MANAGEMENT OF PHOSPHORUS IN THE ANDEAN COUNTRIES OF TROPICAL LATIN AMERICA

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ABSTRACT

One of the major problems in crop production, in the Andepts, Oxisols and Ultisols of tropical Latin America, is the extremely low levels of available phosphorus. In addition, these soils generally have a high phosphorus fixation capacity so substantial amounts of fertilizer phosphorus must be added to satisfy both the plant and the soil requirements. Because of these constraints, along with the relatively high unit cost of phosphorus fertilizers, alternative methods of managing phosphorus for crops must be considered.

This paper considers several economical methods of improving crop production while still satisfying the phosphorus requirements of the plants. These include: 1) Determining rates and placement of phosphorus fertilizers to increase its efficiency, both initially and residually, and 2) Use of cheaper, less soluble forms of phosphorus such as phosphate rock, partially acidulated phosphate rock, and granulated mixtures of phosphate rock with more soluble forms of phosphorus such as single- and triple superphosphate.

Members of the International Fertilizer Development Centre, Phosphorus Project, stationed at CIAT. Soil Fertility and Soil Chemistry Specialists, respectively.

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The acid soils of tropical Latin America (pH < 5.5) present problems of management that, in general, have inhibited the development of an economically successful agriculture in the areas where they occur. These problems are primarily aluminum and manganese toxicity, and low availability of nutrients such as phosphorus, nitrogen, potassium, sulphur, boron, calcium, and magnesium (fig. 1). In addition to the extremely low levels of available phosphorus (table 1) these soils generally contain relatively high amounts of reactive iron and aluminum that combine with available phosphorus, forming compounds in which the phosphorus is either unavailable or only slightly available to plants. This problem of phosphorus fixation is undoubtedly one of the most important in the acid soils of Latin America (fig. 2) and is, in part at least, responsible for the lack of agricultural development of large zones of arable lands that are not being effectively utilized at the present time.

According to Sânchez and Uehara (14), acid soils that fix large amounts of phosphorus are generally medium to fine textured, and high in oxides and hydroxides of iron and aluminum. There are several great groups of soils that present a very high phosphorus fixing capacity. These are primarily the: orders, Oxisols and Ultisols; sub-order, Andepts; and some rhodic or oxic Inceptisols and Alfisols.

Although it is not possible to identify in detail the areas where these high phosphorus fixing soils are predominant, figure 3 and table 2 give a general idea of the magnitude and location of these soils in Latin America (13,14).

Members of the International Fertilizer Development Centre, IFDC, Phosphorus Project, stationed at CIAT. Soil Chemistry and Soil Fertility Specialists, respectively.

Oxisols and Ultisols occupy by far the largest areas and represent about 65% of tropical South America. Although the Andepts do not occupy large areas in the tropics (2.3%) as compared to the Oxisols and Ultisols, they are of great importance because they are located in the main areas of production of crops such as wheat, barley, corn and potatoes. It is also of interest to note that in the "Andept" areas a high percentage of the population of the Andean countries is settled.

Crop Responses to Phosphorus

Crop responses to phosphorus in the Andean countries have been reported mainly from the intermediate to high altitude regions and also in the lowlands dominated by Oxisols and Ultisols. Research conducted in several of the countries in tropical Latin America verifies that phosphorus is one of the most limiting elements for the development of plants growing in Andepts, Oxisols and Ultisols (13). In order to increase the concentration of available phosphorus in these soils, high amounts of phosphate fertilizers must be added (fig. 2).

In Colombia, for example, it is necessary to add substantial amounts of phosphatic fertilizers in order to obtain economically sound yields of crops such as wheat, corn, potatoes and vegetables on Andosols, which are predominant in the Andean mountain ranges (6). For most row crops the optimal phosphorus recommendation is about 100 kg P_2O_5/ha, and for potatoes and other vegetable crops the recommended rate is about 300 kg P_2O_5/ha.

In the Eastern Plains of Colombia, where most of the soils are Oxisols or oxic Inceptisols, it is also necessary to add considerable amounts of phosphorus (50-100 kg P_2O_5/ha) in order to get good yields of cotton, cowpeas, rice, and corn (1). Similar rates are needed in the establishment of improved pastures in this area (15).

In some other regions of Colombia where Alfisols, Entisols, and Inceptisols predominate, it is also common to find phosphorus responses to rice, tomato, cacao, and cassava of 40, 50 75, and 90 kg P_2O_5/ha, respectively (7).

In the "Sierra" of Ecuador (Andean region) potatoes, corn, and wheat responded markedly to phosphorus applications, and the reported economic optimums were in the neighborhood of 240, 180 and 150 kg P_2O_5/ha, respectively (8).

In Perú, Valverde (16) indicates that 70% of the soils of the coastal regions are low to medium in available phosphorus, and 80 to 90% of the soils of the "Sierra" regions are low in this nutrient. Experiments conducted in the Andean zone of Perú have shown that the use of phosphorus increases yields of potatoes, from 55 to 220%, and those of wheat from 27 to more than 1000% (5). In the Amazon Jungle of Perú where the Ultisols are predominant, research by North Carolina State University (10) indicates that the most promising combination for the establishment of _Panicum maximum_ is 2 ton of lime/ha and 25-50 kg P_2O_5/ha/yr. The highest economic yield of corn was realized with about 50 kg P_2O_5/ha.

In the Cerrado of Brazil N.C.S.U. also conducted phosphorus management studies with corn. On these Oxisols the results of their long-term experiment showed that 160 kg P_2O_5/ha was the most promising treatment for the first crop of corn. After four continuous crops, the best economic rate of return was obtained with 320 kg P_2O_5/ha broadcast initially and 80 kg P_2O_5/ha banded for each of the following crops (10).

In Venezuela, on the Ultisols of the "Sabanas", the highest yields for peanuts and beans were obtained with one ton of lime and 80 kg P_2O_5/ha (12).

In Bolivia, research indicates that wheat yields can be increased from 0.9 to 2.3 ton/ha using 60 kg P_2O_5/ha (11). Similarly, potatoes yields were increased by 250% using 70 kg P_2O_5/ha (11). Cotton, one of the most important crops in the Santa Cruz area, requires approximately 75 kg P_2O_5/ha to produce economically acceptable yields (11).

Also in Bolivia, a general survey by the International Soil Testing and Soil Fertility Project of N.C.S.U. (11) indicates that 50% of the soils in the Altiplano region are low in phosphorus, and the other 50% are medium. In the Montaña and Santa Cruz areas the available phosphorus varies among different regions but generally 60 to 80% of them are low. These general figures show the magnitude of the phosphorus problem in Bolivia and the similarity to the situation in other countries, with regard to phosphorus.

It can be seen from these examples that the success of agricultural production in the Latin American tropics is highly dependent on fertilizer phosphorus. In addition to the afore mentioned soil constraints the "on-farm" unit cost of phosphorus is extremely high due to the high acid and transportation costs.

Management of Phosphorus in Tropical Latin America

In order to determine a sound, economic phosphorus management strategy for crops grown on the acid, infertile soils of tropical Latin America, several factors must be taken into consideration:

1.- determining rates and placement of phosphorus fertilizer to increase its efficiency, both initially and residually;
2.- use of cheaper, less soluble forms of phosphorus such as phosphate rock (PR), partially acidulated PR, and granulated mixtures of PR with more soluble forms of phosphorus.

Other factors are also important, but they will not be discussed in this paper. These would include:

1.- the use of soil amendments to enhance the availability of soil applied P; and
2.- the selection of plant species that will tolerate relatively low levels

of available soil phosphorus.

Current Research Being Conducted

In order to study the strategies presented above, to date the IFDC/CIAT Phosphorus Project has initiated field experiments in three regions of Colombia and one in the Amazon Jungle of Perú. In addition many screening trials with various phosphorus carriers are also being conducted in greenhouse trials. Some of the results obtained to date are presented.

Rates of Phosphorus

Several experiments have been conducted with a number of crops to determine the phosphorus rates necessary to maximize production. Although some of these experiments have included several phosphorus carriers, only triple superphosphate (TSP) will be discussed in this section.

Howeler and León (4) established an experiment on a phosphorus deficient Popayán Typic Dystrandept, in Colombia with field beans, using levels of P_2O_5 ranging from 0 to 2200 kg/ha applied before the first planting. The objective of this study was to determine the levels of phosphorus necessary from both an initial and residual standpoint. The yield results of three crops of beans are shown in figure 4. The first harvest showed a good yield response up to 800 kg P_2O_5/ha and the second and third crops up to 400 kg P_2O_5/ha. It would appear that 400 to 500 kg P_2O_5/ha should be recommended if only one phosphorus application is made. Since the yield of the third harvest was quite low it seems reasonable that these high allophane containing soils were fixing large amounts of the applied phosphorus. Thus, the best phosphorus management strategy is probably either to apply less soluble forms of phosphorus initially, or to apply the soluble forms on an annual basis.

In another study Hammond and León (3) established an experiment on a Carimagua Oxisol in Colombia with *Brachiaria decumbens* using rates of 25, 50, 100 and 400 kg P_2O_5/ha as TSP. Figure 5 shows the response of this grass to different levels of phosphorus. Over a two and one-half year period 8 cuttings have been taken and no statistical differences in yields were noted between the 50 and 400 kg P_2O_5/ha treatments. This experiment is also showing good residual effect of the soluble phosphorus that was applied initially. Fertilization after the first year, with the same levels of phosphorus, as a maintenance application would appear reasonable only for the 25 kg P_2O_5/ha treatment, where the yield increase was more than four ton/ha. It is not reasonable to use annual applications of 50 kg P_2O_5/ha or more because yield increases due to these treatments are only of the order of two ton/ha, which would not pay for the additional cost of the fertilizer and its application.

Although the phosphorus fixation capacity of these Oxisols is appreciable it is not as high, for example, as in the case of the Andepts. This in part explains perhaps why the forage grass yielded so well at lower phosphorus rates as compared to the previously mentioned field beans. Also, the _Brachiaria decumbens_ can probably scavenge from phosphorus sources that are less available, than can the field bean.

From these two examples one can conclude that there is, in general, a good initial plant response to soluble forms of added phosphorus in both the Andepts and Oxisols. The residual effect, however, depends upon both the mineralogical and chemical characteristics of the soil as well as the test crop itself.

Placement of Phosphorus

In the Andepts of Latin America phosphorus fertilization of row crops like corn, potatoes, wheat and beans is generally by row application at planting time. Numerous experiments have been conducted in order to elucidate which method of application is the best for the different crops (7).

Howeler and León (3) conducted an experiment on a Typic Dystrandept near Popayán, Colombia, with varying phosphorus rates, sources and methods of application. Three phosphorus fertilizers: TSP, basic slag, and Huila PR from Colombia were applied in a triangle configuration as shown in figure 6. The triangle base simulated broadcast application; the tip, band application; and the intermediate section, strip application. Phosphorus was applied at rates of 75, 150 and 300 kg P_2O_5/ha. Figure 6 also shows the response to the different methods of application for the three phosphorus levels and sources. Yields were significantly better when TSP was band-applied, rather than when broadcast or strip applied, especially at the rate of 300 kg P_2O_5/ha. The 75 kg P_2O_5/ha banded TSP application was as effective as 300 broadcast. The efficiency of the TSP was increased by reducing phosphorus fixation through minimizing soil-fertilizer contact. The method of application did not effect the efficiency of basic slag, but that of PR was slightly higher when broadcast and incorporated.

A second crop was reseeded in the same rows as the first without disturbing the original phosphorus treatments. Figure 7 shows the average response for both the initial and residual effect. Although banding TSP was beneficial for the first planting, it was not any more effective than other methods of application for the second.

In tropical Latin America phosphorus fertilization of pastures has generally followed the classical approach of broadcast and incorporation of superphosphate during establishment, followed by periodic top dressings. Recently, however, some research has been initiated by Fenster and León to ascertain the effect of phosphorus carriers, rates and placement on pasture establishment and maintenance in Quilichao, Colombia. Basal levels of 0 to 400 kg P_2O_5/ha as Pesca PR were broadcast and incorporated after which TSP treatments were superimposed either as a topdress, band, broadcast-incorporated, or stripped application. Results of the first two cuttings of <u>Brachiaria decumbens</u> are presented in Figure 8.

When the Pesca PR was not applied, the highest yields were realized with 100 kg P_2O_5/ha of TSP broadcast and incorporated. In this instance broadcast and incorporation of the TSP was superior to other methods of application. When a basal treatment of 100 kg P_2O_5/ha as PR was broadcast and incorporated, however, there was no difference in yield due to method of application of TSP. Yield increases due to phosphorus levels, however, were evident. For the establishment of *Brachiaria decumbens*, it apparently is not necessary to apply more than 50 kg P_2O_5/ha as TSP if there is a basal application of at least 100 kg P_2O_5/ha as PR. These results are in agreement with other experiments by Sãnchez, León and Ayarza (4) in the establishment of other grasses such as *Panicum maximum* and *Andropogon gayanus*.

Visual observations in these and other similar experiments on the low phosphorus supplying soils, would indicate that when only banded phosphorus is applied, root growth is somewhat restricted to the band area, thus making plants more susceptible to drought, even during short periods when it does not rain. This situation is common in many of these Oxisols and Ultisols because of the stable sand-sized aggregates at the surface.

More research is needed to ascertain the merits of phosphorus placement in pasture and annual crop production in these types of soils. In the case of annual crops, long-term experiments by Yost et al. (10) with corn at the Cerrado Center in Brazil, indicate that a combination of broadcast plus band placed phosphorus is also the most promising strategy.

Use of Cheaper, Less Soluble Forms of Phosphorus

The use of PR as a source of phosphorus for pasture production appears both economically and agronomically attractive, due to its residual value and lower unit cost of phosphorus. A number of forage production experiments have been conducted in tropical Latin America using direct application of PR, Recent works in Brazil, Perú and Colombia have shown very encouraging results (1,3,4,10).

In 1976 a long-term field experiment was established by Hammond and León on a Carimagua Oxisol in Colombia, with Brachiaria decumbens, comparing six PR sources with TSP at phosphorus rates ranging from 0 to 400 kg P_2O_5/ha. Figure 9 shows the total dry matter of eight cuttings over a two and one-half year period. Only at the first harvest was TSP superior to PR sources. Thereafter all PRs increased their effectiveness with time and in most instances had surpassed the yields of comparable TSP treatments by the third harvest. After eight cuttings it would appear that 50 to 100 kg P_2O_5/ha are adequate for near maximum production of Brachiaria decumbens, regardless of the phosphorus carrier used.

Similar results were obtained by Hammond and León using common beans (four harvests) on a Popayán Typic Dystrandept, and cassava (three harvests) on a Carimagua Oxisol respectively,(3, 4).

Use of Partially Acidulated and Mini-Granulated PR

From the experiments discussed previously, it is apparent that many of the PRs, although they perform well with time, are initially inferior to the more soluble phosphorus sources. The works of McLean and Wheeler (9) would indicate that partially acidulating these PRs to levels of from 10 to 20% could overcome this problem. The partially acidulated PR would provide a soluble source of phosphorus initially while still maintaining the desirable characteristics of low cost and residual value of the PR. In this area of research in Latin America, some research with beans by Howeler (2) has shown very encouraging results.

In general PR must be finely ground in order for it to be effective. This creates certain problems since the product is usually quite dusty and hard to spread evenly on the field. With this in mind, a field experiment was established to determine both the effect of partial acidulation and granule size of both high and low reactivity PRs, on yield of peanuts and rice on a

Carimagua Oxisol. The granules were made by taking finely ground PR, partially acidulating it with H_2SO_4, and granulating with a 3.3% KCl binder. Two particle sizes were used: powdered (- 200 mesh) and minigranules (-48+140 mesh). For the first crop of peanuts, figure 10 illustrates quite clearly that the minigranules are just as effective as the powdered materials at the two rates of application.

Partial acidulation with H_2SO_4, however, did not show any improvement in yield when compared with the Florida and North Carolina PRs. Research conducted at the Fertilizer Technology Division of IFDC showed that partial acidulation with H_2SO_4 and subsequent drying of the granules produced a material that was almost completely covered by a thin layer of insoluble anhydrous or hemidydrate $CaSO_4$ that either occluded release of the phosphorus or physically prevented contact of the PR with the soil. This may explain the lack of response by the plant to applications of these products.

Recent studies at IFDC headquarters are showing promising results with partial acidulation of PR with H_3PO_4 [1/].

Triple Superphosphate and PR Mixtures

Another possibility for improving phosphorus availability in PRs is to physically mix them with acid forming material such as TSP. By using a material such as TSP there is also the added benefit of supplying an immediately available form of phosphorus.

Accordingly, a field experiment on a Quilichao Ultisol was established to study the effect of ratio of TSP to PR on yield of *Brachiaria decumbens*, and a rice-peanuts rotation. The results, for the sum of two cuttings of Brachiaria decumbens (fig. 11 and 12), would indicate that ratio of TSP to PR

[1/] L. Hammond, personal communication.

is important. In the case of Pesca PR a 75:25 ratio of TSP to PR seems to be superior, whereas with the medium reactivity Huila PR, a 25:75 or 50:50 ratio appears to be the best.

In the case of rice, only a 50:50 ratio of TSP to PR was used, but results of the first harvest, figure 13, indicate that some of the mixtures and more reactive PRs are performing as well or better than TSP alone. In this instance, best results were obtained with a mixture of TSP and Huila PR, and Huila PR alone at all levels of phosphorus used. Although these results appear promising further cropping must take place before any definitive statements can be made.

Results of these experiments do suggest, however, that another experiment of this nature should be conducted in which the finely ground materials are granulated to determine the effect of aggregate size. Further, the granulation of these mixtures would insure intimate contact between the PR and TSP so that the acid from TSP would be more likely to react with the rock and not be dissipated in the soil.

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Table 1. Characteristics of some representative acid infertile soils in Colombia and Brazil

Horizon	Clay	Sand	pH	O.M.	Exchangeable cations (meq/100 g)					Al Saturation	Available P *
(cm)	%	%	(H_2O)	%	Al	Ca	Mg	K	CEC	%	(ppm)
COLOMBIA - CIAT Quilichao: Ultisol (Orthoxic Palehumult, clayey, kaolinitic, isohyperthermic)											
0 - 20	71	4	4.1	7.1	2.7	.65	.49	.36	4.2	64	1.8
CIAT Carimagua: Oxisol (Tropeptic Haplustox, fine-clayey, mixed, isohyperthermic)											
0 - 20	37	6	4.9	5.3	2.8	.20	.20	.10	3.4	82	0.9
LA SELVA: Inceptisol (Typic Dystrandept)											
0 - 20	42.8	0.3	5.0	22.5	1.5	.10	.40	.20	3.2	47	2.0
BRAZIL - CERRADO CENTER: Oxisol (Typic Haplustox, fine, kaolinitic, isohyperthermic - LVE)											
0 - 10	45	36	4.9	3.1	1.9	.20	.20	.10	2.4	79	tr

* Bray II extraction method.

Table 2. Approximate Dristibution of some suborders of Oxisols, Ultisols and Inceptisols in tropical South America.

Order	Suborder	Area	Percentage of Area
		(million ha)	
Oxisols (Ferralsols)	All suborders	636	45.3
Ultisols (Acrisols)	Aquults	48	
	Udults, Ustults, and Humults	220	
		268	19.1
Inceptisols	Aquepts	1	
	Andepts	32	2.3
	Tropepts	81	
		114	8.2

Source: Sánchez, P.A. Properties and Management of Soils in the Tropics - Calculated from the FAO-UNESCO Soil Map of the World: South America, and converted to Soil Taxonomy equivalents.

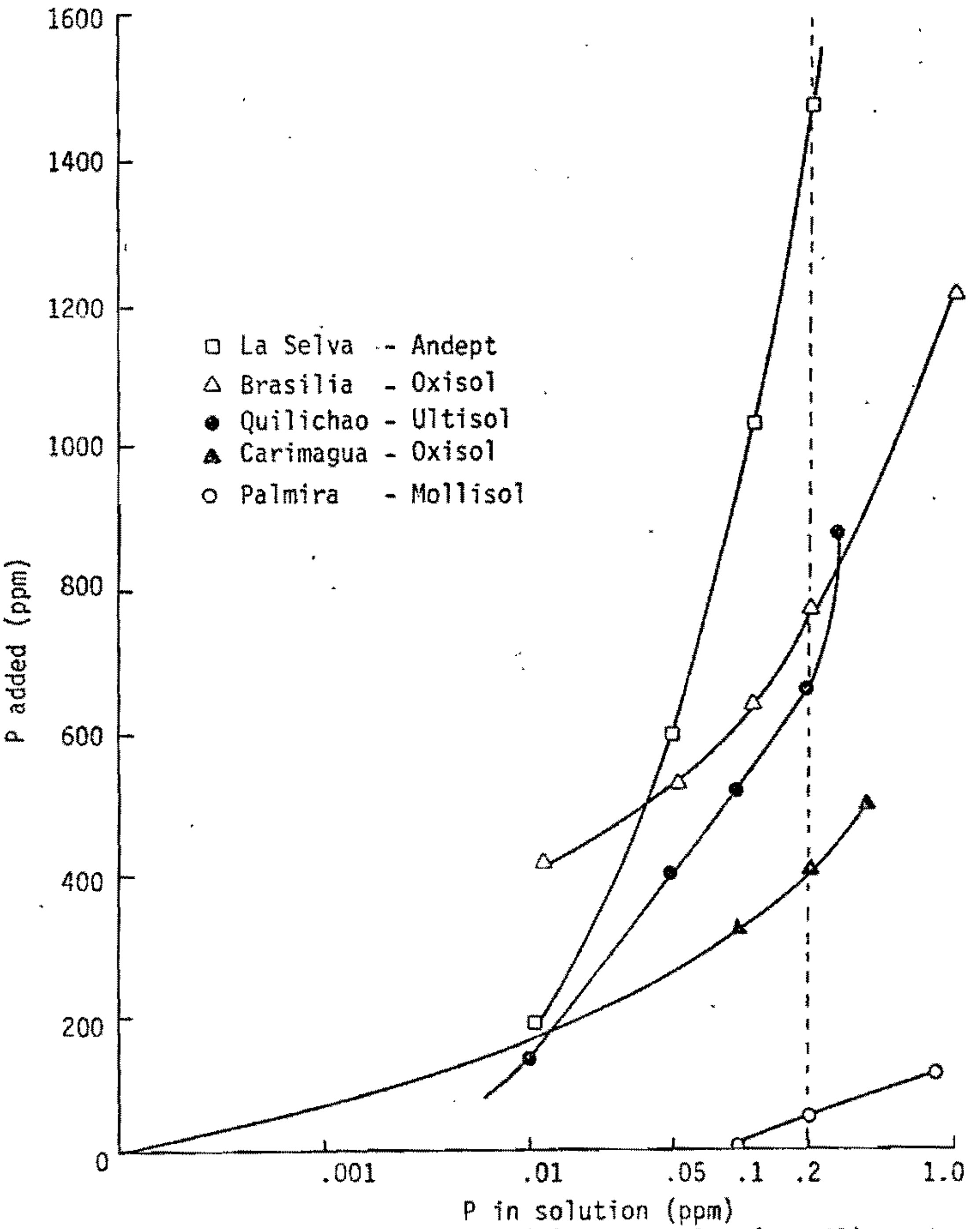

Figure 2. Phosphorus isotherms of CPAC-Brasilia (Brazil), and La Selva, CIAT-Quilichao, CNIA-Carimagua, CIAT-Palmira (Colombia).

Adapted from CIAT Annual Report (1977).

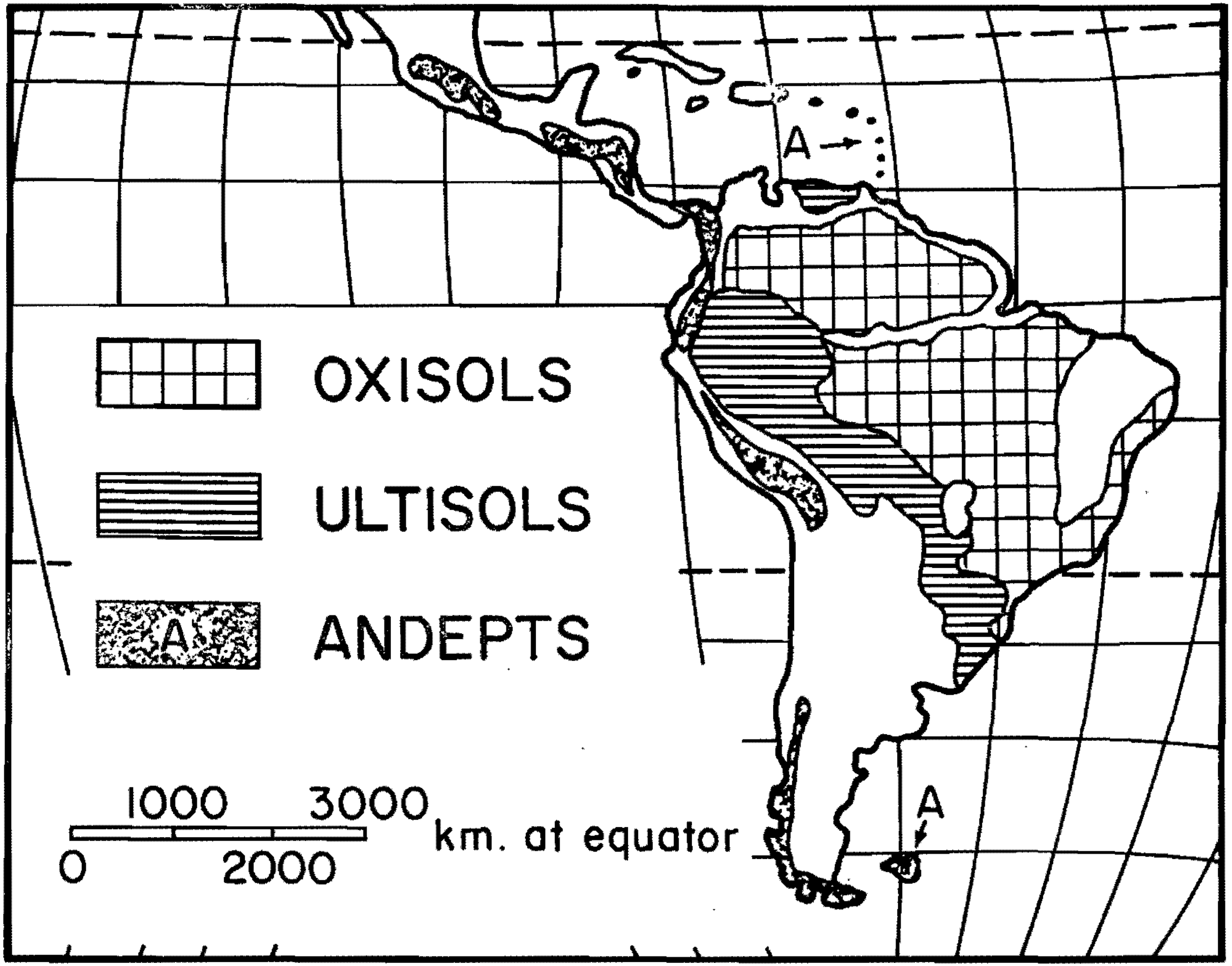

Figure 3. Distribution of Oxisols, Ultisols and Andepts.

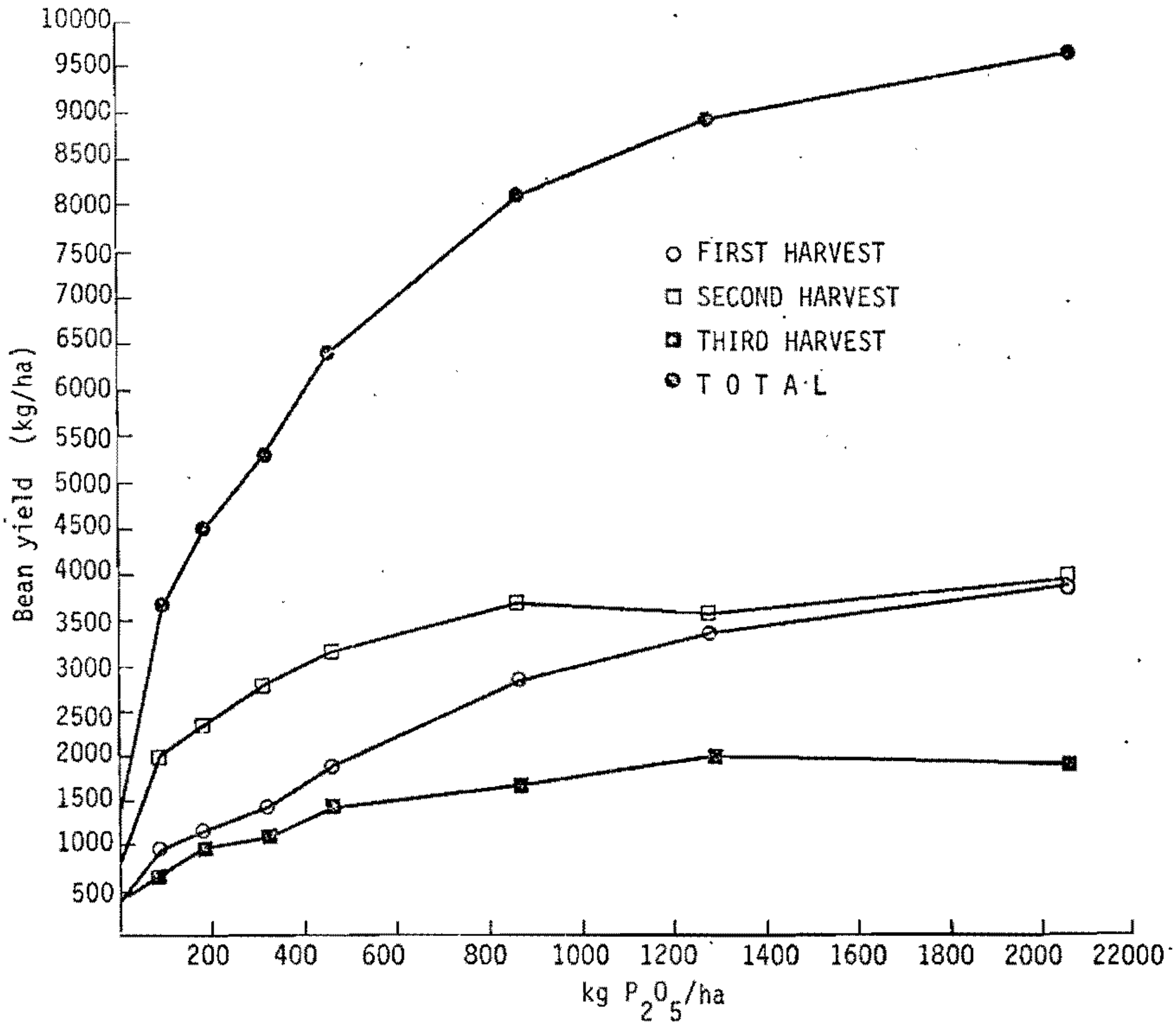

Figure 4. Field bean response to P_2O_5 in Popayán, Colombia.

Source: CIAT, Annual Report 1978.

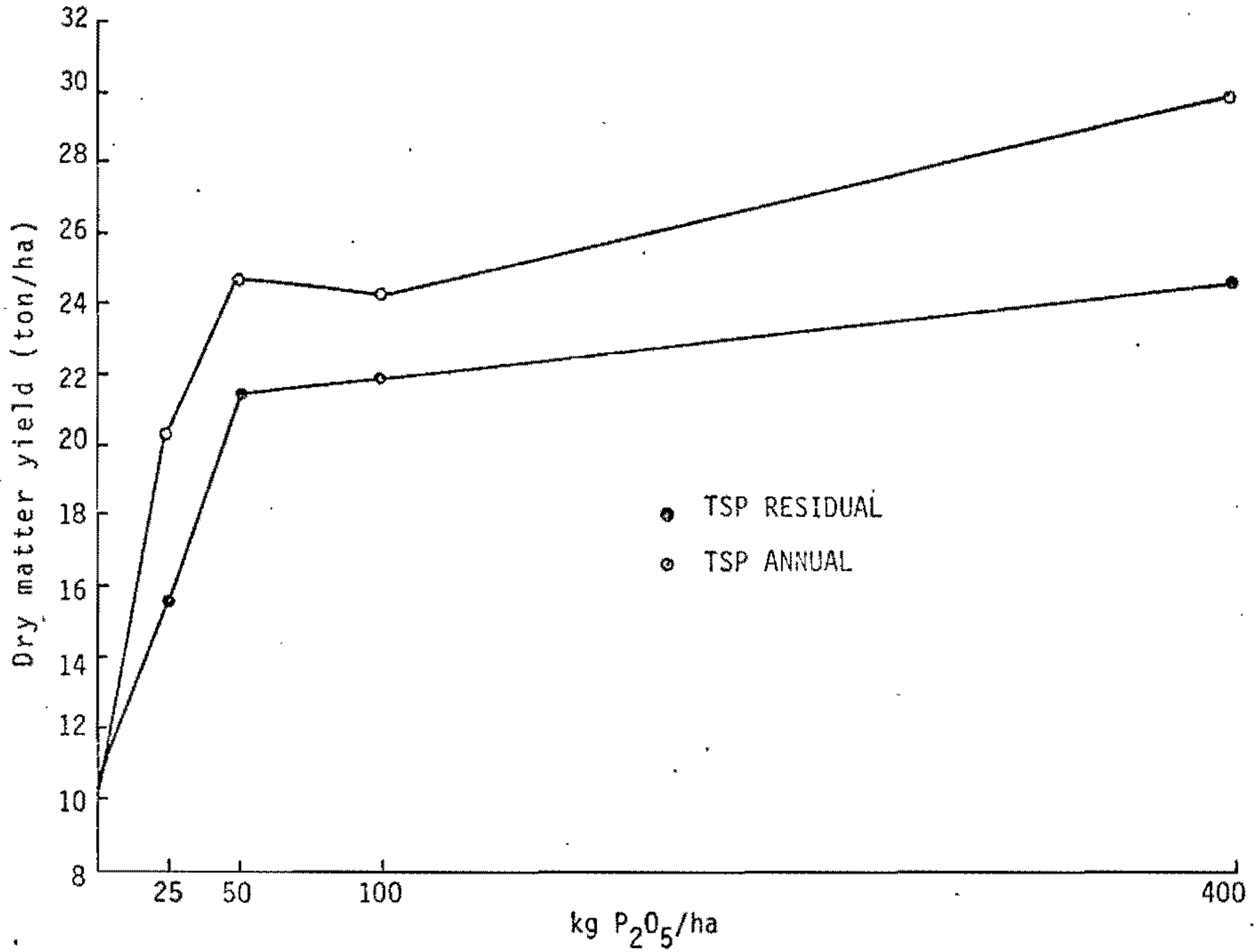

Figure 5. Phosphorus response of Brachiaria decumbens grown on a Carimagua Oxisol (sum of eight harvests). In the annual treatment P was reapplied one year after planting.

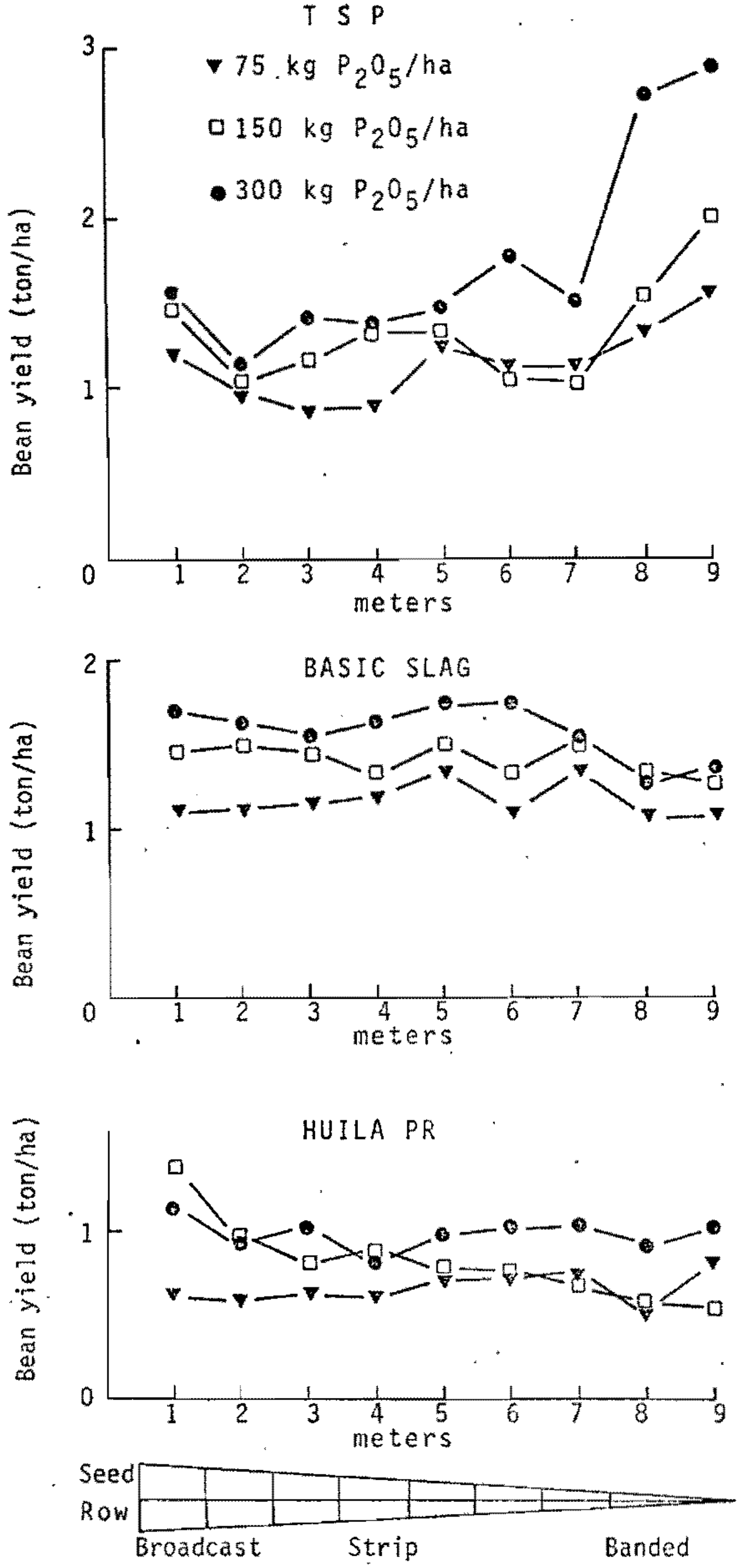

Figure 6. The effect of fertilizer distribution, applied at three levels and sources of phosphorus, on bean yield in Popayán.

Source: CIAT Annual Report, 1977.

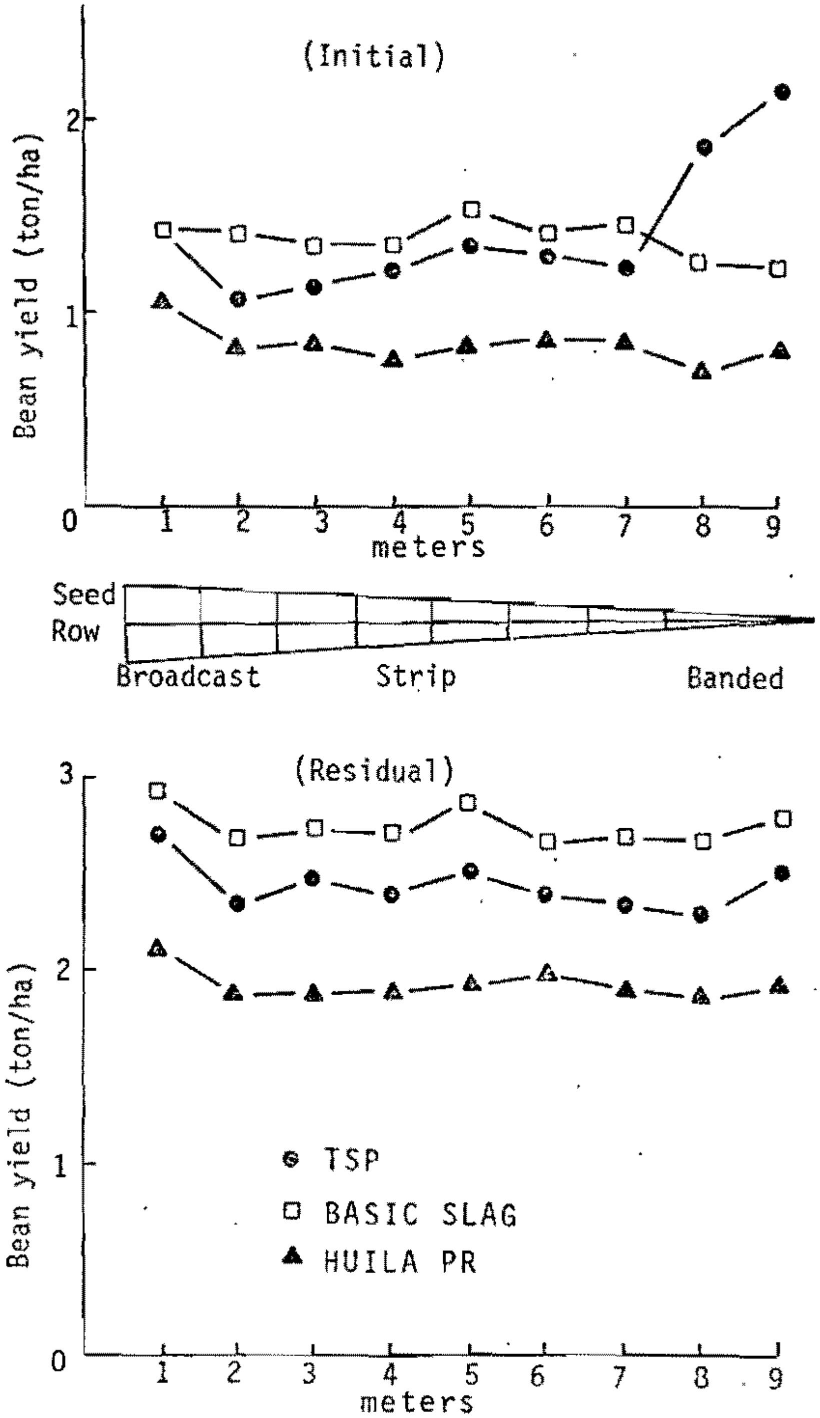

Figure 7. Bean yield (average of three P-levels) showing initial and residual effects of the distribution of fertilizers applied as three sources of phosphorus.

Source: CIAT - Annual Report, 1977

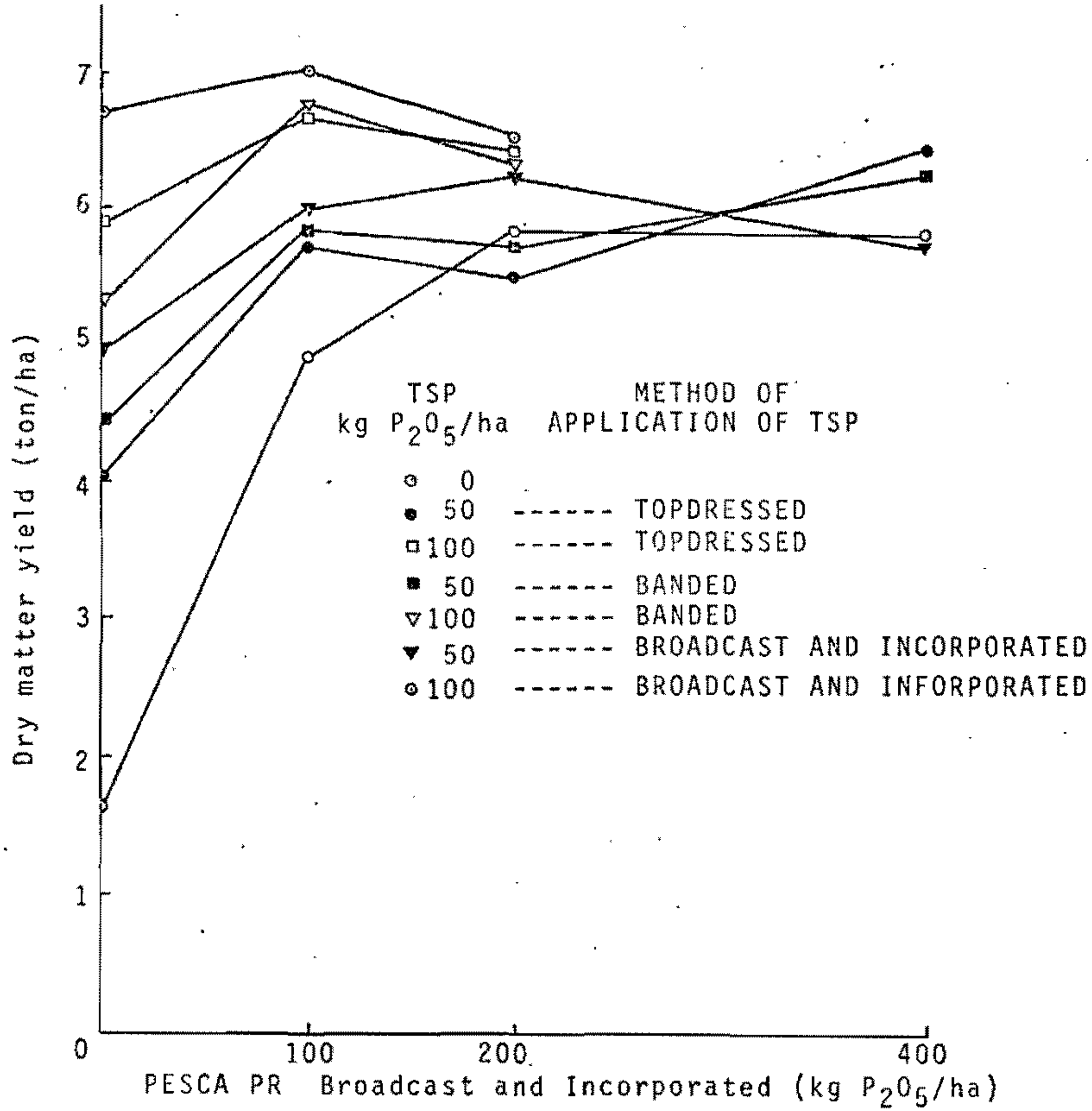

Figure 8. Management of phosphorus in establishing and maintaining a forage species, *Brachiaria decumbens*, on a Quilichao Ultisol.

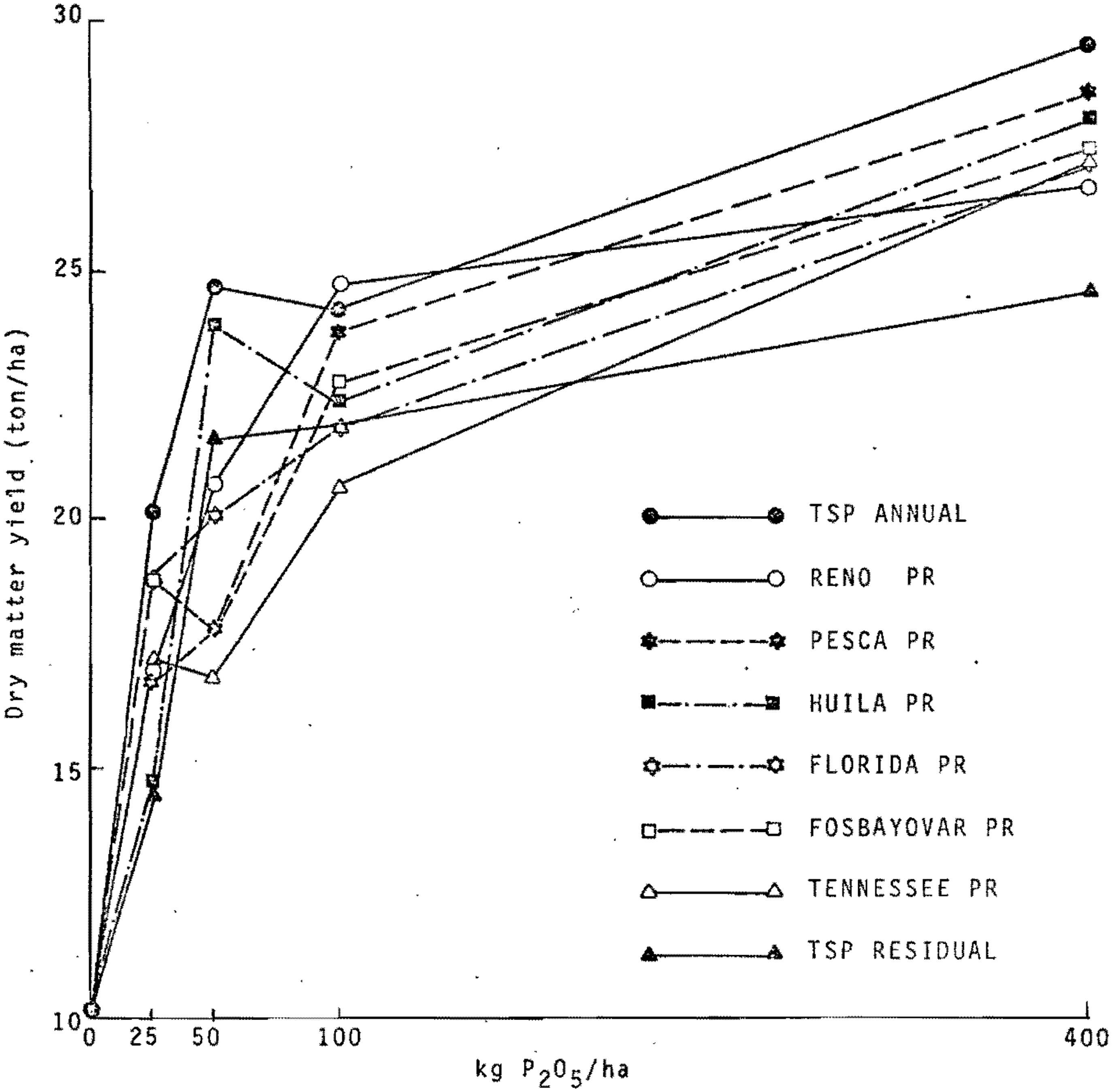

Figure 9. Effect of phosphorus carrier and rate on yield of *Brachiaria decumbens* (eight cuttings) grown on a Carimagua Oxisol.

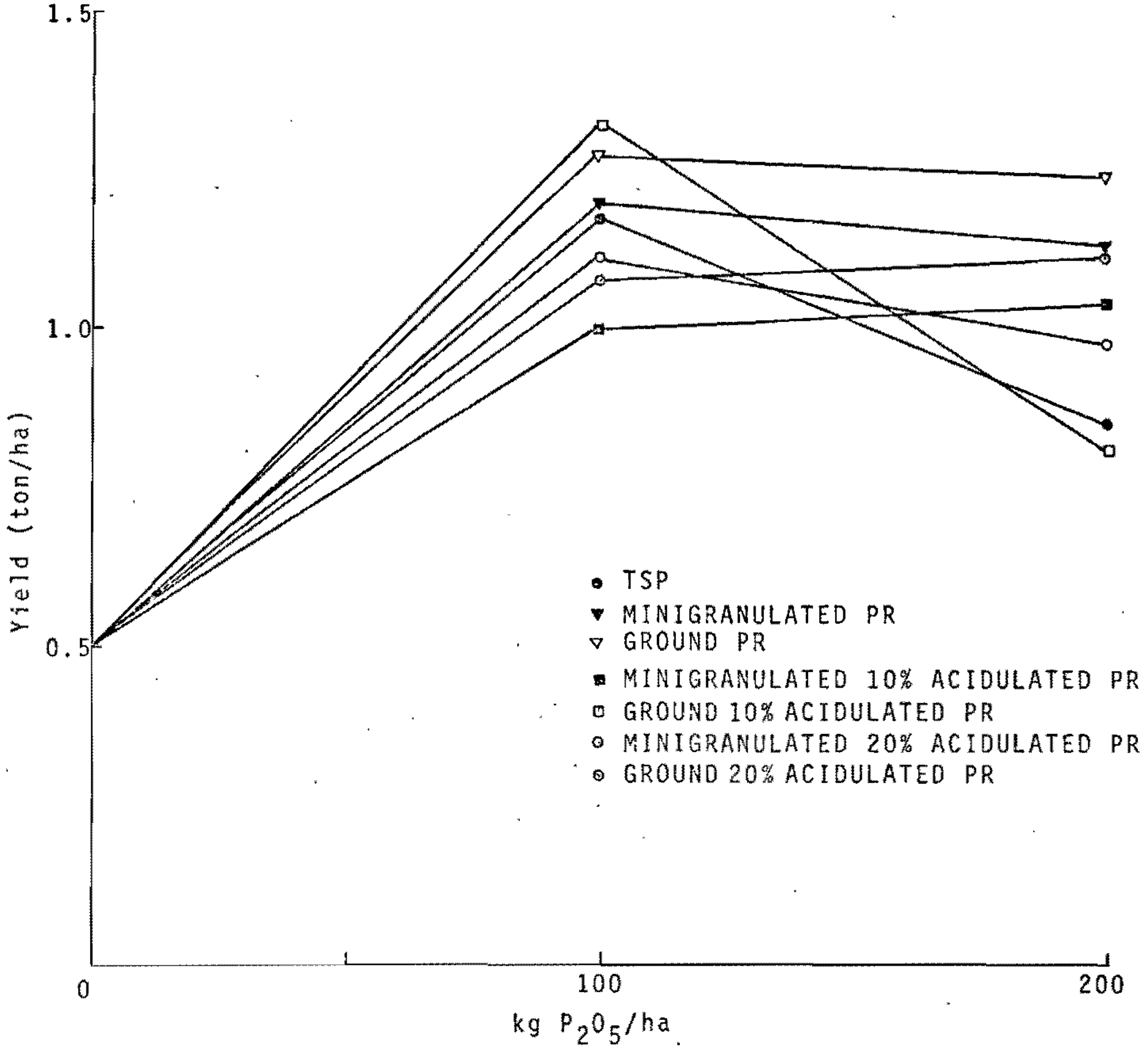

Figure 10. Effect of TSP, FLORIDA PR, partially acidulated FLORIDA PR, and granule size on yield of peanut grown on a Carimagua Oxisol.

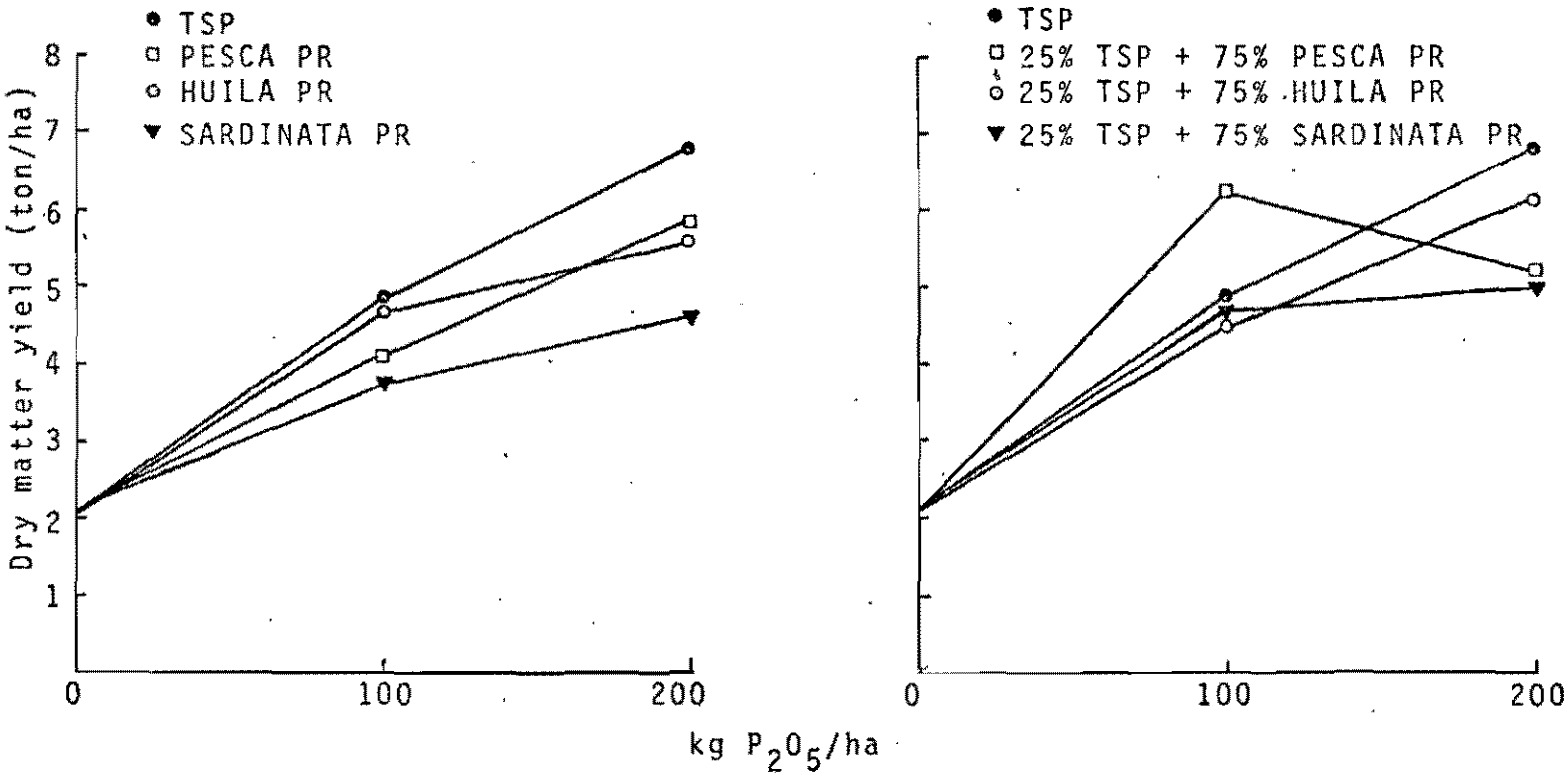

Figure 11. Effect of a 3:1 ratio of PR to TSP on yield of <u>Brachiaria decumbens</u> grown on a Quilichao Ultisol (sum of two cuttings).

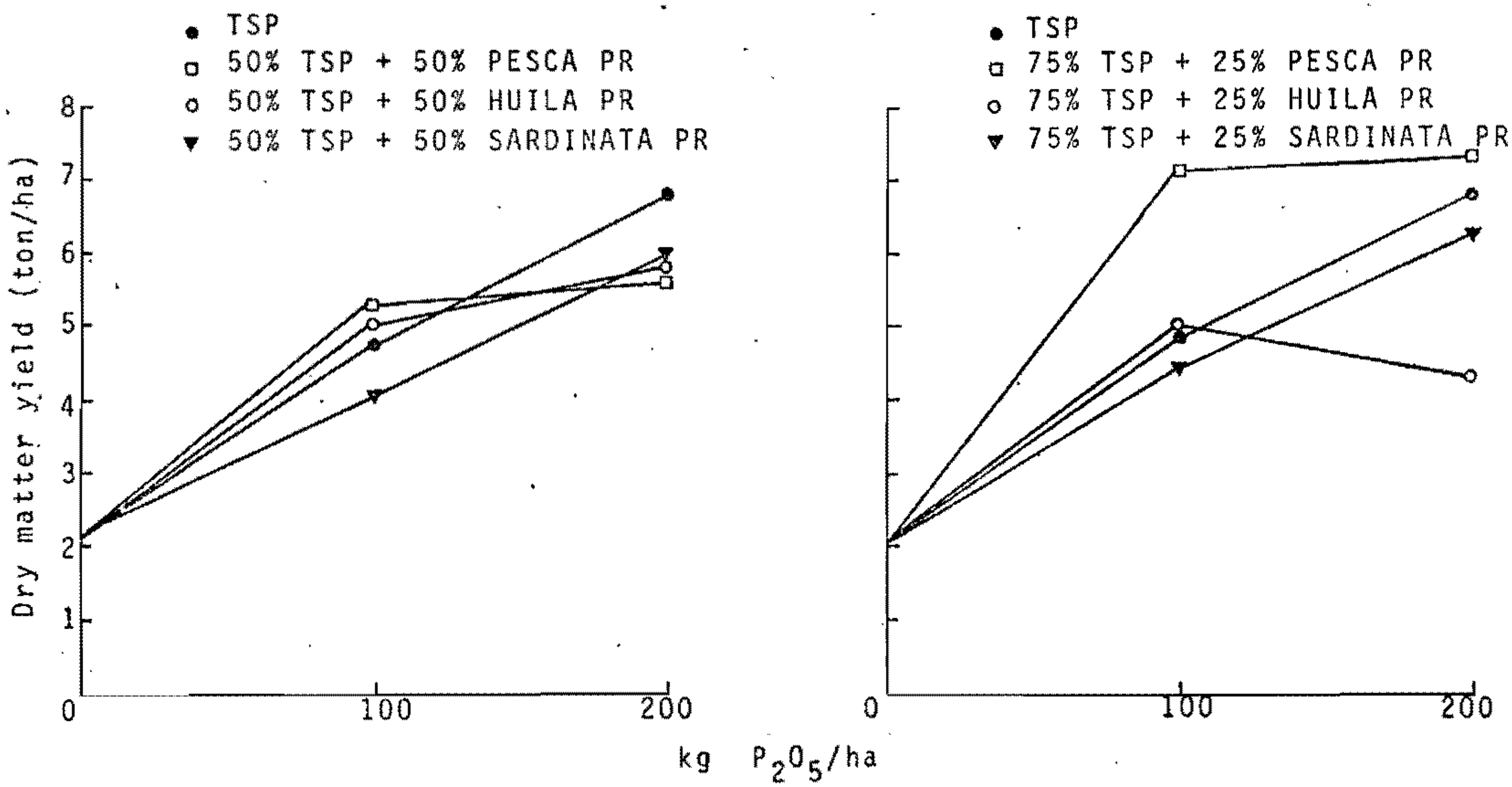

Figure 12. Effect of 1:1 and 1:3 ratios of PR to TSP on yield of *Brachiaria decumbens* grown on a Quilichao Ultisol (sum of two cuttings).

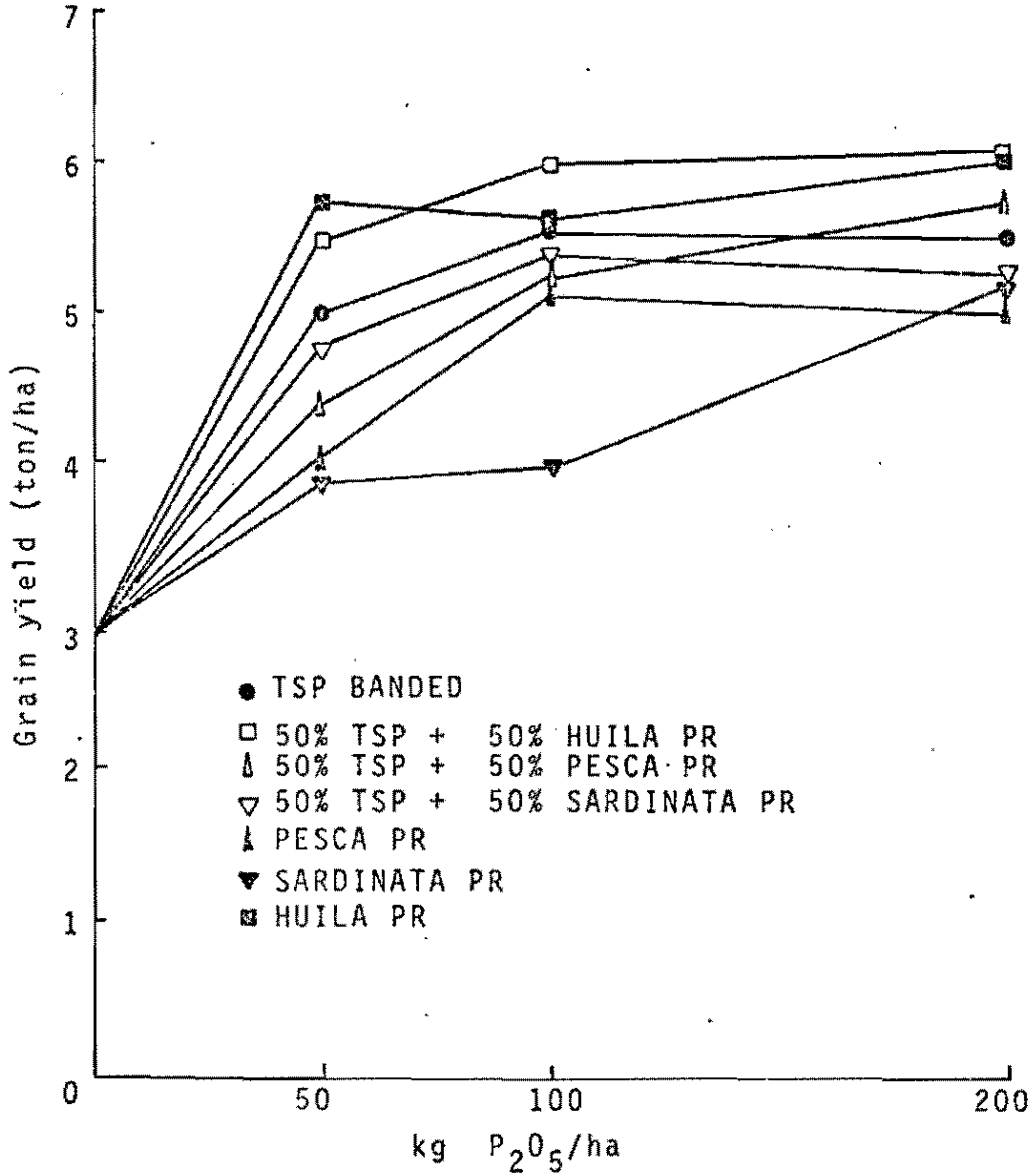

Figure 13. Effect of TSP, three Colombian PR, and equal mixtures of TSP and PR, on yield of rice (CICA 8) grown on a Quilichao Ultisol.