THE USE OF NUCLEAR AND RELATED TECHNIQUES FOR EVALUATING THE AGRONOMIC EFFECTIVENESS OF PHOSPHATE FERTILIZERS, IN PARTICULAR ROCK PHOSPHATE, IN VENEZUELA: I. PHOSPHORUS UPTAKE, UTILIZATION AND AGRONOMIC EFFECTIVENESS

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Abstract. Field experiments were conducted to evaluate the efficiency of natural and modified rock phosphate using conventional and isotopic techniques in an acid soil from El Pao, Cojedes state, Venezuela, using maize and sorghum with the application of different phosphate fertilizers to measure dry matter production, P accumulated in plant, efficiency parameters using isotopic techniques or yield. Finally, commercial plots were established with the application of soluble P fertilizers and rock phosphate products to validate the results obtained in the field experiments. The results showed highly significant differences between partially acidulated rock phosphate, natural rock phosphate, and the check plot in dry matter production, and P accumulation in plant and grain yield. When the efficiency parameters were evaluated in microplots with ^{32}P-TSP at 60 days of plant growth, it confirmed results obtained in semi commercial plots where the P in the plant derived from the fertilizer was 46% with partially acidulated rock phosphate (PAR) and 14% with natural Riecito rock phosphate (RR). Utilization coefficients of P by the plants were 34.2 and 8.8% for both treatments, respectively. The Substitution relation parameter showed that just 0.8 kg of P of PAR or 3.1 kg P of RR was required to produce the same yield as 1 kg P of TSP. These results were further validated in 5 ha commercial plots using corn and sorghum.

1. INTRODUCTION

A more rational use of P fertilizers has been proposed in order to counteract the dependency of imported fertilizers, which are very important to maintain and increase agricultural productivity [1]. To achieve more rational use of P fertilizers, the knowledge of P dynamics and availability in tropical soils as well as the evaluation of soil and crop management factors to increase the efficiency of the fertilizers applied need to be known [2].

Previous research conducted in laboratory and greenhouse settings [3] using nuclear and related techniques to evaluate the agronomic effectiveness of phosphate fertilizers showed a high variability in P fixing capacity of the soils ($r1/Ro$= 0.02 to 0.76) with the same level of available P. This variability was also associated with a range of 10 to 88% of P removed by the Bray solution being available P. Incubation studies showed that the effectiveness of the P sources were related to their reactivity and the soil P fixing properties. Increasing the fixing capacity caused a significant reduction in the E value independent of the P source used. A high positive and significant correlation between P extracted by Bray and the E value ($r = 0.95$) showed the affinity of the Bray extractant for some forms of available P in soils where rock phosphate was applied. In the greenhouse experiment, crop response was related to the P fixing properties of the soil, the initial availability and solubility of the P source used. The P derived from the fertilizer (%Pdf) and the Utilization Coefficient (UC) decreased significantly withthe increase of P fixing capacity indicating a lower availability for the crop.

The objective of this study was to quantitatively evaluate P uptake and utilization from P fertilizers, in particular rock phosphates, and to enhance their agronomic effectiveness in order to obtain agronomic and economic recommendations on the efficient use of P fertilizers under the soils and climatic conditions of Venezuela. The effect of the P fixing capacity of the soil on P availability parameters in the soil and the efficient use of P fertilizers of different solubility was evaluated. Plant parameters were obtained using conventional and isotopic techniques, in order to calculate the amount of P isotopically exchangeable in the soil, the percentage of P in the plant derived from the fertilizer, the utilization coefficient of P by the plant and the substitution relation in kg of P for each source required to produce dry matter and grain yield similar to a highly soluble source such as triple superphosphate.

2. MATERIALS AND METHODS

The following P sources were evaluated: Riecito Rock Phosphate (RR, 12.7% P), 40% Acidulated Riecito Rock Phosphate (RR40, 10.7% P), 60% Acidulated Riecito Rock Phosphate (RR60, 14% P) and Triple Superphosphate (TSP, 19.7% P). The solubility in ammonium citrate pH 7 was 1.6, 6.5, 8.4, and 13.3% of total P for RR, RR40, RR60, and TSP, respectively.

The percentage of P derived from the fertilizer (%Pdf) was determined experimentally by applying the procedure described by Morel and Fardeau [4], Zapata and Axmann [5], and Salas et al. [2] for evaluating fertilizers that cannot be labeled directly with the ^{32}P radioisotope, where $^{32}PO_4$ is added to soil to label soil-available P. The Utilization Coefficient (UC) was also determined for each of the treatments comparing the P in plant derived from the fertilizer (Pf) with the total amount of P applied using the equation suggested by the International Atomic Energy Agency [6].

The field experiment was conducted in El Pao soil to evaluate the efficiency of the different P fertilizers using conventional and isotopic techniques. The same P fertilizers described earlier were used in addition to a check plot without P. The design was a complete randomized block with 5 replications in a semi commercial area of 2800 m^2 and each experimental plot had an area of 80 m^2. The corn hybrid planted was PB8 with a plant density of 62500 plants/ha. A basic fertilization was applied at 40 kg N/ha and 66 kg K/ha at planting and a side dressing with N at 21 days after planting at 87 kg N/ha. The P treatments were applied at a rate of 44 kg P/ha broadcast for the natural Riecito rock phosphate and banded at 5 cm depth for the 40% and 60% acidulated Riecito rock phosphates. The evaluation of biomass and P accumulation in plant were measured at 20, 31, 45, 60 and 120 days after planting. The method of measuring these variables were similar to the one described for the greenhouse experiment [2]. The variables measured were dry matter (kg/ha), grain yield (kg/ha), and total P accumulation in plant in each sampling (kg P/ha). Efficiency of P fertilizer use was determined by conventional methods, which included: 1. Utilization Coefficient assuming that the quantity of P in plant derived from the fertilizer (Pdf) was the difference between the P accumulated in each treatment and the P in the check plot, 2. Increment of grain yield per unit of P applied, 3. Amount of grain producedper unit of P absorbed by the plant.

The isotopic parameters were calculated using Triple Superphosphate (^{32}P-TSP, 18.5 MBq/g P) in a microplot in each treatment placed in a band at 5 cm depth and at a rate of 9 kg P/ha at planting. The size of the microplot was 6.4 m^2 that was situated in the middle of the 80 m^2 experimental plots. The isotopic parameters (P in plant derived from the fertilizer, Pdf; P utilization by the plant, UC) were measured at 60 days after planting in the microplots in the same way as described for the field experiment. These parameters are measured indirectly because the rock phosphates cannot be tagged with ^{32}P therefore, the method determines the effectiveness of these P sources based on the P uptake difference derived from a traced P fertilizer used as reference (^{32}P-Triple Superphosphate). The procedure has been documented elsewhere [5, 6]. It is based, first in the application of ^{32}P fertilizer to all treatments (microplots) to measure the isotopic parameters and second, to calculate the uptake and efficiency parameters of the rock phosphates following equations described by the authors mentioned before [5, 6].

To validate the results obtained in the experimental field plots, a 5 ha demonstration was conducted in Valle La Pascua and Tigre soils with corn and sorghum where grain yield was measured. Corn was planted in both soils and in the Valle La Pascua soil simple sources of N-P-K were used to apply 120 kg N/ha (Urea), 26 kg P/ha and 50 kg K/ha (potassium chloride) with the difference that the P source was either natural Riecito rock phosphate (RR), 40% acidulated Riecito rock phosphate (RR40), or triple superphosphate (TSP). In the Tigre soil an N-P-K formula (12-24-12 or 14-14-14 where the source of P is triple superphosphate) was compared to the same amount of nutrient applied in simple sources using 40% acidulated Riecito rock phosphate as the P source. The check plot did not receive N, P or K fertilizers. Because of the size of the commercial plots, just one plot per crop-soil was established in each location.

3. RESULTS

The soil properties have been described previously [2,3,7,8]. The dry matter production and P absorption by the corn plants in the semicommercial field experiment as a function of the growing stages of the crop and the sources of P applied are shown in Fig. 1 and 2. Figure 1 shows the increase in dry matter production which was statistically different at 31, 45, 60 and 120 days between the acidulated rock phosphates treatments and the values obtained with the natural Riecito rock phosphate and the check plot. In the case of plant P accumulation (Fig. 2), there was significant differences between the rock phosphate treatments and the check plot. No significant differences were found between the acidulated rock phosphate treatments, thus acidulation at 40 % yielded as much dry matter and accumulated P in the plant as the acidulation at 60 %. This information is very important fromthe industrial point of view, for the commercial production of these P sources.

Table I shows the treatment effects using efficiency parameters obtained by conventional and isotopic techniques in the microplots (^{32}P) at 60 days after planting. Dry matter production and P accumulation confirmed the results explained in Fig. 1 and 2 from the experimental plots. From the 44 kg P/ha applied in each treatment, the Pdf represented 3.9, 15.0, and 12.4 kg P/ha with statistically differences between the acidulated treatments and the natural Riecito rock phosphate. These values represented 14.0, 46.5, and 35.1 as % Pdff and 74.8, 46.5, and 56.4 as % P derived from the soil (%Pds) for RR, RR40, and RR60, respectively. Similarly, the Utilization Coefficient of P changed significantly between the acidulated tretaments and the natural rock phosphate. The use efficiency of P obtained from the field experiment increased with the increase of the solubility of the P sources used. The comparison between the conventional methods with the isotopic techniques to determine the use efficiency of the P applied (Table II) showed an overestimation of the utilization values obtained by the conventional (P uptake difference) method because any increase in P uptake in method is considered derived from the P fertilizer applied not taking in consideration the soil P supply. The values of dry matter production, P accumulation by the corn plants, and efficiency parameters were arranged similar to the grain yield shown in Fig. 3. Even though the yield of the check plot is considered good for El Pao location (4,950 kg/ha), they increased to 5,994 with the natural Riecito rock phosphate, to 6,895 with RR40and to 7,680 kg/ha with RR60 (Table II).

Figures 4, 5, and 6 show the results obtained in the field plots in Valle La Pascua and Tigre soils with corn and sorghum. The results were similar in both locations with very low or no yields (798 and 0) for the check plot (no N-P-K applied). A yield of just 2063 kg/ha for the natural Riecito rock phosphate indicated the low availability of this source for annual crops as was shown in laboratory, greenhouse, and experimental field plots experiments. Corn grain yield increased from 2686 to 3805 kg/ha using TSP as a highly soluble P source. The highest yield (3317 to 3849 kg/ha) was obtained with RR40. The mean values for each Figure were statistically different. These results confirmed the general order of P efficiency for the P sources used. Figure 6 shows a similar experience with sorghum in El Tigre soil under the same methodology explained in Fig. 5. The results were similar to corn, showing the lower yield in the check plot (1965 kg/ha), the yield increase to 3153 kg/ha with the formula where the P source was TSP and the best yield was obtained with RR40 (3546 kg/ha). The mean values were statistically different.

An agronomic and economic efficiency analysis was done to show the advantages of the Riecito partially acidulated rock phosphate (RR40) compared to a high soluble P source (Table III) using the data of sorghum yield in El Tigre (Fig. 6). The increase in agronomic and economic efficiency with RR40 showed that the partially acidulated rock phosphate had agronomic and economic advantages compared to a highly soluble P source (triple superphosphate).

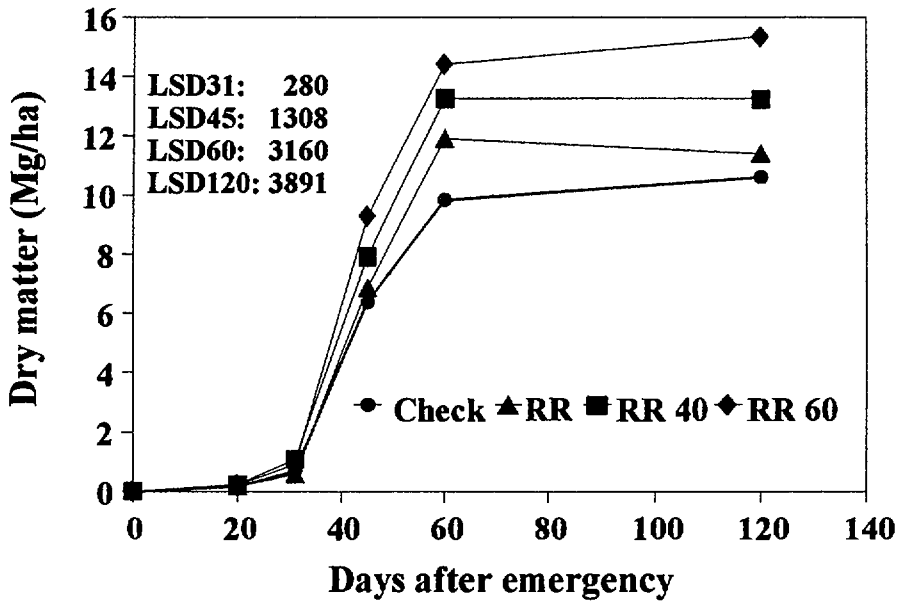

Fig. 1. Effect of the treatments evaluated on total P accumulation at different growth stages of corn.

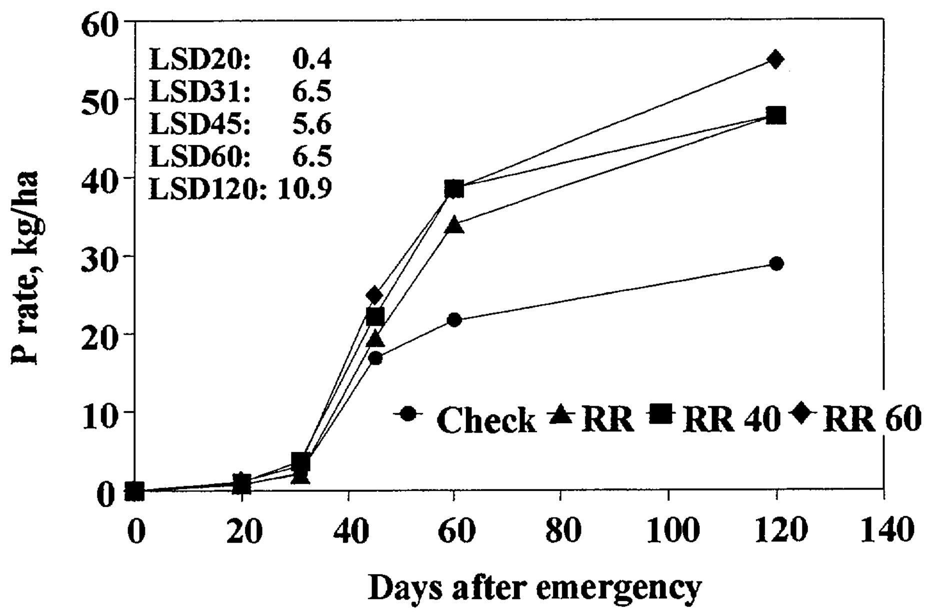

Fig. 2. Effect of treatments evaluated on total P accumulation at different growth stages of corn.

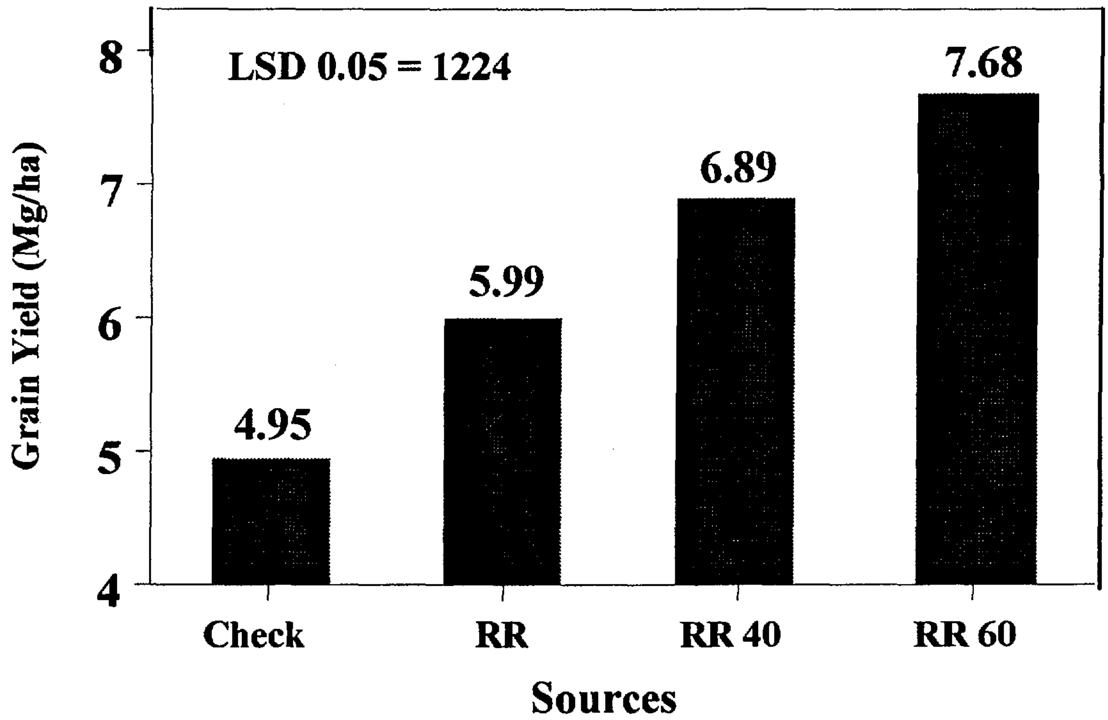

Fig. 3. Effect of treatments on grain yiel of corn (120 days after emergence) from experimental field plots.

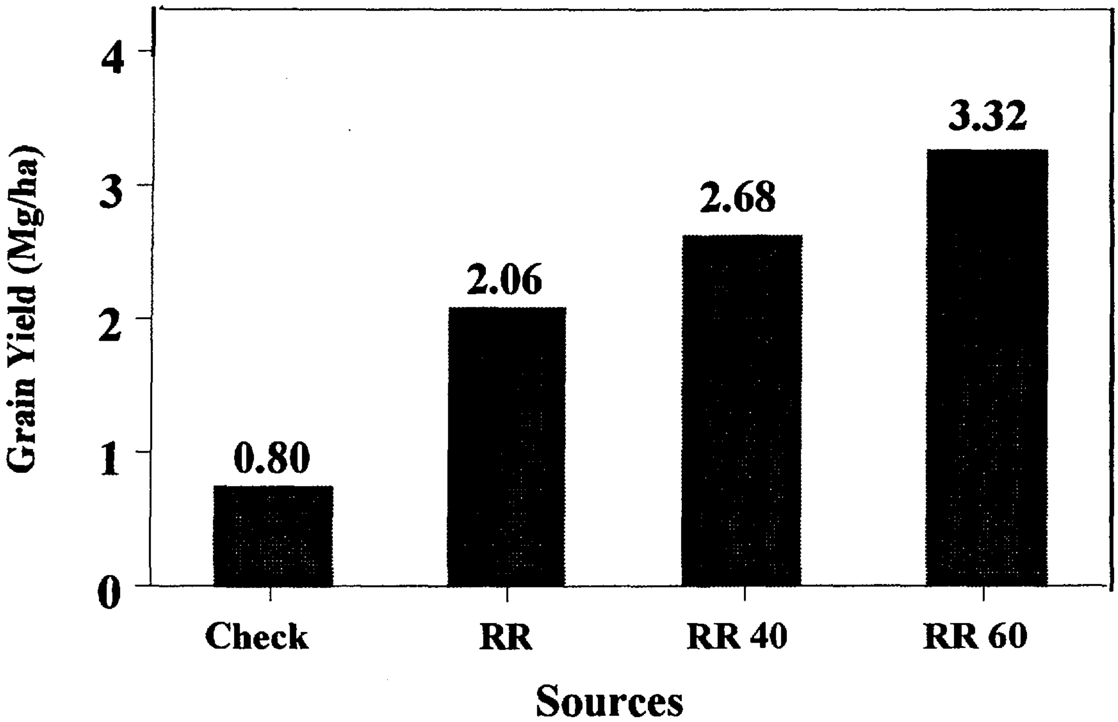

Fig. 4. Effect of P sources on corn yield in Valle La Pascua soil in the commercial experiment in 1997.

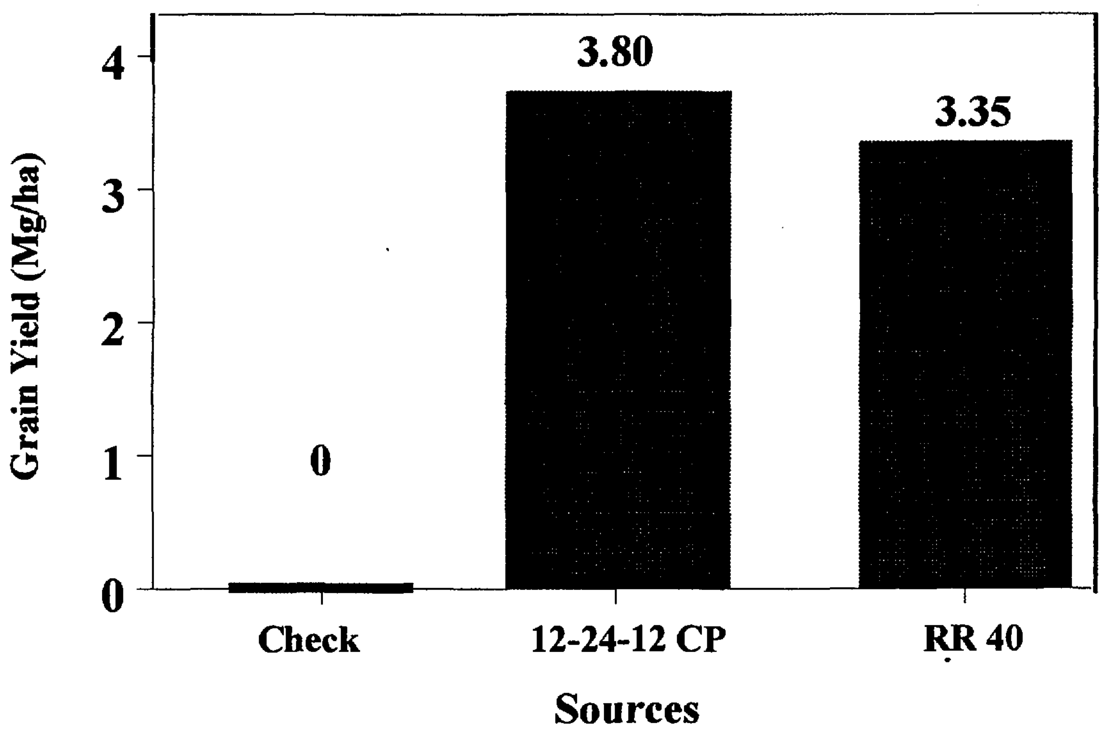

Fig. 5. Effect of P sources on corn yield in El Tigre soil in the commercial experiment in 1997.

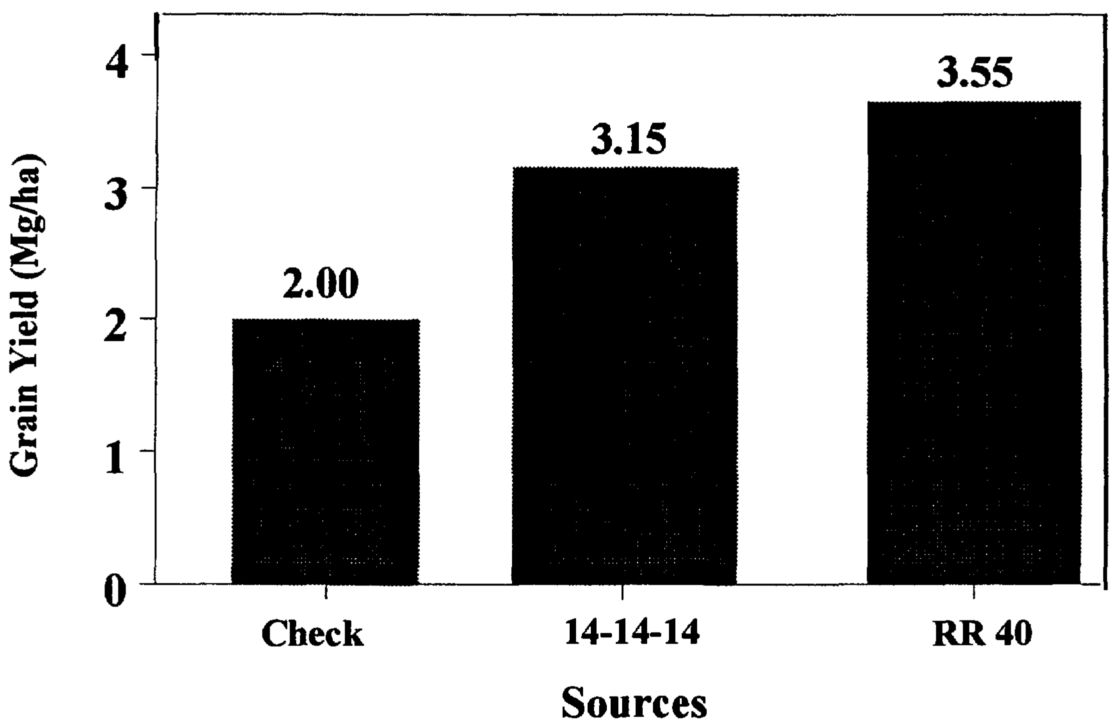

Fig. 6. Effect of P sources on sorghum yield in El Tigre soil in the commercial experiment in 1997.

TABLE I. EFFECT OF TREATMENTS ON EFFICIENCY PARAMETERS OBTAINED BY CONVENTIONAL AND ISOTOPIC TECHNIQUES AT 60 DAYS IN THE MICROPLOT WITH ^{32}P-TSP

Treatments	Dry matter kg/ha	Total P Accum. kg P/ha	AE [1] cpm/mgP	Pdf [2] kgP/ha	Pdf [3] %	Pds [4] %	UC [5] %
Testigo	9792 c	20.6 c	4237 a	---	---	---	---
RR	11230 b	28.0 b	3634 b	3.9 b	14.0 c	74.8 a	8.8 b
RR 40	11260 b	32.3 a	2741 c	15.0 a	46.5 a	46.5 b	34.2 a
RR 60	13980 a	35.1 a	2260 c	12.4 a	35.1 b	56.4 b	28.2 a
LSD (0.05)	8	4.2	395	4.7	11.3	10.3	10.3

[1] Specific Activity in the plant.
[2] P in the plant derived from the fertilizer.
[3] % P in the plant derived from the fertilizer.
[4] % P in the plant derived from the soil.
[5] % of P utilization by the plant.

TABLE II. COMPARISON BETWEEN USE EFFICIENCY PARAMETERS OBTAINED BY CONVENTIONAL AND ISOTOPIC TECHNIQUES IN THE FIELD WITH CORN IN EL PAO

Treatments	Grain yield kg /ha	Total P Accumulated kg P/ha	UC_{iso} [1] %	UC_{conv} [2] %
Check	4950 c	28.8 b	---	---
RR	5994 ab	47.7 a	8.8 b	43.0 b
RR 40	6895 ab	47.9 a	34.2 a	43.4 b
RR 60	7680 a	54.8 a	28.2 a	59.0 a
LSD (0.05)	1224	10.0		

[1] UC_{iso}: % of P utilization of P applied from fertilizer at 60 days, with isotopic techniques.
[2] UC_{conv}: % of P utilization of P applied from fertilizer at 60 days, with conventional techniques obtained by difference in the P absorption, according to the following equation:
$\%UC_{conv} = 100 * (P_{trat} - P_{check})/P_{applied}$, $P_{applied} = 44$kgP/ha

TABLE III. AGRONOMIC AND ECONOMIC EFFICIENCY OF P FERTILIZERS FOR SORGHUM IN EL TIGRE SOIL IN 1997 IN THE COMMERCIAL EXPERIMENT[1]

Treatments [2]	Grain Yield, kg/ha	Agronomic [3] Efficiency, kg Grain / kg P Applied	Economic [4] Efficiency, \$ Profit / \$ Invested in P fertilizers
CHECK	1996	-	-
TSP	3153	71.66	18.28
RR40	3546	80.59	26.77

[1] P Applied: 44 kg P/ha; Corn Price: 0.25 \$/kg grain; Prices of P Sources: 0.73 \$/kg P (RR40); 0.98 \$/kg P (TSP)
[2] CHECK: No P Applied; RR40: Riecito Rock Phosphate Acidualted at 40 %; TSP: Triple Superphosphate.
[3] Agronomic Efficiency: Grain yield (kg/ha)/P applied (kg/ha).
[4] Economic Efficiency: \$ received for grain yield/\$ invested in P fertilizer.

4. CONCLUSIONS

1. An acidulation higher than 40% of Riecito rock phosphate did not increase significantly the availability and efficiency of P from this fertilizer.
2. The isotopic technique allowed the determination of P absorbed by the plant from the fertilizers, thus obtaining the real use efficiency of the evaluated fertilizers.
3. The increase in agronomic and economic efficiency with RR40 showed that the partially acidulated rock phosphate had agronomic and economic advantages compared to a water-soluble P source like triple superphosphate.
4. The series of laboratory, greenhouse, and field research work conducted during 4 years together with the results of experiments conducted in Venezuela with natural and modified rock phosphate during the last 10 years, have produced a great economic and social impact in the agriculture of the country, up to a point that Riecito rock phosphate is commercialized under the name of "Superfosforita" for use in acid soils and permanent crops. Since October 1998, an industrial plant will be operating to produce 150,000 t of 40 % partially acidulated rock phosphate (Fosfopoder) to cover the local P demand for annual crops in acid soils and for exportation. This approach will allow for the rationalization of phosphate fertilizer use in Venezuela and give local farmers a national product of low cost and of high agronomic and economic efficiency.

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