Al-saturation, and low Ca and P nutrients. We proposed to combine the strategies of using Al-tolerant species/cultivars with using indigenous phosphate rock (PR) for direct application to overcome the above-mentioned constraints so that the maximum yield potential of a selected cultivar may be achieved.

The direct application of indigenous PR is an economically attractive alternative to the use of the more expensive, imported water-soluble P fertilizers [e.g., triple superphosphate (TSP), diammonium phosphate (DAP)]. Some developing countries in the humid tropical regions (e.g., Colombia, Peru, Brazil, Venezuela, Bolivia, Thailand, Sri Lanka, Tanzania, Zimbabwe, Uganda, Burundi, and Togo) have phosphate deposits, which, if used to supplement other phosphates would allow a saving of much needed foreign exchange (Hammond et al., 1986). The proposed research, therefore, was very relevant to USAID's major mission which is to help developing countries in increasing agricultural production with cost-effective inputs.

We presented a systematic plan to carry out the research work through laboratory and field studies.

INCUBATION STUDY

INTRODUCTION

Phosphorus (P) is one of the most limiting nutrient for crop production especially in acid tropical soils. Some of the tropical soils have high P-sorption capacities which makes successful crop growth more difficult in an already P-deficient soil. Adequate P fertilization is therefore essential for economic and sustainable crop production (Menon, et al., 1991). Due to the high cost of P fertilizers, the use of conventional water-soluble P fertilizers has been limited especially for those countries which have to import fertilizers. Phosphate Rock (PR) deposits occur in several countries of Asia, Africa, Latin America, and even in some parts of United States. Some of these PRs are chemically reactive and can be used effectively as a substitute for the expensive P fertilizers especially in acid soils (Leon, et al., 1986; Hammond et al., 1986). Some of these PRs have low chemical reactivity and perform poorly, especially when used for crop with short growing seasons. Partially acidulated PRs are as effective as superphosphate for certain crops (Hammond, et al., 1986; Chien and Hammond, 1989).

The objective of this incubation study (which was a prelude to greenhouse and field studies) was to evaluate the chemical changes that occurred in relation to the effectiveness of three PRs (Pesca, Huila and Sechura) from humid tropic regions relative to Triple Super Phosphate (TSP) in three soil types (two from Colombia South America and one from USA).

MATERIALS AND METHODS

Three soil types were selected for this incubation study, two from Colombia South America (Inceptisol and Oxisol) and Hartselle silt loam from USA. The Inceptisol and Oxisol has pH of 4.5 and 4.9 respectively, while the Hartselle soil had pH of 4.5. All three soil were low in phosphate content (<2 ppm) and had over 70% aluminum saturation. The P content of the phosphate rocks and TSP are as follows: Pesca and Huila 8.7%, Sechura 13% and TSP 21%. Three Phosphate Rocks (PR), Pesca and Huila from Colombia and Sechura from Peru South America and water-soluble Triple Super Phosphate (TSP) were used as P sources. Three P rates of 100, 200 and 400 mg/kg were mixed with 100 g soil of each type. The finely ground PRs were mixed with ground soil (passed through 2 mm sieve), watered to field capacity (20%) and incubated at 30°C. Samples were taken in duplicate for chemical analyses up to 10 weeks (initial, one week, three weeks, six weeks and 10 weeks). pH, P, exchangeable Ca, Mg, K and Al, CEC and percent Base Saturation (%BS) were determined at each sampling time.

RESULTS AND DISCUSSION

The three soil types treated with PRs and TSP generally showed the same trend in pH changes during the 10-week incubation study (Fig. 1, and 9). pH increased during the first 10 days and then generally decreased until 6 weeks. Hartselle silt loam and Colombian Oxisol had higher pH after 10 weeks of incubation than their initial pHs. Colombian Inceptisol had slightly lower pH than the initial pH after 10 weeks especially with Pesca and TSP treatments. Hammond, 1979 reported that Phosphate Rock will increase the pH up to 0.4 unit, however our data shows the increase is much higher especially early after application. pH changes in soils followed the same trend with different rates of PRs and TSP. Phosphate was measured by recently developed method (Pi method) by International Fertilizer Development Center (IFDC) (Mennon, 1989). Phosphate levels changes in Inceptisol and Oxisol followed the same trend in all treatment, however P in the TSP treatments decreased sharply by the first week than stabilized throughout the study but remained significantly higher than levels due to PRs. P changes in Hartselle Soil was very erratic for both the PRs and TSP treatments. (Fig. 2, 6 and 10). Among the PRs, Sechura PR treated soil had higher P at any time followed by Huila and Pesa, this is in direct relationship with their chemical reactivity which follow the same trend as Sechura>Huila>Pesca. Exchangeable Al decreased sharply through the first 3 weeks in all soils. This is attributed to the increase in pH in the first week of incubation (Fig. 3, 7 and 11). Sechura and Huila PRs treated soil reduced the exchanngeable Al more than Pesca and TSP. Chien, 1982 reported that exchangeable Al was reduced throught the first 9 weeks then stayed the same until week 15 in an incubation study in greenhouse. Our data indicated that eachangeable Al at first decreased and then increased sharply in all treatments after week three. In the case of the Hartselle soil, the exchangeable Al level finally increased to levels similar to initial levels. Exchangeable Ca increased sharply during the first week of incubation then decreased up to six weeks in all therr soils (Figs. 4, 8 and 12) Huila and Sechura PRs treated soil increased the exchangeable Ca more than Pesa and TSP. Generally, the same trend was observed in all treatments, when pH increased, exchangeable Al decreased and Ca increased. The reduction in exchangeable Al and increased in pH and exchangeable Ca will give a possible beneficial effects on the direct application of phosphate rocks especially if more chemically reactive kind is used on acid tropical soils for crop production.

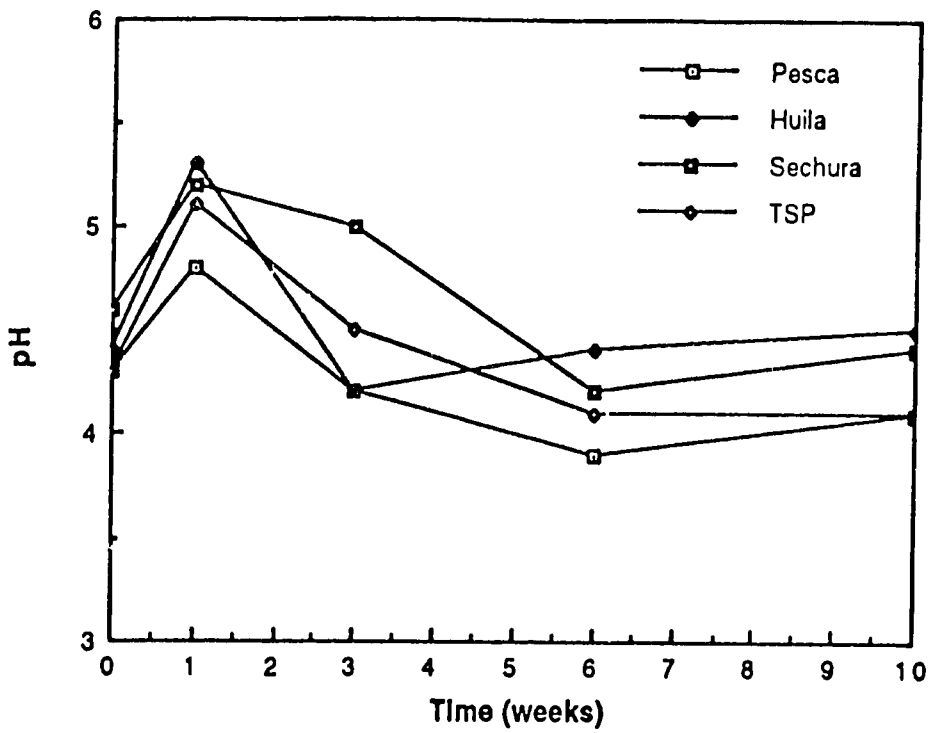

Fig.1 pH changes in a Colombian soil (Inceptisol) treated with four different P sources during 10-week incubation study

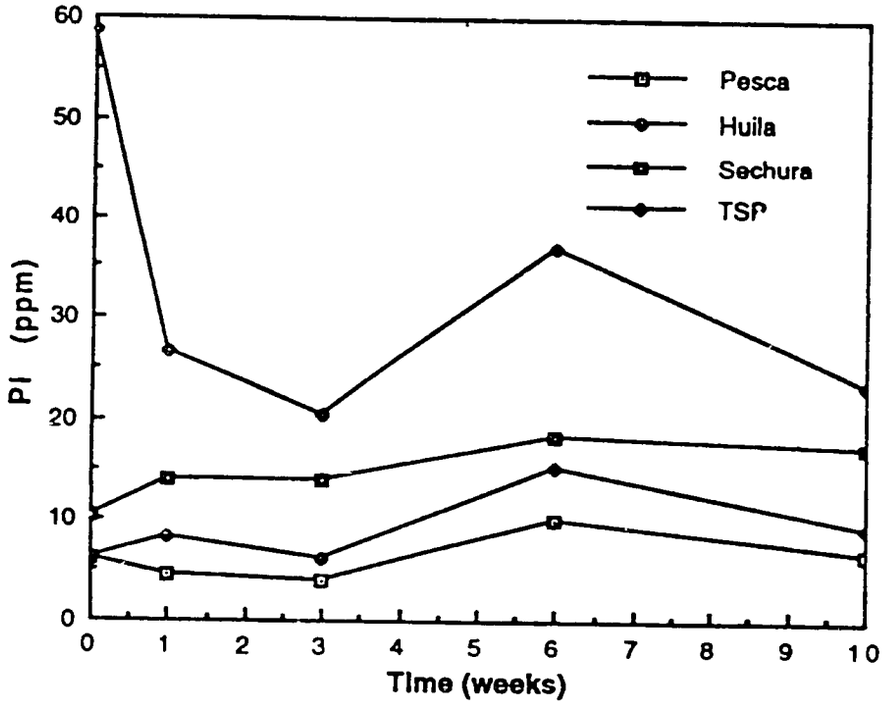

Fig.2 Pi changes in a Colombian soil (Inceptisol) treated with four different P sources during 10-week incubation study

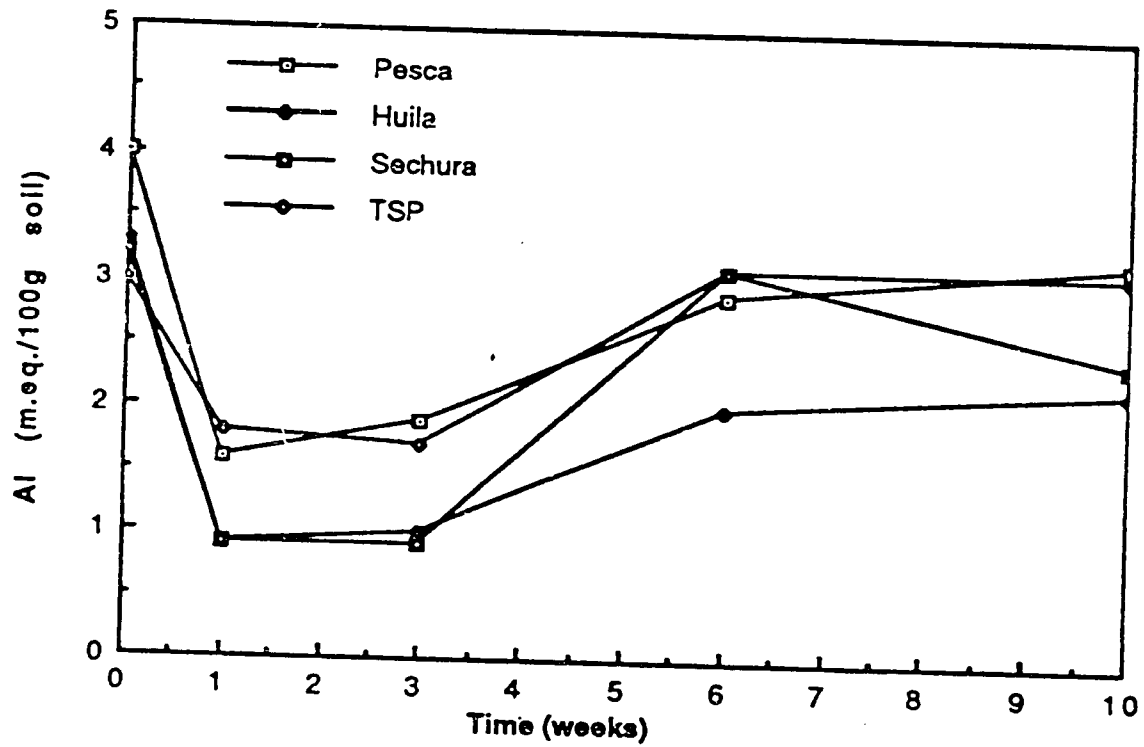

Fig.3 Exchangeable Al in a Colombian soil (Inceptisol) treated with four different P sources during 10-week incubation study

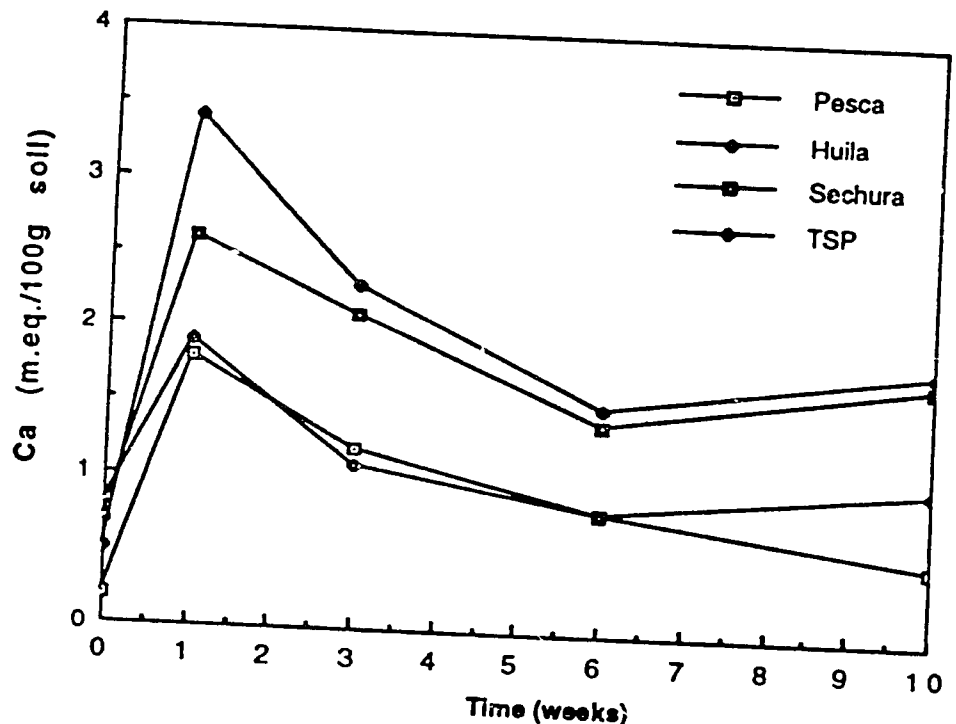

Fig.4 Exchangeable Ca in a Colombian soil (Inceptisol)treated with four different P sources during 10-week incubation study

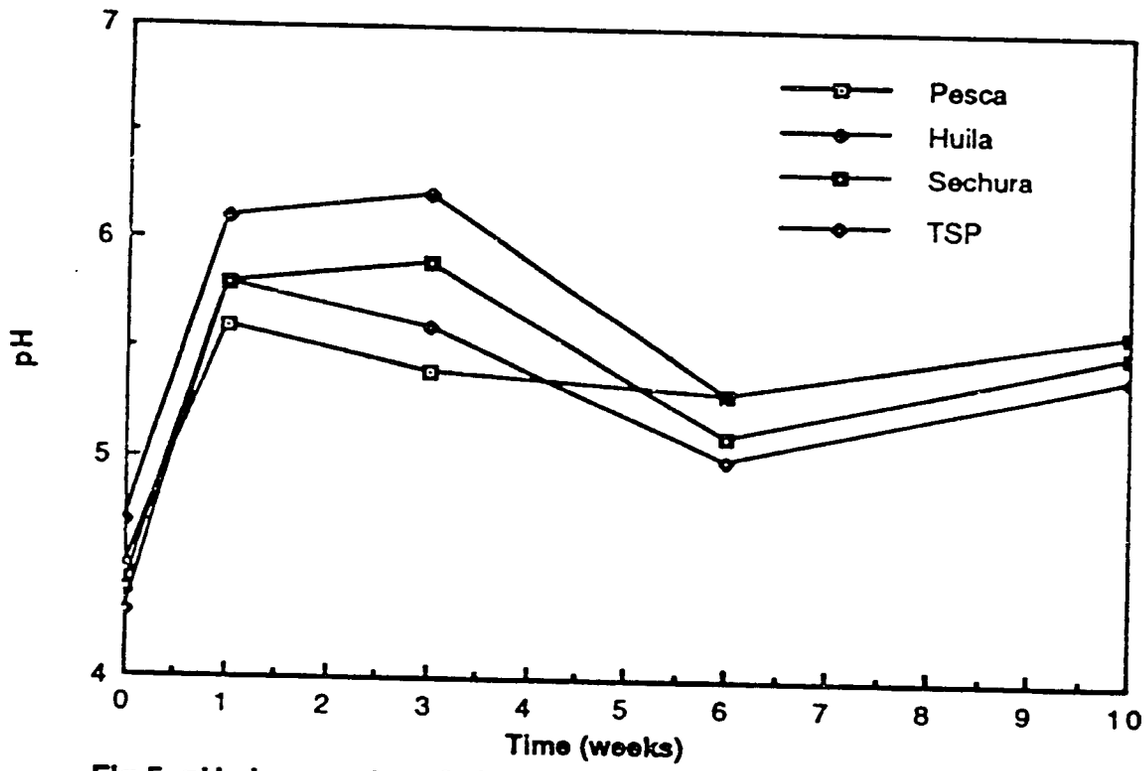

Fig.5 pH changes in a Colombian soil (Oxisol) treated with four different P sources during 10-week incubation study

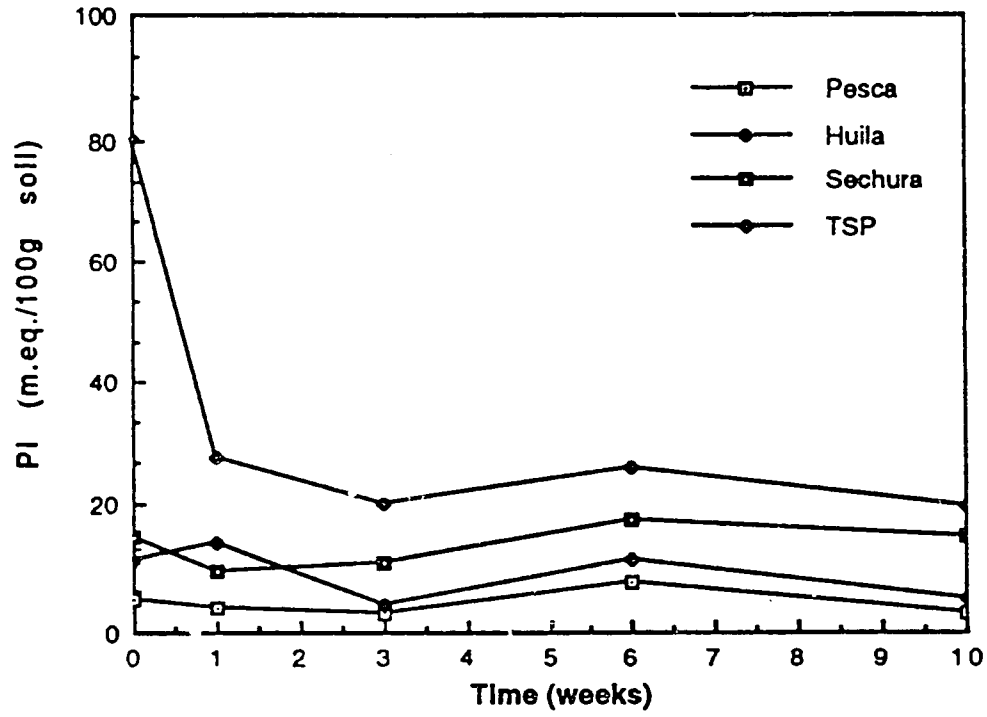

Fig.6 PI changes in a Colombian soil (Oxisol) treated with four different P sources during 10- week incubation study

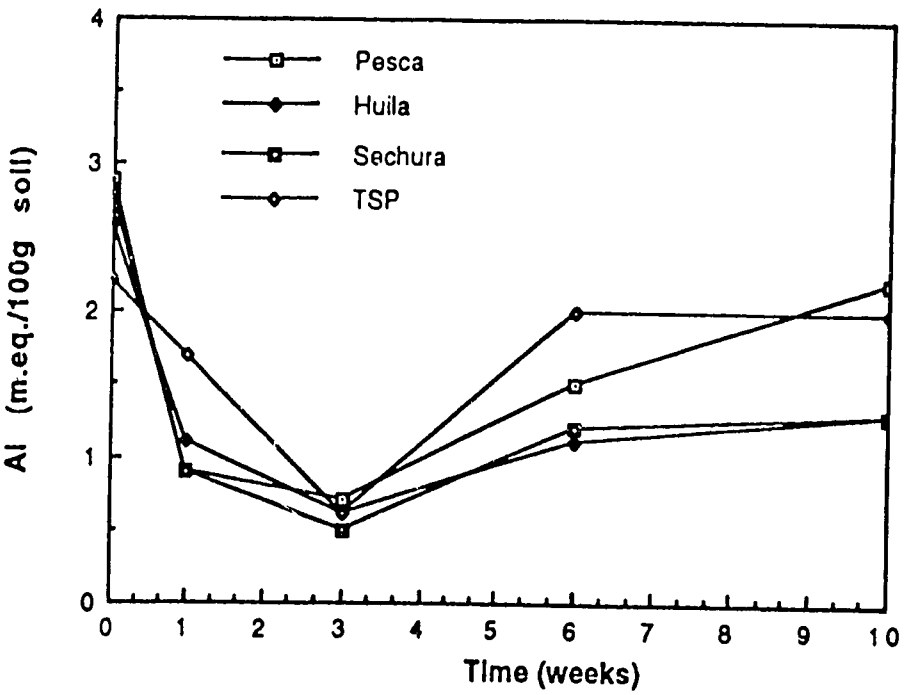

Fig.7 ExchangeableAl in a Colombian soil (Oxisol) treated with four different P sources during 10-week incubation study

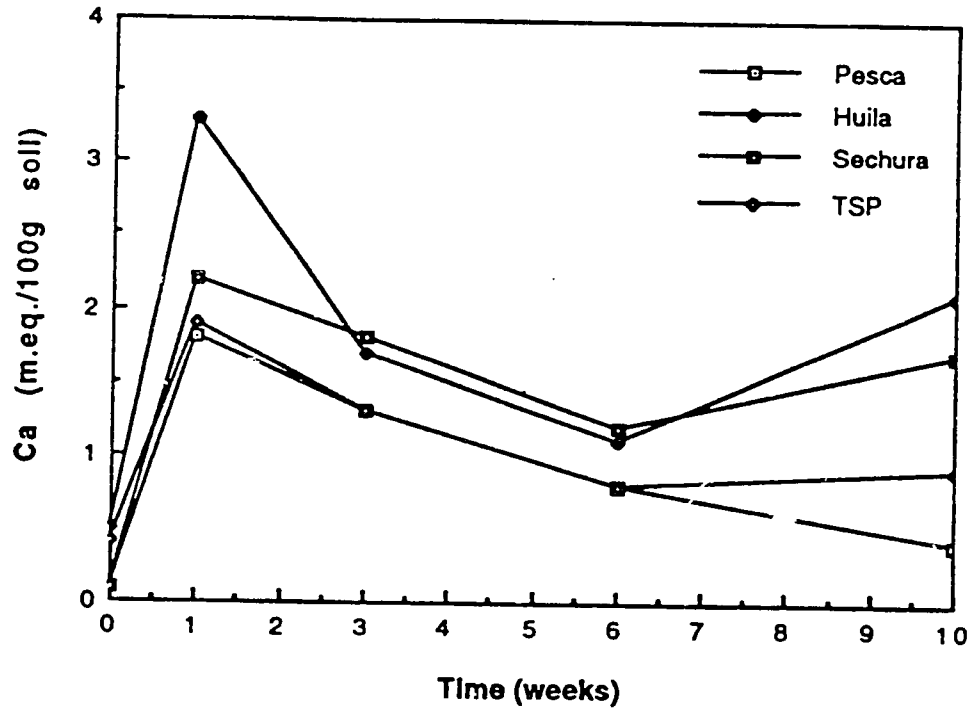

Fig.8 Exchangeable Ca in a Colombian soil (Oxisol) treated with four different P sources during 10-week incubation study

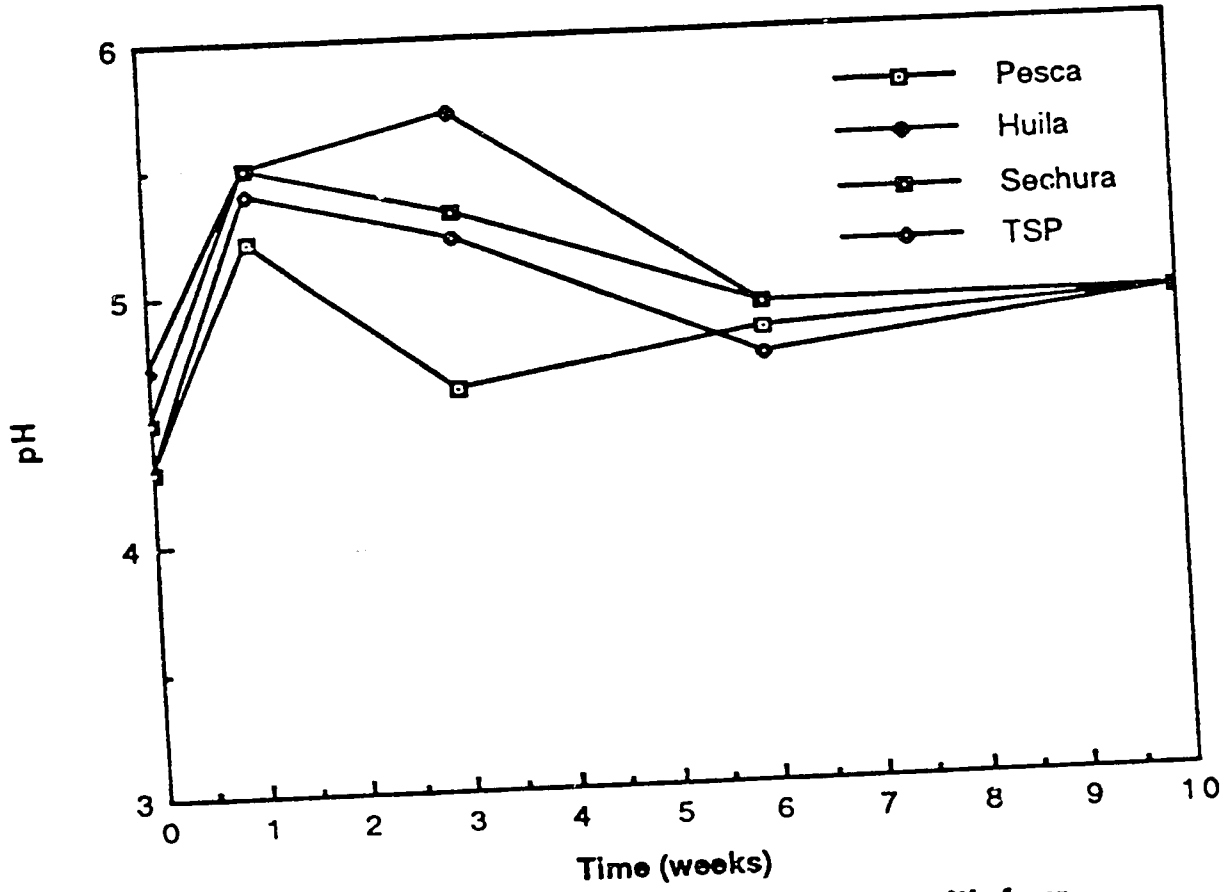

Fig.9 pH changes in a Hartselle soil treated with four different sources during 10-week incubation study

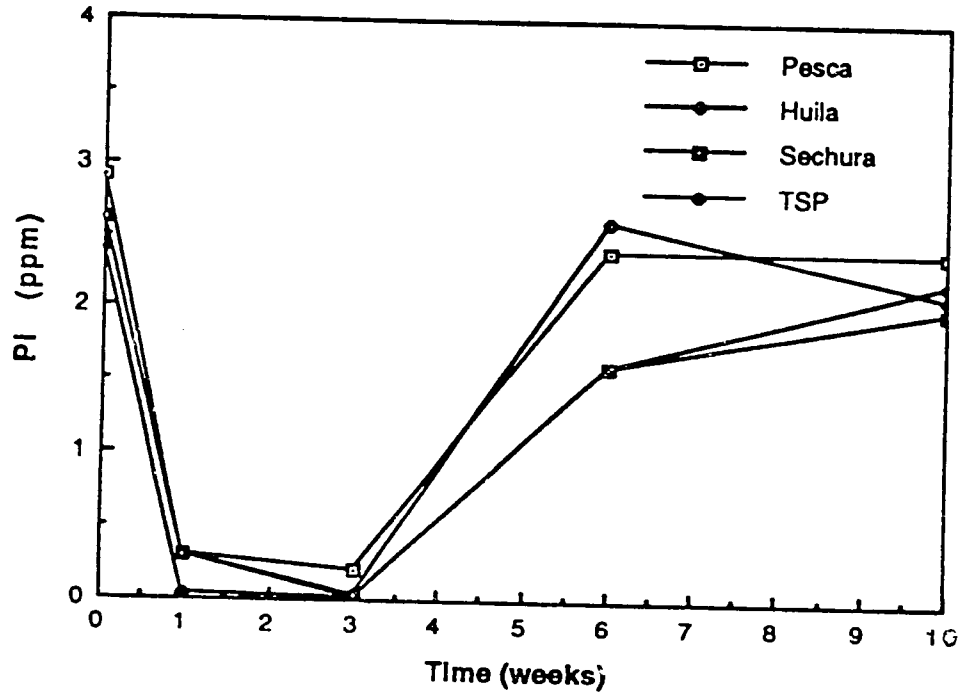

Fig.10 PI changes in a Hartselle soil treated with four different P sources during 10-week incubation study

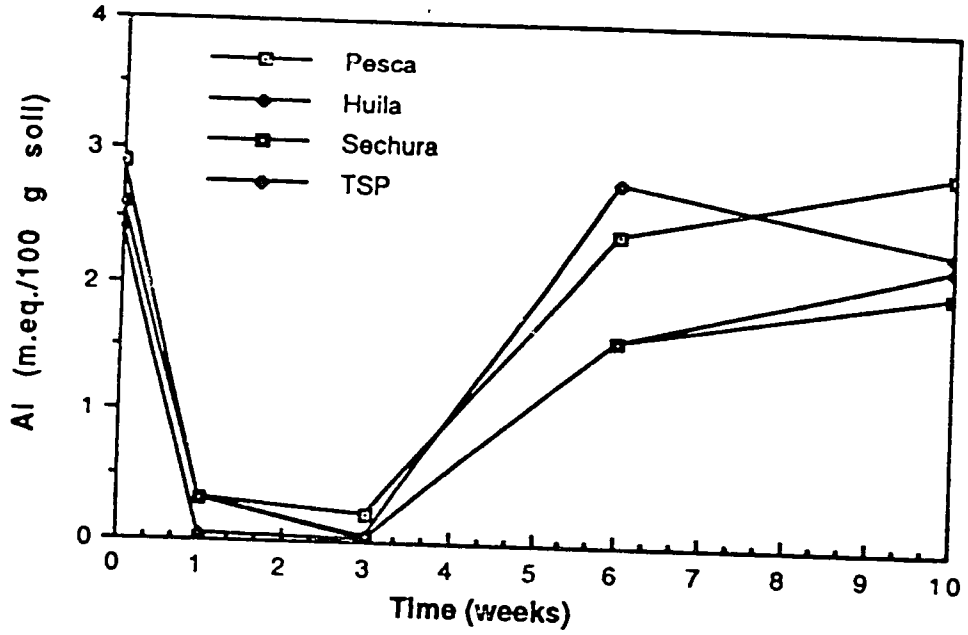

Fig.11 Exchangeable Al in Hartselle soil treated with four different P sources during 10-week incubation study

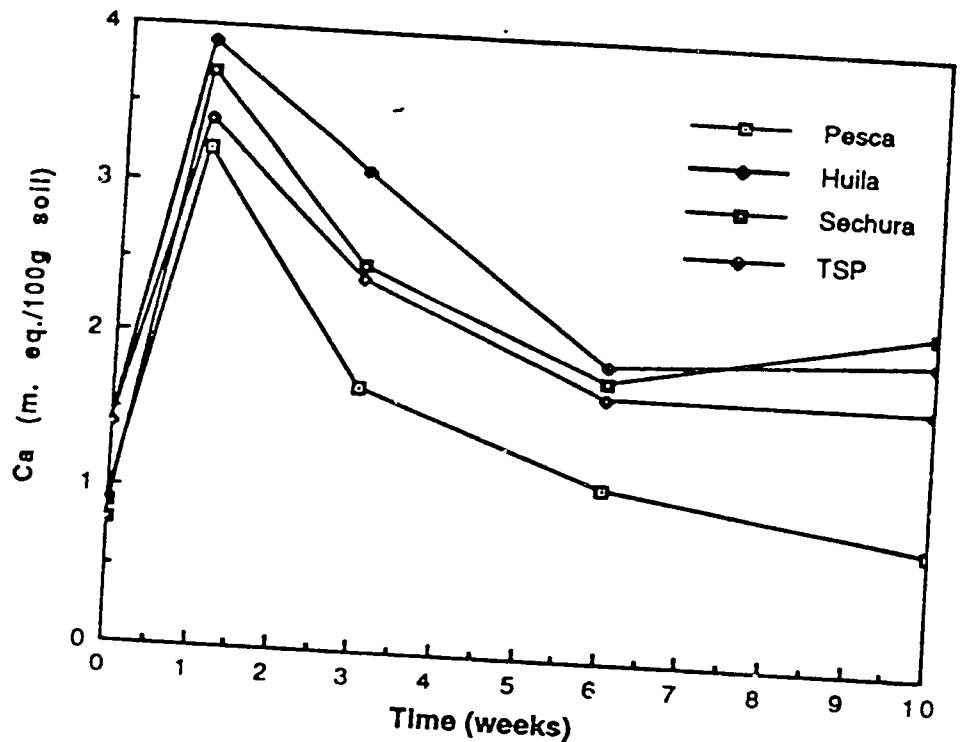

Fig.12 Exchangeable Ca in a Hartselle soil treated with four different P sources during 10-week incubation study

FIELD STUDIES

1992 EXPERIMENTS

Introduction

The objective of this study was to investigate the effect of two phosphate rocks (PRs) indigenous to Colombia on the growth of aluminum-tolerant soybean cultivars grown on acid soils in Colombia's East Plain. During August to December 1992 (first semester), two field trials were carried out by the researchers of the Instituto Colombiano Agropecuario (ICA), Colombia.

Experiment No. 1

Materials and Methods

This experiment was conducted on an Oxisol (Humbriorthox) in San Martin County. Some of the soil properties are shown in Table 1.

Sources of P were two PRs indigenous to Colombia (Huila and Pesca) and a commercial-grade triple superphosphate (TSP). Rates of P applied were 0, 50, 100, and 150 kg P/ha. In ten treatments, the soil was limed with 1,500 kg/ha of dolomitic lime. In the remaining three treatments, which included check, Huila PR, and TSP at only one P rate (150 kg P/ha), the soil was not limed.

An Al-tolerant soybean cultivar locally available (ICA variety-Soyica Araria) was used. The P fertilizers were broadcasted and incorporated using a garden rake. The soybean seeds were placed in rows 40 cm apart. Before planting (August 27-28), the seeds were inoculated with rhizobium inoculant (ICAJOL). All treatments received constant applications of 20 kg N/ha as urea and 90 kg K_2O/ha as KCl. Three replicates were made for each treatment. Soybean plants were grown to maturity and harvested on December 17.

Results and Discussion

Weather conditions were average, and the plants in this experiment had a normal growth; rainfall, in particular, was considered sufficient for this crop. Table 2 shows the the soybean grain yields obtained with various P fertilizers. It can be seen that TSP was more effectie than Huila PR

and Pesca PR in increasing soybean yield at any rate. A significant increase in yield with P treatments also indicated that the soil was very P deficient.

To compare the relative agronomic effectiveness (RAE) of PR with respect to TSP, the RAE is defined as

$$\text{RAE, \%} = \frac{Y_{PR} - Y_0}{Y_{TSP} - Y_0} \times 100$$

where Y_{PR} = yield obtained with PR at a given P rate.
Y_{TSP} = yield obtained with TSP at the same P rate.
Y_0 = yield obtained with check (no P added).

The calculated RAE values of various P sources are shown in Table 2. On the limed soil, the RAE values of Huila PR were from 43% to 58% and the values of Pesca PR were from 34% to 52%. The higher RAE values for Huila PR than for Pesca PR were due to the fact that Huila PR is more reactive than Pesca PR. The citrate solubility of Huila PR is 1.5%, whereas the citrate solubility of Pesca PR is only 0.8%.

Although the two indigenous PRs were less effective than the imported TSP in increasing soybean yield, it should be pointed out that the cost of PRs is also less than that of TSP. If the cost of PR is less than one-third that of TSP, it would be more cost-effective for the resource-poor farmers in Colombia to use PRs.

Without liming, soybean yields were very low for check, Huila PR, or TSP (Table 2). Although the ICA variety is Al-tolerant, apparently the variety could not grow well on the Oxisol with Al-saturation at 70%. However, the RAE value of Huila PR with respect to TSP was increased from 57% with liming to 70% without liming. In other words, in the absence of liming the potential use of PR with respect to TSP increases. This tends to support the main hypothesis being tested in this research project that the use of indigenous PR would be more attractive for Al-tolerant soybean cultivars grown on tropical acid soils without liming. The results to be obtained from the residual effect during the second semester should provide more data with which to test the proposed hypothesis.

Experiment No. 2

Materials and Methods

Because the quantities of seeds of two United States Al-tolerant cultivars (Forest and Padre) supplied by Mississippi State University were not enough for the experiment during the first semester, it was decided that ICA would plant the seeds on soil under optimum conditions: limed soil, irrigated plots, and optimum P rate with TSP. The plants would be grown to maturity to multiply the seeds to be used for the experiments in the second semester, 1993.

This experiment was established in a plot at La Libertad Research Center, Colombia. Some of the chemical properties of the soil (Ultisol) are shown in Table 3.

Before planting, the following materials were applied to the soil: 1.0 t/ha of dolomitic lime, 70 kg P_2O_5/ha as TSP, 25 kg N/ha as urea, and 90 kg K_2)/has as KC!. The two U.S. varieties were inoculated with ICAJOL. Row width was 50 cm, and the seeds were placed at a distance of approximately 5 cm. There were enough seeds to plant 1,000 m^2 of each variety. Plantsing date was September 15, 1992.

Results and Discussion

Germination - The seed germination was excellent; none of the seedling died.

Flowering - Flowereing was initiated after 35 to 40 days, and at this stage there was a very distinctive difference in the plant size of the two varieties. The short one was named Line 1, and the tall one was named Line 2. Some of the flowers abscised.

Pod Development - Both varieties produced a large number of pods, but the majority of them remained unfilled. The dry pods showed spots, indicating that fungal growth developed on some of the few grains. The stems and the leaves remained green at maturity, even though the pods were already dry.

Grain Yield - Grain yield of Line 1 was only 7 kg of good-quality seed per 1,000 m2. The Line 2 grain was of poor quality.

Future Plan - Because of the poor yields of these two U.S. varieties, it is impossible to use these varieties for the field trials to be carried out during the second semester, 1993. It has been decided to use two additional local varieties to replace the two U.S. varieities. One of the two local varieties will be Al-tolerant, and the other one will be Al-sensitive. It is expeceted that the Al-tolerant soybean cultivar will respond more to PRs with respect to TSP than will the Al-sensitive soybean cultivar.

Table 1. **Properties of the Soil (Oxisol) Used in Experiment No. 1**

pH	OrganicMatter (%)	Bray II (ppm)	Al	Ca	Mg (meq/100g)	K	Na	Al-Saturation (%)
4.2	4.5	3.5	2.75	0.62	0.26	0.17	0.13	70

Table 2. **Soybean Grain Yield and Relative Agronomic Effectiveness (RAE) Obtained With Various P Fertilizers**

Treatment No.	Lime[a]	P Source	P Rate (kg P/ha)	Yield (kg/ha)	RAE[b] (%)
1	+	Check	0	908	0
2	+	TSP	50	2,525	100
3	+	TSP	100	2,792	100
4	+	TSP	150	3,067	100
5	+	Huila PR	50	1,600	43
6	+	Huila PR	100	2,000	58
7	+	Huila PR	150	2,133	57
8	+	Pesca PR	50	1,450	34
9	+	Pesca PR	100	1,792	47
10	+	Pesca PR	150	2,025	52
11	-	Check	0	167	0
12	-	TSP	150	1,017	100
13	-	Huila PR	150	758	70
				$LSD_{0.05}$ 192	

a. Lime = 1,500 kg/ha.

b. RAE, % = $\frac{Y_{PR}-Y_O}{Y_{TSP}-Y_O} \times 100.$

Table 3. **Properties of the Soil (Oxisol) Used in Experiment No. 2**

pH	OrganicMatter (%)	Bray II (ppm)	Al	Ca	Mg (meq/100g)	K	Na	Al-Saturation (%)
4.6	1.9	15.5	2.00	1.13	0.39	0.11	0.13	53

1993 EXPERIMENTS

Introduction

The objective of this study was to investigate the effect of two phosphate rocks (PRs) indigenous to Colombia on the growth of aluminum-tolerant soybean cultivars grown on acid soils in Colombia's East Plain. During April to August 1993 three field trials were carried out by the researchers of the Instituto Colombiano Agropecuario (ICA), Colombia. This report summarizes the results obtained from these three experiments.

Experiment No. 1

Materials and Methods

After harvesting the soybean crop that was planted on the Oxisol in San Martin County in 1992, the soybean seeds (ICA variety—Soyica Ariari) were planted for the second semester on April 6, 1993, to measure the residual effects of two indigenous PRs (Huila and Pesca) and TSP. Before planting, soil samples were taken for chemical analyses. The seeds were inoculated with Bradyrhizobium inoculant (ICA-J01). Constant fertilizers applied were 20 kg N/ha as urea and 60 kg K_2O/ha as KCl. Soybean plants were grown to maturity and were harvested on July 28.

During the previous experiment (first semester, 1992), rates of P applied were 0, 50, 100, and 150 kg P/ha. In ten treatments the soil was limed with 1,500 kg/ha of dolomitic lime. In the remaining three treatments, which included check, Huila PR, and TSP at only one P rate (150 kg P/ha), the soil was not limed.

Results and Discussion

Liming apparently did not change soil pH regardless of the P treatments. However, liming decreased Al saturation from 73%-78% without liming to 42%-62% with liming (Table 1).

Without liming in 1992, there was no grain yield in plots designed to test the residual effect of PR in 1993. Plants from the check (no P added) died 45 days after planting, and those plants from the treatments with Huila PR and TSP showed severe Al toxicity. Although the ICA variety (Soyica Ariari) is more Al tolerant, apparently the variety was unable to grow well on the Oxisol with Al saturation at 73%-78% (Table 1).

With liming, the soybean plant responded very well to the P treatments. With no P added, the soybean grain yield was very low, only 604 kg/ha (Table 2). With P treatments, the soybean yield increased significantly, ranging from 1,281 kg/ha with Pesca PR at 50 kg P/ha to 2,385 kg/ha with TSP at 150 kg P/ha. Among the P sources, TSP was the most effective P fertilizer in increasing soybean yield followed by Huila PR which was slightly more effective than Pesca.

To compare the relative agronomic effectiveness (RAE) of PR with respect to TSP, the RAE is defined as

$$\text{RAE, \%} = \frac{Y_{PR} - Y_0}{Y_{TSP} - Y_0} \times 100$$

where Y_{PR} = yield obtained with PR at a given P rate.
Y_{TSP} = yield obtained with TSP at the same P rate.
Y_0 = yield obtained with check (no P added).

The calculated RAE values of various P sources are shown in Table 2. The average RAE values across P rates of Huila PR and Pesca PR are 71% and 67%, respectively. It should be noted that the RAE values of Huila PR and Pesca PR of the initial effect (first semester, 1992) were 53% and 44% for Huila PR and Pesca PR, respectively. Thus, the relative effectiveness of PRs with respect to TSP was greater in the residual effect than that of the initial P treatments. Furthermore, the difference between Huila PR and Pesca PR in agronomic effectiveness was also less in the residual effect than in the initial effect, suggesting that chemical reactivity of PR is less important in the residual effect.

Although the two indigenous PRs were less effective than the imported TSP in increasing soybean yield, it should be pointed out that the cost of PRs is also less than that of TSP. With the current cost of Huila PR in Colombia at only approximately one-third of that of TSP on a P_2O_5 basis, it should be more cost-effective for the resource-poor farmers in Colombia to use PRs rather than TSP.

Experiment No. 2.

Materials and Methods

This experiment was conducted on an Inceptisol (Oxic Distropep) at ICA La Libertad site. Some of the soil properties are shown in Table 3.

Sources of P were two PRs (Huila and Pesca) and TSP. Rates of P applied were 0, 50, 100, and 150 kg P/ha. On May 3, 1993, an application of 1.0 t/ha of dolomitic lime was made to all the plots except nine plots where lime was not applied. These nine plots received 0 and 150 kg P/ha as TSP and Huila PR.

Three locally available soybean cultivars were used. These were:

Variety 1: Soyica Ariari
Variety 2: Lita 9
Variety 3: Soyica P-32

Varieties 1 and 2 are considered more Al tolerant and Variety 3 less Al tolerant. The seeds were inoculated with ICA-J01 Bradyrhizobium inoculant. Constant fertilizers applied were: 20 kg N/ha as urea at planting and 90 kg/ha K_2O/ha as KCl one-half applied at planting and one-half at 20 days afterward.

The P fertilizers were broadcast and incorporated with a garden rake on May 21, 1993. The soybean seeds were placed in rows 40 cm apart. After planting, herbicide was applied to control weed formation. Soybean plants were grown to maturity and were harvested during September 13-24, 1993.

Results and Discussion

Data of soybean grain yield obtained with Soyica Ariari variety are shown in Table 4. With a low rate of P (50 kg P/ha) in the limed soil, both Huila PR and Pesca PR were not effective in increasing soybean yield as compared with the check (no P added). On the other hand, TSP significantly increased the yield. The maximum yield obtained with TSP was at 100 kg P/ha. Further increase in P rate to 150 kg P/ha did not increase the yield. For both Huila PR and Pesca PR, similar maximum yields as that with TSP were obtained at the highest P rate (150 kg P/ha). In other words, these two PRs can produce similar maximum yield as that of TSP if the rate of PRs applied increases. The result seems to contradict the belief generally found in literature reports that PR may not be able to reach the same maximum yield as with TSP, regardless of the increase in rate of PR applied.

In the unlimed soil, a decrease in yield, as compared with yields on the limed soil, was observed for the check (no P added) and for the TSP and Huila PR applications. This decrease was apparently due to the high Al saturation (74%) of the soil (Table 3). At 150 kg P/ha, Huila PR and TSP produced the same yield (Table 4). Since the RAE values of Huila PR were the same (102%) whether the soil was limed or not, it was not possible to test the proposed hypothesis that the use of indigenous PR would be more attractive for Al-tolerant soybean cultivars grown on tropical acid soils without liming.

It should be pointed out that both Oxisol and Inceptisol had approximately the same high level of Al saturation (73%-78% for Oxisol in Table 1 and 74% for Inceptisol in Table 3). However, Soyica Ariari cultivar, which is a more Al tolerant variety, grew rather well on the unlimed Inceptisol as compared with the limed soil, whereas the same cultivar grew very poorly on the unlimed Oxisol. It appears that some factors other than Al saturation may also limit the plant's growth on the unlimed Oxisol.

Data of soybean grain yield obtained with Lita 9 variety on the limed Inceptisol are shown in Table 5. Significant P response was observed with all the P sources. TSP was more effective than Huila PR and Pesca PR. The two PRs were approximately equally effective in increasing soybean yield, and they were approximately 52%-70% as effective as TSP.

Data of soybean grain yield obtained with Soyica P-34 variety on the limed Inceptisol are shown in Table 6. At 50 kg P/ha rate, TSP was more effective than Huila PR and Pesca PR. At 100 kg P/ha, Huila PR was 72% as effective as TSP and Pesca PR was as good as TSP. At 150 kg P/ha, both Huila PR and Pesca PR were found to be even more effective than TSP. Since the soil was limed, Al-saturation and Ca nutrient should not be factors for TSP to be less effective than PRs. At the present time, we cannot provide the explanation.

To compare the effect of soybean variety on the relative effectiveness of PR with respect to TSP on the limed Inceptisol, RAE values were calculated by averaging the RAE values across P rates and are shown in Table 7. The effectiveness of variety follows the order of Soyica P-34 > Lita 9 > Soyica Ariari. For a given variety, Pesca PR tended to be slightly more effective than Huila PR, despite the fact that Huila PR is more reactive than Pesca PR. Table 8 shows the average soybean grain yield obtained with or without P sources across all the P rates. For the check, the effectiveness of soybean variety follows Soyica Ariari > Soyica P-34 = Lita 9. For TSP, the order is Soyica Ariari = Lita 9 > Soyica P-34. For Huila PR and Pesca PR the three varieties were almost equally effective in producing soybean yield. Since the Inceptisol was limed,

Al-saturation was most likely not the factor affecting the effectiveness of variety in increasing soybean grain yield. Table 9 shows the effect of soybean variety on the net increase of grain yield obtained with various P sources. It appears that Lita 9 variety was the most effective among three varieties in increasing grain yields obtained with P sources over that of control (no P added). The other varieties (Soyica Ariari and Soyica P-34) were more or less the same in increasing grain yield.

Experiment No. 3.

Materials and Methods

This experiment was conducted on an Oxisol (Umbriorthox) at ICA La Laguna site. Some of the soil properties are shown in Table 10.

Sources of P applied were two PRs (Huila and Pesca). Rates of P used were 0, 50, 100, and 150 kg P/ha. On April 7, 1993, dolomitic lime at a rate of 1.5 t/ha was applied to all the treatments, except 9 plots for treatments with 0 and 150 kg P/ha as TSP and Huila PR.

The same soybean varieties used in Experiment No. 2 were also used in this experiment. On May 5, 1993, the P fertilizers were broadcast and incorporated with a garden rake. The inoculated soybean seeds were placed in rows 40 cm apart. Soybean plants were grown to maturity and were harvested during August 24 to September 3, 1993.

Results and Discussion

Data of soybean grain yield obtained with Soyica Ariari variety are shown in Table 11. Because of very high Al saturation (84% in Table 10), the soybean yields were very low with or without P fertilizers on the unlimed Oxisol. Although the variety is more Al tolerant, the plants still could not grow well due to acidity and Al toxicity. A similar result was also obtained in Experiment No. 1 on the unlimed Oxisol (second semester, 1993).

Upon liming, significant P response was observed with P treatments. TSP was the most effective one among the P sources. It is interesting to compare the yield data of Table 2 with that of Table 11 obtained with the same limed Oxisol. It can be seen that the initial P effect (Table 11) was greater than the residual P effect (Table 2) in producing grain yield. For check alone, the grain yield was even increased twofold in the initial effect as compared to the residual effect.

Data of soybean yield obtained with the other two varieties, Lita 9 and Soyica P-34, are shown in Table 12 and Table 13, respectively. Again, TSP was the most effective P source in increasing soybean yield. Table 14 shows the effect of soybean variety on the relative effectiveness of PR with respect to TSP on unlimed Oxisol. The RAE values were calculated as averages across all P rates. For a given soybean variety, Huila PR was found to be more effective than Pesca PR. This can be explained by the fact that Huila PR is more reactive than Pesca PR. However, the difference between Huila PR and Pesca PR in RAE was found to be smaller in the residual effect than that in the initial effect. With Soyica Ariari variety, the difference was 15% in the initial effect (Table 14) and it was 9% in the residual effect (Table 2) using the average RAE values of Huila PR and Pesca PR. This again supports the previous statement that the chemical reactivity of PR plays a smaller role in the residual effect than in the initial effect of PR.

Table 15 shows the effect of soybean variety on the grain yield obtained with or without P treatments on the limed Oxisol. Similar to the limed Inceptisol where Soyica Ariari variety was found to be the most effective one in producing grain yield (Table 8), the same variety was also the most effective one in producing grain yield on the limed Oxisol (Table 15). The effect of soybean variety on the net increase in grain yield obtained with P treatments on limed Oxisol is shown in Table 16. It appears that Soyica P-34 variety grain yield increased the highest with all three P sources whereas the other two varieties (Lita 9 and Soyica Ariari) were about the same in producing net increase in grain yield on the limed Oxisol. On the limed Inceptisol, however, Lita 9 variety was found to be the most effective in producing net increase in grain yield (Table 9). This indicates that the soybean variety that produces the highest absolute grain yield is not necessarily the one that produces the highest net increase in grain yield. This points needs to be considered when we try to select a suitable soybean variety that might produce the maximum net economic return with the use of P fertilizers.

Summary and Conclusions

During 1993, three field experiments were conducted to study the initial and residual effects of two indigenous PRs (Huila and Pesca) against imported TSP on soybean grain yield on two acid soils (Oxisol and Ultisol) in Colombia. Three local soybean varieties (two more Al tolerant—Soyica Ariari and Lita 9; one less Al tolerant—Soyica P-34) were grown on the two soils with or without liming. The results are summarized as follows.

1. On both soils without liming, the Soyica Ariari variety, which is more Al tolerant, still could not grow well because of very high Al saturation levels (74%-84%) of the unlimed acid soil. Consequently, it was not possible to test the proposed hypothesis that the use of indigenous PR would be more attractive for the Al-tolerant soybean cultivars grown on tropical acid soils without liming. However, it was also observed that factors other than Al saturation may also influence the effect of soybean variety on soybean grain yield obtained with various P sources.

2. TSP was more effective than PRs in increasing soybean grain yields on limed acid soils both for initial and residual effects. However, PRs should be more cost effective for fertilization if the cost of PR is only one-third to one-half of TSP on a per kilogram P_2O_5 basis.

3. The relative effectiveness of PRs with respect to TSP was increased from the initial effect to the residual effect. The average RAE values for two PRs are 48% and 68%, respectively, in the initial and residual effects on the limed Oxisol. Chemical reactivity of PR also was found to be less important in the residual effect than in the initial effect.

4. The effect of soybean variety on the grain yield varied with (1) absolute yield or net increase yield over the control, (2) sources of P fertilizer, (3) rates of P applied, and (4) types of soil. All these need to be considered when we try to optimize the economic benefit of using P fertilizers for soybean production on acid soils.

Table 1. **Soil pH and Al Saturation of Soil Samples Taken Before Planting**

Lime	P Source	P Rate	pH	Al Saturation
			(kg P/ha)	(%)
+	Check	0	4.9	53
+	TSP	50	4.9	59
+	TSP	100	4.8	62
+	TSP	150	4.9	44
+	Huila PR	50	4.9	42
+	Huila PR	100	4.8	57
+	Huila PR	150	4.9	52
+	Pesca PR	50	4.9	53
+	Pesca PR	100	4.8	63
+	Pesca PR	150	4.9	53
-	Check	0	4.8	78
-	TSP	150	4.7	78
-	Huila PR	150	4.9	73

Table 2. **Soybean Grain Yield and Relative Agronomic Effectiveness (RAE) of the Residual Effect of Various P Fertilizers on Limed Oxisol, Soybean Variety: Soyica Ariari, Second Semester, 1993**

P Source	P Rate	Yield	RAE
	(kg P/ha)	(kg/ha)	(%)
Check	0	604	0
TSP	50	1,724	100
TSP	100	2,130	100
TSP	150	2,385	100
Huila PR	50	1,354	67
Huila PR	100	1,667	70
Huila PR	150	1,937	75
Pesca PR	50	1,281	60
Pesca PR	100	1,708	72
Pesca PR	150	1,817	68
$LSD_{0.05}$ 311			

Table 3. **Properties of the Soil (Inceptisol) Used in Experiment No. 2**

pH	Organic Matter	Bray II	Exchangeable					Al-Saturation
			Al	Ca	Mg	K	Na	
	(%)	(ppm)	(me/100 g)					(%)
4.9	2.5	5.5	2.7	0.53	0.20	0.14	0.08	74

Table 4. **Soybean Grain Yield and Relative Agronomic Effectiveness (RAE) of Various P Fertilizers in Inceptisol, Soybean Variety: Soyica Ariari, First Semester, 1993**

Lime	P Source	P Rate	Yield	RAE
		(kg P/ha)	(kg/ha)	(%)
+	Check	0	1,650	0
+	TSP	50	2,188	100
+	TSP	100	3,198	100
+	TSP	150	2,937	100
+	Huila PR	50	1,693	8
+	Huila PR	100	2,094	29
+	Huila PR	150	2,958	102
+	Pesca PR	50	1,675	5
+	Pesca PR	100	2,510	54
+	Pesca PR	150	2,875	95
-	Check	0	1,048	0
-	TSP	150	1,896	100
-	Huila PR	150	1,917	102
$LSD_{0.05}$ 415				

Table 5. **Soybean Grain Yield and Relative Agronomic Effectiveness (RAE) of Various P Fertilizers on Limed Inceptisol, Soybean Variety: Lita 9, First Semester, 1993**

P Source	P Rate	Yield	RAE
	(kg P/ha)	(kg/ha)	(%)
Check	0	1,125	0
TSP	50	2,437	100
TSP	100	2760	100
TSP	150	3,000	100
Huila PR	50	1,812	52
Huila PR	100	2,041	56
Huila PR	150	2,438	70
Pesca PR	50	1,916	60
Pesca PR	100	2,219	67
Pesca PR	150	2,373	67
$LSD_{0.05}$ 415			

Table 6. **Soybean Grain Yield and Relative Agronomic Effectiveness (RAE) of Various P Fertilizers on Limed Inceptisol, Soybean Variety: Soyica P-34, First Semester, 1993**

P Source	P Rate	Yield	RAE
	(kg P/ha)	(kg/ha)	(%)
Check	0	1,291	0
TSP	50	1,970	100
TSP	100	2,333	100
TSP	150	2,373	100
Huila PR	50	1,385	14
Huila PR	100	2,041	72
Huila PR	150	2,823	142
Pesca PR	50	1,689	59
Pesca PR	100	2,323	99
Pesca PR	150	2,854	144
$LSD_{0.05}$ 415			

Table 7. **Relative Agronomic Effectiveness (RAE) in Increasing Soybean Grain Yield Obtained With Various P Fertilizers and Soybean Varieties on Limed Inceptisol, First Semester, 1993**

Variety	P Source	RAE
		(%)
Soyica Ariari	TSP	100
Soyica Ariari	Huila PR	46
Soyica Ariari	Pesca PR	51
Lita 9	TSP	100
Lita 9	Huila PR	59
Lita 9	Pesca PR	65
Soyica P-34	TSP	100
Soyica P-34	Huila PR	76
Soyica P-34	Pesca PR	101

Table 8. **Soybean Grain Yield Obtained With Various P Fertilizers and Soybean Varieties on Limed Inceptisol, First Semester, 1993**

P Source	Variety	Yield
		(kg/ha)
Check	Soyica Ariari	1,650
	Lita 9	1,125
	Soyica P-34	1,291
TSP	Soyica Ariari	2,774
	Lita 9	2,732
	Soyica P-34	2,225
Huila PR	Soyica Ariari	2,248
	Lita 9	2,097
	Soyica P-34	2,083
Pesca PR	Soyica Ariari	2,353
	Lita 9	2,169
	Soyica P-34	2,288

Table 9. **Increase in Soybean Grain Yield Obtained With Various P Fertilizers and Soybean Varieties on Limed Inceptisol, First Semester, 1993**

P Source	Variety	Increase in Yield
		(kg/ha)
TSP	Soyica Ariari	1,124
	Lita 9	1,607
	Soyica P-34	934
Huila PR	Soyica Ariari	598
	Lita 9	972
	Soyica P-34	792
Pesca PR	Soyica Ariari	703
	Lita 9	1,044
	Soyica P-34	997

Table 10. **Properties of the Soil (Oxisol) Used in Experiment No. 3**

pH	Organic Matter	Bray II	Exchangeable					Al Saturation
			Al	Ca	Mg	K	Na	
	(%)	(ppm)	(me/100 g)					(%)
4.5	3.9	4.0	3.4	0.26	0.14	0.13	0.13	84

Table 11. **Soybean Grain Yield and Relative Agronomic Effectiveness (RAE) of Various P Fertilizers in Oxisol, Soybean Variety: Soyica Ariari, First Semester, 1993**

Lime	P Source	P Rate	Yield	RAE
		(kg P/ha)	(kg/ha)	(%)
+	Check	0	1,236	0
+	TSP	50	2,346	100
+	TSP	100	2,589	100
+	TSP	150	2,874	100
+	Huila PR	50	1,374	12
+	Huila PR	100	2,555	97
+	Huila PR	150	2,513	78
+	Pesca PR	50	1,457	20
+	Pesca PR	100	1,873	47
+	Pesca PR	150	2,444	74
-	Check	0	84	0
-	TSP	150	593	100
-	Huila PR	150	373	57
$LSD_{0.05}$ 308				

Table 12. **Soybean Grain Yield and Relative Agronomic Effectiveness (RAE) of Various P Fertilizers on Limed Oxisol, Soybean Variety: Lita 9, First Semester, 1993**

P Source	P Rate	Yield	RAE
	(kg P/ha)	(kg/ha)	(%)
Check	0	569	0
TSP	50	1,638	100
TSP	100	1,860	100
TSP	150	2,666	100
Huila PR	50	1,055	45
Huila PR	100	1,402	65
Huila PR	150	1,846	61
Pesca PR	50	916	32
Pesca PR	100	1,208	49
Pesca PR	150	1,083	25
$LSD_{0.05}$ 308			

Table 13. **Soybean Grain Yield and Relative Agronomic Effectiveness (RAE) of Various P Fertilizers on Limed Oxisol, Soybean Variety: Soyica P-34, First Semester, 1993**

P Source	P Rate	Yield	RAE
	(kg P/ha)	(kg/ha)	(%)
Check	0	569	0
TSP	50	1,680	100
TSP	100	2,471	100
TSP	150	2,471	100
Huila PR	50	1,583	91
Huila PR	100	1,694	59
Huila PR	150	2,278	90
Pesca PR	50	1,332	69
Pesca PR	100	1,540	51
Pesca PR	150	1,749	62
$LSD_{0.05}$ 308			

Table 14. **Relative Agronomic Effectiveness (RAE) in Increasing Soybean Grain Yield Obtained With Various P Fertilizers and Soybean Varieties on Limed Oxisol, First Semester, 1993**

Variety	P Source	RAE
		(%)
Soyica Ariari	TSP	100
Soyica Ariari	Huila PR	62
Soyica Ariari	Pesca PR	47
Lita 9	TSP	100
Lita 9	Huila PR	57
Lita 9	Pesca PR	35
Soyica P-34	TSP	100
Soyica P-34	Huila PR	80
Soyica P-34	Pesca PR	61

Table 15. **Soybean Grain Yield Obtained With Various P Fertilizers and Soybean Varieties on Limed Oxisol, First Semester, 1993**

P Source	Variety	Yield
		(kg/ha)
Check	Soyica Ariari	1,236
	Lita 9	569
	Soyica P-34	569
TSP	Soyica Ariari	2,603
	Lita 9	2,054
	Soyica P-34	2,207
Huila PR	Soyica Ariari	2,147
	Lita 9	1,434
	Soyica P-34	1,852
Pesca PR	Soyica Ariari	1,924
	Lita 9	1,069
	Soyica P-34	1,540

Table 16. **Increase in Soybean Grain Yield Obtained With Various P Fertilizers and Soybean Varieties on Limed Inceptisol, First Semester, 1993**

P Source	Variety	Increase in Yield
		(kg/ha)
TSP	Soyica Ariari	1,367
	Lita 9	1,485
	Soyica P-34	1,638
Huila PR	Soyica Ariari	911
	Lita 9	865
	Soyica P-34	1,283
Pesca PR	Soyica Ariari	688
	Lita 9	500
	Soyica P-34	971

505050