EVALUATION AND IMPROVEMENT OF AGRONOMIC PRACTICES

Nitrogen Fixation by Rhizobium phaseoli

Strain Selection and Testing

IBIT trial. Results have been obtained to date from eight collaborating organizations in the second International Bean Inoculation Trial (IBIT), distributed during 1980. Scientists from whom results have been received are shown in Table 1; the strains used in the second trial are shown in Table 2.

Significant responses to inoculation were obtained in five of the eight locations, with strains CIAT 166 and 407 outstanding. By contrast, CIAT 57 (syn CC 511) again fared poorly, yielding less than the uninoculated control in both the Lethbridge and Hawaii trials. Subsequent tests in Leonard Jars have shown that this strain is subject to loss of effectiveness and cannot now be recommended. Full details of these trials will be published separately.

Inoculation trials at Popayan. Two inoculation trials were carried out at the CIAT station in Popayan. Despite soil organic matter contents in excess of 30%, significant yield responses to inoculation were obtained in both trials. The first trial was a simple inoculation experiment to determine the need to inoculate at this location. It used cultivar Cargamanto and contrasted inoculation with strain CIAT 899 against plots receiving no inoculation. In this trial, plots without inoculation were clearly chlorotic, and there was a yield difference of 392 kg/ha in favor of the inoculated treatments.

Table 1. Collaborators from whom results in the second IBIT trial,[a] 1980, have been received.

Scientist(s)	Institution	Country
J. Day	Rothamsted Exp. Station	England
P. Graham	CIAT	Colombia
J. Halliday	NIFTAL, Univ. of Hawaii	USA
R. Lepiz	INIA	Mexico
L.D. Ploper & J.R.Ricci	Estación Experimental Obispo Colombres, Tucuman	Argentina
M. Quintero	Instituto Tecnológico Durango	Mexico
R. J. Rennie & G.A. Kemp	Dept. of Agriculture, Lethbridge	Canada
A. Teixera Vargas	EMCAPA	Brazil

a. Results are still pending for a further six locations.

Table 2. Strains of Rhizobium included in the second IBIT trial, 1980.

CIAT No.	Original No.	Source	Comments
57	CC511	CSIRO, Canberra, Australia	Included in IBIT for 1979
127	Z 65	CIAT, Colombia	
161	Z 146	CIAT, Colombia	
166	Z 151	CIAT, Colombia	
255	Z 272	PROMYF, Honduras	Included in IBIT for 1979
390	Z 723	CIAT, Colombia	
407	-	CIAT, Colombia	
727	127 K47	Nitragin Co, USA.	
904	487	RGS, Porto Alegre, Brazil	Included in IBIT for 1979
952	486	RGS, Porto Alegre, Brazil	

A second trial comparing the best strains of the two IBIT trials was carried out. Results are shown in Table 3, with strain CIAT 166 significantly outyielding the control to which 100 kg/ha urea had been applied. Strains CIAT 899, 407, and 632 also performed well in this trial.

Tolerance to soil acidity. Experiments undertaken in 1980 looked at tolerance to acid pH in strains of Rhizobium phaseoli, the related ability to grow in a laboratory medium of pH 4.5, and tests for survival in Santander de Quilichao soil. In 1981, two further experiments were undertaken to compare the nodulating ability of acid-tolerant and susceptible rhizobia in soils of varying pH. While the results are reported in detail elsewhere (Field Crops Research, in press), Table 4 shows clearly that yield responses to inoculation can be achieved in soils of pH 4.5 when acid-tolerant strains such as CIAT 899 are used. Current studies are evaluating strain-by-cultivar interaction in acid soil tolerance.

Varietal Tolerance to Inoculation at Low Soil pH

Ten accessions of P. vulgaris were evaluated for ability to nodulate in acid soil conditions. Each was grown at pH 4.5 and 5.5. Four different inoculant strains were used: CIAT 899 and 2516, which are tolerant of pH 4.5 in Keyser-Munns medium; and CIAT 632 and 904, which did not grow at this pH. Varieties differed significantly in tolerance to acid soil conditions (Table 5).

Table 3. Response of *P. vulgaris* BAT 76 to inoculation with various strains of *Rhizobium* at El Porvenir, Popayan, May 1981.

Strain used	Yield (kg/ha)	Significance level[a]
CIAT 166	2314	a b
CIAT 899	2126	a b
CIAT 407	2085	a b
CIAT 632	2084	a b
CIAT 255	2033	b c
+N control (100 kg urea)	2024	c d
-N control	1892	c d
CIAT 676	1824	c d
CIAT 904	1804	c d
CIAT 161	1780	d
CIAT 903	1666	d
CIAT 640	1654	d

a. Treatments joined by the same line are not significantly different at the 5% level.

Table 4. Influence of strain of *Rhizobium* and inoculation method used, and lime applied, on yield (kg/ha) of *P. vulgaris* cv. BAT 76 in Popayan, 1981.

Strain and inoculation method used	Lime applied (ton/ha)[a]		
	0 (pH 4.50)	2 (pH 4.75)	4 (pH 5.20)
Not inoculated	1791	1881	2325
Inoculation with CIAT 632 (not acid tolerant)			
a. Slurry inoculated	1475	2385	2875
b. Lime pelleted	1969	1904	3147
c. Granular, soil applied	1863	2163	2135
Average	1769	2150	2719
Inoculation with CIAT 899 (acid tolerant)			
a. Slurry inoculated	2575	2508	2530
b. Lime pelleted	1912	2674	2865
c. Granular, soil applied	2442	2160	3083
Average	2309	2447	2826

a. *F* (inoculation), 12.14**; *F* (lime level), 10.39**; *F* (inoculant strain), 6.19*; *F* (method of inoculation) and all interaction terms, n.s. at the 5% level.

Table 5. Response of 10 P. vulgaris cultivars to inoculation with acid-tolerant or nontolerant strains of Rhizobium at pH 4.5.

	Strains tolerant to pH 4.5				Strains not tolerant to pH 4.5			
	899		2516		632		904	
Identification	Plants nod. (%)	Nodules/ plant (no.)	Plants nod. (%)	Nodules/ plant (no.)	Plants nod. (%)	Nodules/ plant (no.)	Plants nod. (%)	Nodules/ plant (no.)
A 188	62	31	50	19	0	0	20	5
Catu	71	10	100	18	20	1	0	0
BAC 66	14	31	0	0	0	0	14	2
A 86	28	4	44	10	10	4	11	1
G 4201	0	0	20	2	0	0	16	2
G 6079	78	24	100	27	66	7	90	5
V 8016	83	56	100	38	75	2	75	12
G 2331	70	24	50	29	44	5	0	0
G 2641	20	1	12	4	71	4	12	1
V 8024	20	1	25	20	60	7	40	2

Effect of Selection for Low Soil Phosphorus Tolerance on Nitrogen Fixation in Bean Cultivars

Studies undertaken in previous years have shown that adequate phosphorus is essential for nitrogen fixation in *P. vulgaris*. Because of this, studies were undertaken to consider the effect of selection for tolerance to low soil phosphorus on nodulation and nitrogen fixation. The cultivars Iguaçu (considered tolerant to low soil phosphorus) and ICA-Tui (sensitive) were grown in a nutrient medium devoid of nitrogen and containing 1, 4, or 16 ppm phosphorus; their growth, nitrogen fixation, phosphorus uptake, and partitioning were examined at weekly intervals. At 16 ppm phosphorus, nitrogen fixation (measured by nitrogen accumulation) and phosphorus accumulation in the two varieties was very similar, although ICA-Tui showed somewhat superior plant development. However, when only 4 ppm phosphorus was supplied, the phosphorus uptake and nitrogen fixation of Iguaçu was markedly superior to that achieved by ICA-Tui. As a result, plant development in Iguaçu exceeded that in ICA-Tui by 37%. At 1 ppm growth, nitrogen fixation and phosphorus uptake of both cultivars was poor.

Biology and Control of Insect Pests

Cultural Control of *Empoasca kraemeri*

Crop association is a common practice in Latin America. It is also an important tool in pest management. The effect of maize plant density in a maize/bean association on *Empoasca* population levels was studied. Adult population levels were consistently lower in plots with higher maize density (Figure 1). Number of nymphs followed the same trend. These relationships could not be attributed to biological factors (i.e., enhancement of the efficacy of natural enemies). The results suggested that microclimatic conditions could be responsible for the lower leafhopper populations.

Economic Injury Levels for Leafhopper in Susceptible and Resistant Bean Varieties

Two susceptible varieties were compared to the leafhopper-resistant EMP 81. It is evident (Figure 2) that farmers who were not willing or did not know how to use insecticides will make a profit with the resistant material even at very high *Empoasca* population levels (more than 7 nymphs/leaf). The economic injury level for the susceptible varieties BAT 41 and Diacol Calima were three and less than one nymphs/leaf, respectively. This illustrates the importance of plant resistance as a means of reducing the number of applications of costly and hazardous insecticides.

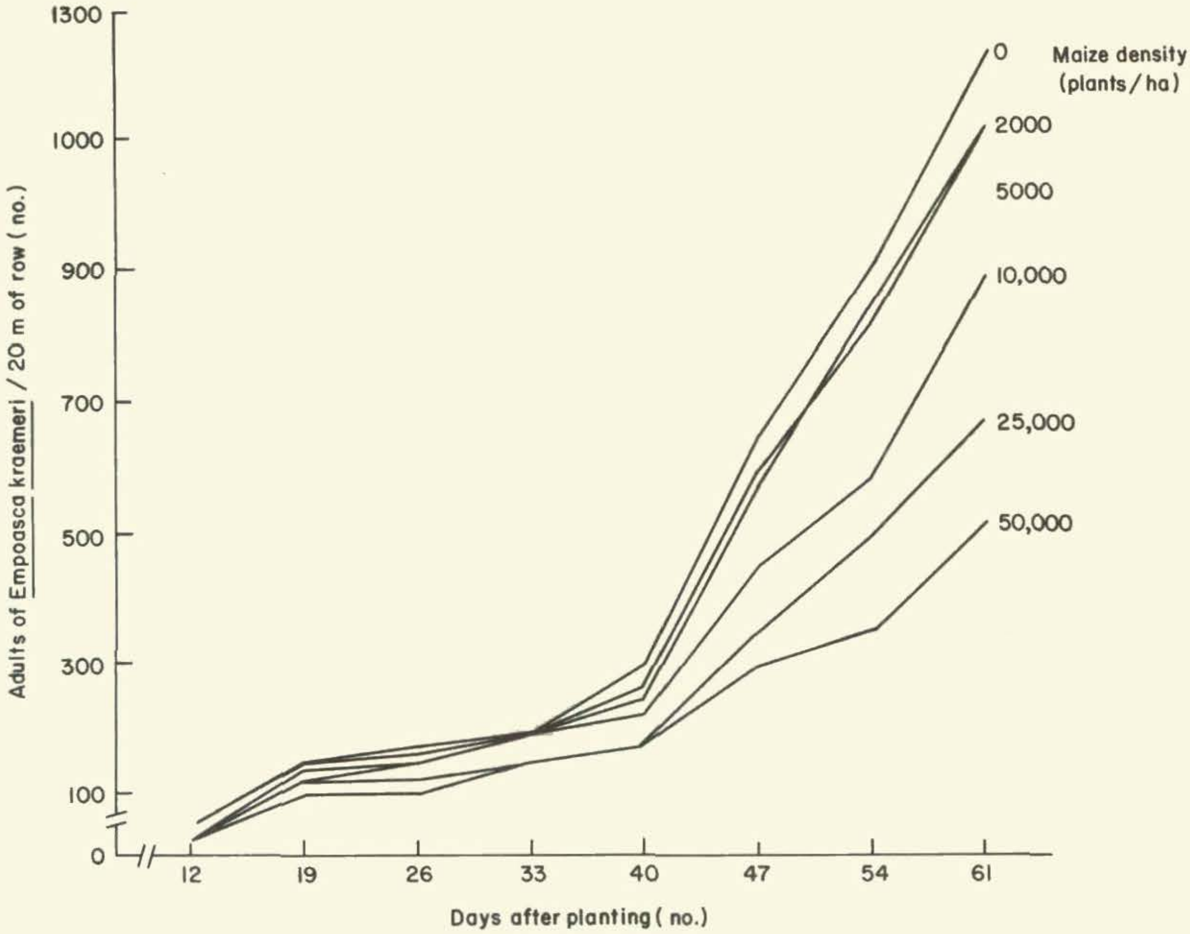

Figure 1. Effect of maize density planted in association with beans on numbers of adult Empoasca kraemeri (averages of four replicates, CIAT, 1981).

P Fertilization and P Sources

Time of Application for P Fertilizers

It is a common farmer practice to apply fertilizers on hills late after beans germinate. Any form of phosphorus fertilizer, however, needs ample time to become available to the plant. Ground rock phosphate needs the longest time to become available, compared to other acidulated types of phosphatic fertilizers. More time for phosphorus availability will be needed when soil moisture is low. An experiment was carried out at the CIAT-Quilichao station, on soil with two distinct phosphorus levels, to study the time of application of phosphorus fertilizers. The low soil phosphorus plot had 4.3 ppm, and the high soil phosphorus plot had 25.6 ppm (Bray II method for P extraction).

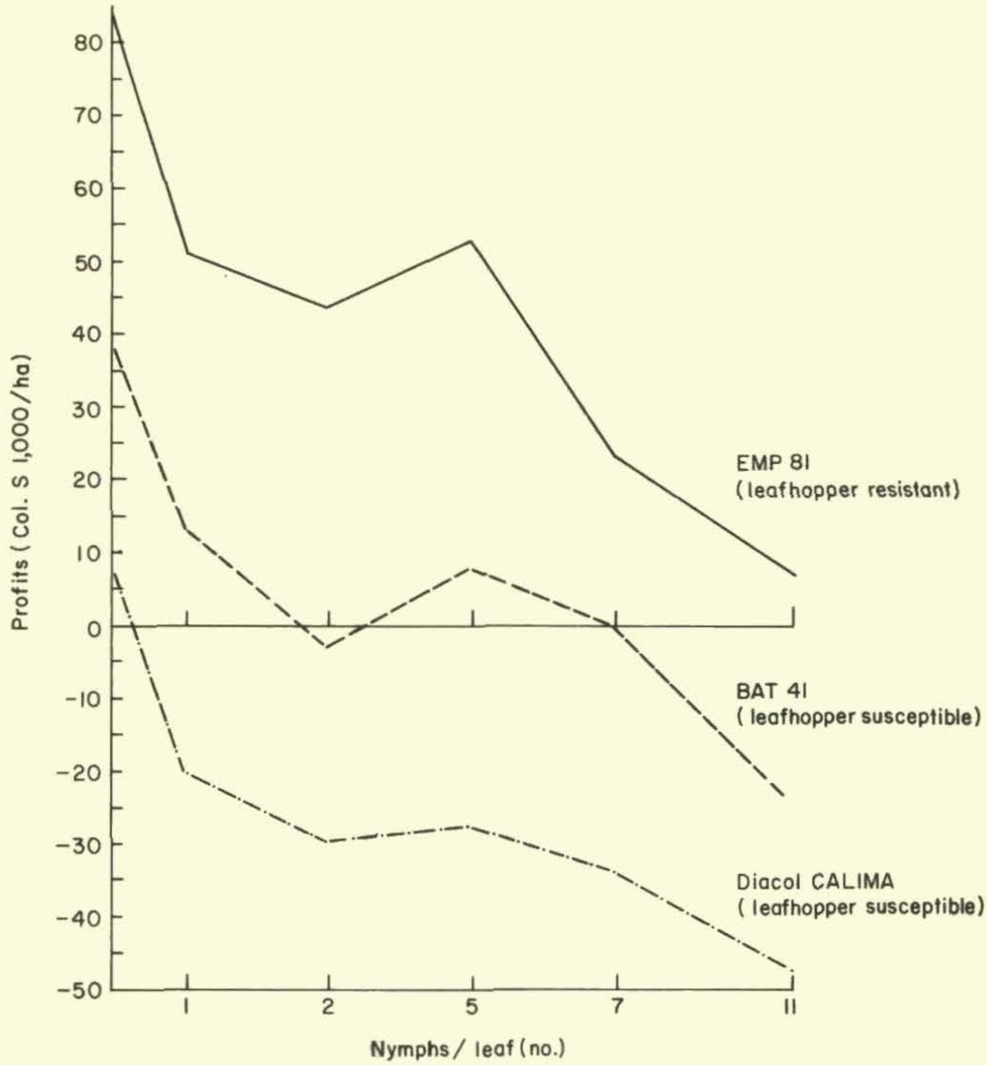

Figure 2. Profits obtained with three bean varieties at increasing Empoasca kraemeri population levels. Fields were sprayed when population levels were 1, 3, 5, 7, and above-7 nymphs/leaf.

Four bean varieties, two efficient and two inefficient in phosphorus use, were planted at the same time, and three dates of phosphorus applications at the rate of 131 kg P/ha were banded (1) at planting time, (2) 21 days after germination, and (3) at flowering time. A check without additional phosphorus was also included.

Figure 3 and Figure 4 show the performance of the efficient lines, Carioca and G 4000, compared to the inefficient lines, Puebla 152 and BAT 47. Efficient lines always gave higher yields than the inefficient ones at all dates of phosphorus applications and soil phosphorus levels, except on high phosphorus soils, when phosphorus fertilizer was applied at flowering, at which time the average yield of the inefficient materials was the same as that of the efficient ones.

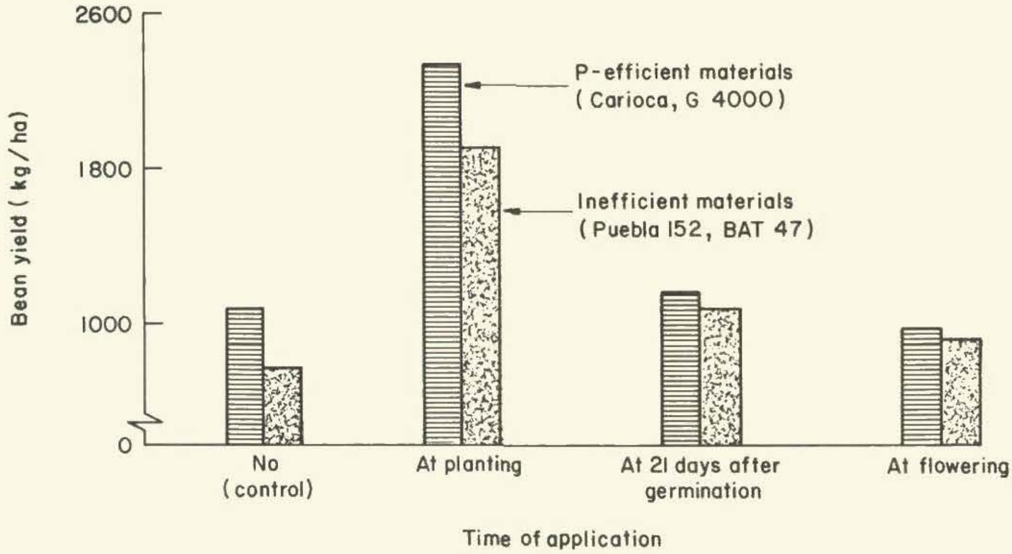

Figure 3. Yields of efficient and inefficient bean varieties as affected by time of application of P fertilizer (applied in bands) on soil with low P content (4.2 ppm P Bray II).

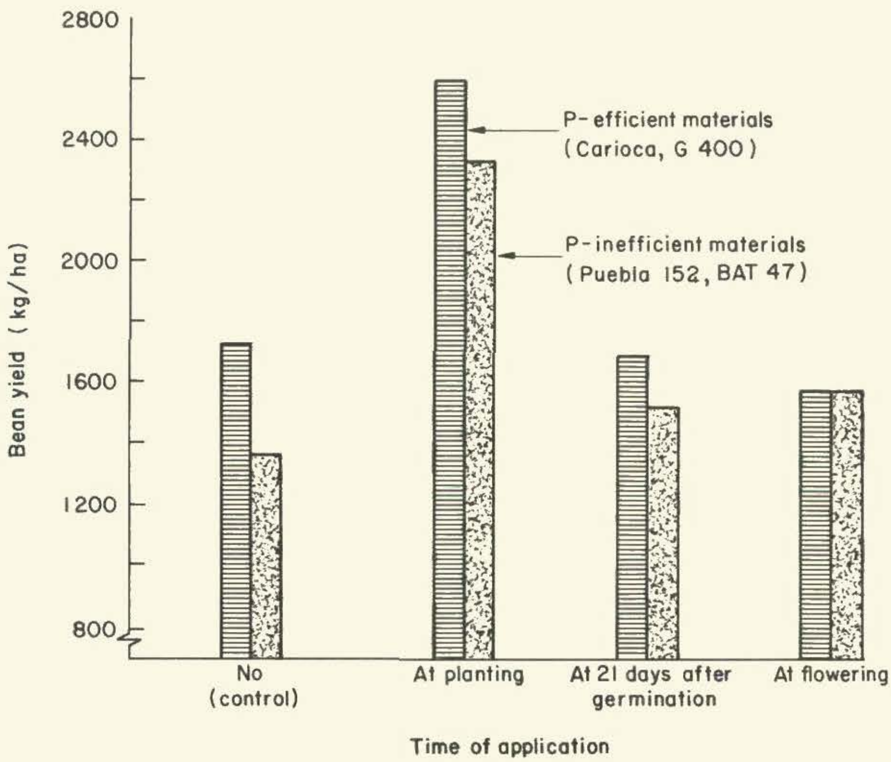

Figure 4. Yields of efficient and inefficient varieties as affected by time of application of P fertilizer (applied in bands) on soil with high P content (25.6 ppm P Bray II).

The best date for phosphorus application, for both levels of phosphorus in the soil, was at planting. On soils with low phosphorus availability, the yields of plots that received phosphorus fertilizer late after planting were almost as low as if they had not been fertilized. The later the time of application relative to planting date, the lower were the yields. The same results were obtained from plots with high phosphorus soils; the only difference was the average yield levels.

These results suggest that the optimum time to apply phosphorus fertilizer for beans is at planting and that the later the application relative to the planting date, the less effective will be the phosphorus fertilizer.

The Effect of Depth of P Fertilizer Application on Bean Yield

In soils where phosphorus is a limiting factor, banding is always recommended. When rainfall distribution is also a negative factor for production, deep phosphorus fertilizer application might be useful, because this will force bean roots to grow deeper in the soil, where soil moisture depletes slower than on the surface. In this experiment, phosphorus fertilizer was banded on two depth levels, 5 and 25 cm below the soil surface. Three levels of phosphorus (0, 66, and 131 kg P/ha) were applied, and four varieties of beans were planted.

Figures 5 and 6 show the average yield of beans at two depths of application of three levels of phosphorus. The average yield did not differ significantly between the two application methods, but there was a consistent tendency for deep phosphorus fertilizer application to give higher yields than superficial applications. The superficial phosphorus application tended to decrease the yield at a high dose of phosphorus (131 kg P/ha).

Comparing the two distinct varieties--Carioca, the efficient, and Puebla 152, the inefficient--both of growth habit 3, yield differences were significant. With no phosphorus fertilizer, both varieties gave better yield on deep preparation than on the superficial one. Carioca on superficial land preparation yielded almost the same as Puebla 152 on deep land preparation. At 66 kg P/ha, Carioca outyielded Puebla 152 no matter what method of application of phosphorus was used. Yield of Carioca was still improved with deep application of 131 kg P/ha, but not with superficial application. Yield of Puebla 152 decreased with both methods of application when phosphorus application was increased to 131 kg P/ha.

In future studies, the combined effect of drought stress immediately after germination, as normally occurs in the Brazilian bean-production area, will be combined with depth of phosphorus application.

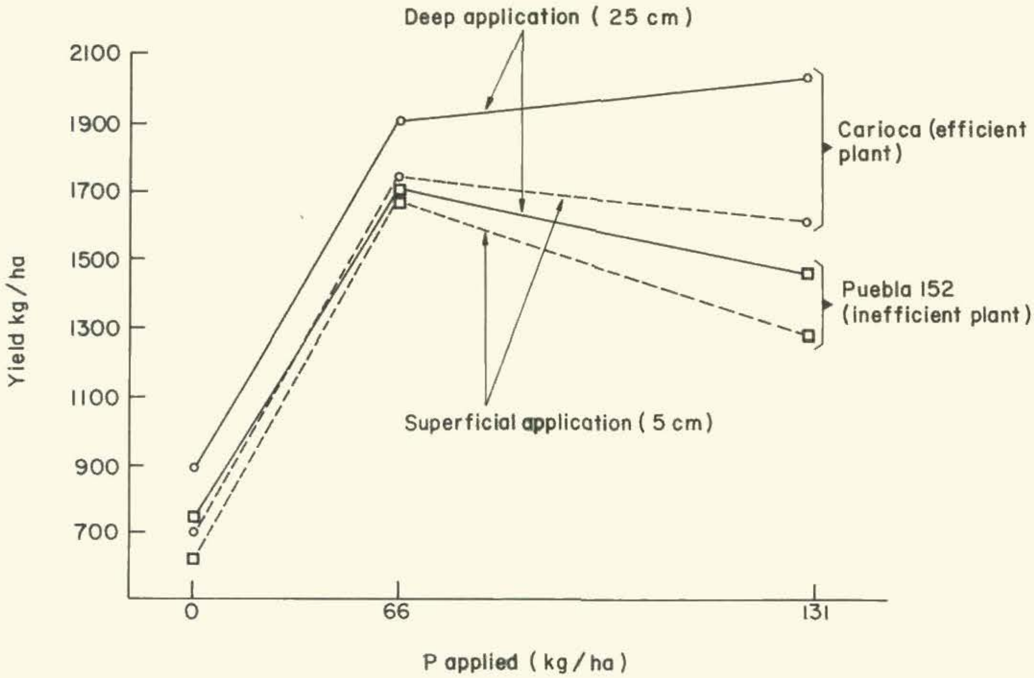

Figure 5. Effect of depth of phosphatic fertilizer application (5 and 25 cm) on average bean yield at three levels of phosphorus application.

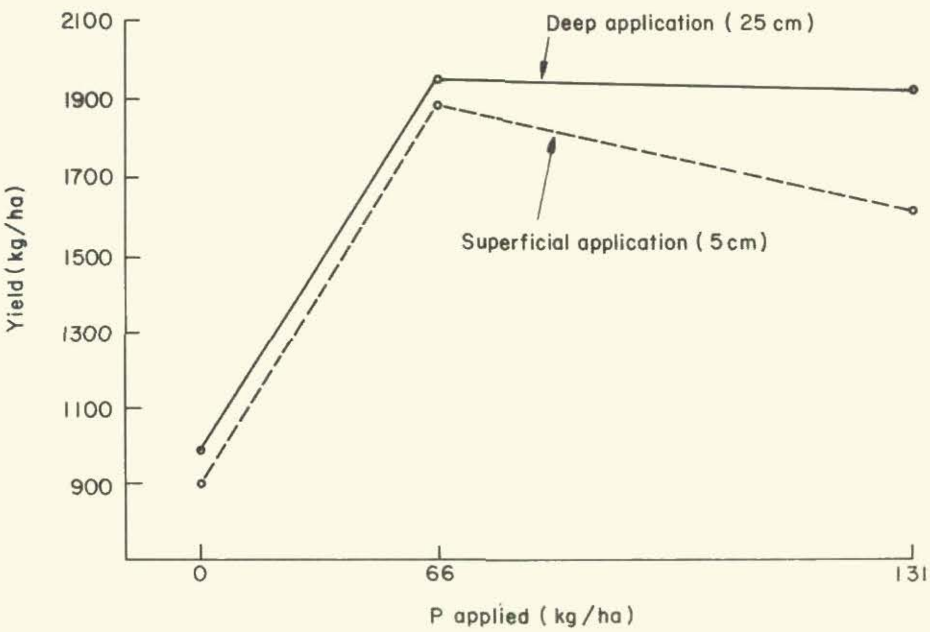

Figure 6. Effect of depth of phosphatic fertilizer application (5 and 25 cm) on average bean yield at three levels of phosphorus.

Use of Alternative P Sources for Bean Production

Before 1981, the IFDC/CIAT Phosphorus Project did not utilize beans (Phaseolus vulgaris) as a test crop to evaluate alternative phosphorus sources except for the period 1976-77 when four successive crops of beans (variety Huasanó) were grown at Las Guacas experimental station in Popayan to compare seven sources of finely ground phosphate rock (PR) with triple superphosphate (TSP). In 1981, however, it was determined that additional information was required to understand the agronomic effectiveness of reduced solubility phosphorus products applied to Andept soils in order to more completely characterize the relative change in phosphorus availability of PR sources with changes in soil chemical properties, and to determine if PR's or modified PR's were economic fertilizer alternatives. As a part of this evaluation, one greenhouse experiment with soil from CIAT-Popayan and two field experiments at CIAT-Popayan were conducted.

The Andept at Popayan, on which the beans were grown, differs considerably from the Oxisols (at Carimagua) and the Ultisols (at Quilichao), on which many previous evaluations of finely ground and modified phosphate rock have been conducted. Table 6 illustrates some of these soil properties from field experiment sites. The most notable differences are the higher percentage of organic matter, the high aluminum concentration, and the increased phosphorus retention capacity from the Carimagua to the El Refugio sites. These properties can also be observed when the Andept from CIAT-Popayan is compared to the Andept from Las Guacas.

Table 6. Properties of soils at several field experimental sites of CIAT.

	Carimagua (Typic Haplustox)	Quilichao (Orthoxic Palehumult)	Las Guacas (Typic Unbrandept)	El Refugio (Typic Dystrandept)
Organic matter (%)	1.9	7.1	12.4	29.2
pH (1:1 water)	4.9	4.1	4.9	4.7
Bray P-1 (ppm P)	1.2	1.8	2.6	1.7
Exch. Ca (meq/100 g)	0.15	0.65	0.16	0.43
Exch. Mg (meq/100 g)	0.02	0.49	0.76	0.29
Exch. K (meq/100 g)	0.04	0.36	0.51	0.12
Exch. Al (meq/100 g)	1.50	2.70	2.55	3.05
Effective CEC (meq/100 g)	1.71	4.20	5.98	3.89
Al saturation (% effective CEC)	88	64	43	78
P retention (% with 100 ppm added)	32	40	52	72

The original results obtained in Las Guacas indicated that yields from the first crop after application of phosphorus were significantly related to the citrate solubility of the finely ground PR source, and that TSP was the most effective source. The decision as to whether or not PR is a suitable substitute for soluble phosphorus depends, among other things, therefore, upon (1) the source of PR available in the region and (2) the comparative cost of that source with the cost of soluble phosphorus sources. For example, at a rate of application of 88 kg P/ha, Gafsa PR was 87% as effective as TSP with North Carolina and Sechura PR, 75%; Huila PR, 66%; and Central Florida PR, 51%; Pesca PR, however, was only 7% as effective as TSP. The Huila PR deposit has the closest relationship to Popayan soil.

Another factor to be considered in determining suitability of phosphorus sources is the residual value. Unlike the mobile nutrients, phosphorus remains in the vicinity of application for long periods of time if erosion is not severe and remains available to provide a portion of the crops' requirements for a number of cropping periods. In Figure 7, it can be observed that the highly reactive PR's (Gafsa and North

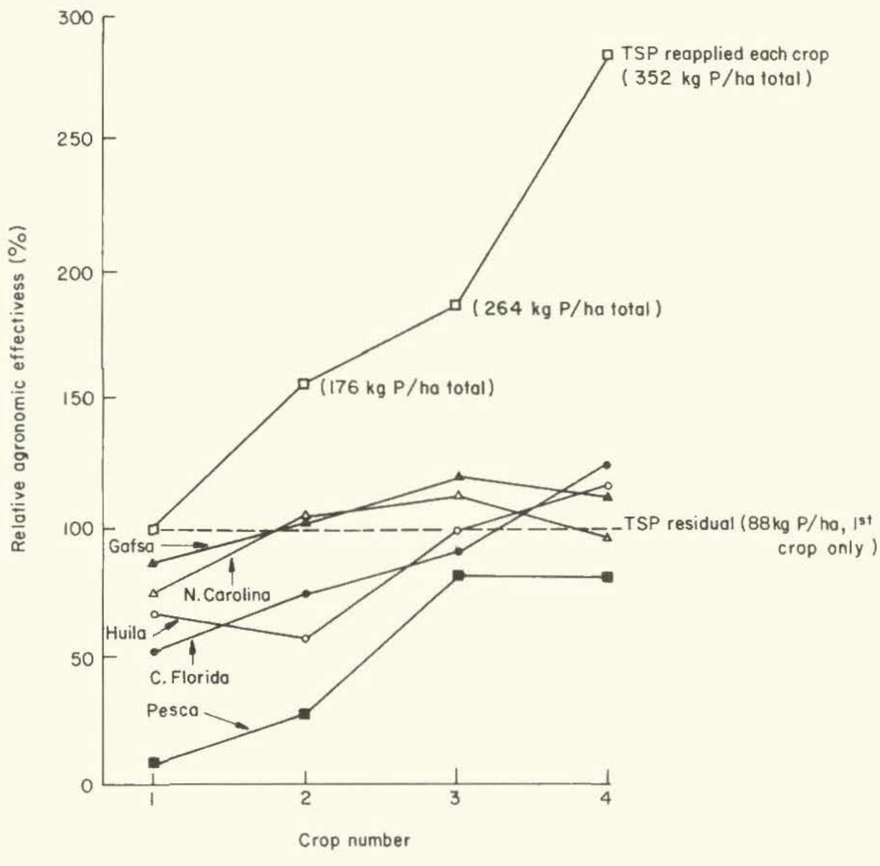

Figure 7. Residual effect of five sources of phosphate rock compared with residual and fresh TSP during four consecutive crops of beans (Las Guacas, Popayan, Colombia).

Carolina) were equal or better than TSP in providing residually available P in each of the three subsequent semesters following the initial cropping period. The medium reactivity PR's (Central Florida and Huila) tended to increase in effectiveness until they became equal to residual TSP in the third crop. The low reactivity Pesca PR increased sharply in effectiveness through the first three crops, as compared to residual TSP, increasing from only 7% to 27% and to 82% during the first, second, and third semesters of cropping.

The comparison of the PR's to residual TSP, as well as to TSP reapplied fresh each semester, illustrated other points of interest. First, it was expected that the effectiveness of TSP would have declined at a rapid rate in an Andosol. In this soil, however, even the residual phosphorus supplied by the soluble phosphorus source remained highly effective. Yields of beans were increased 110%, 109%, and 106% with a single application of 88 kg P/ha during the first three semesters of cropping following the application. This illustrates that not only did TSP remain effective, but also, moreover, the PR's, which increased relative to TSP, were increasing in actual effectiveness. This continued high level of efficient use of residual phosphorus from TSP can also be observed in Figure 8, where it is illustrated that the yield response curves are nearly identical in both the second- and

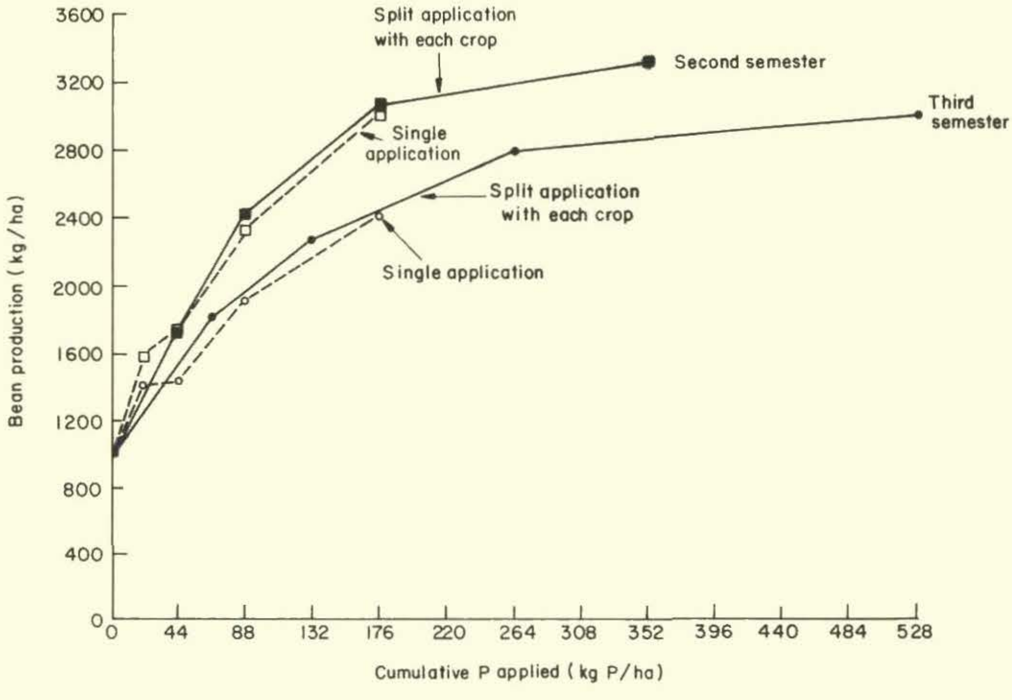

Figure 8. Production of beans as related to rate of TSP application applied either as a single application prior to the first crop or as fresh repeated applications (Las Guacas, Popayan, Colombia).

third-semester crops grown in the experiment regardless of whether a given amount of TSP was applied in a single application prior to the first crop or split into fresh fractional applications of TSP prior to each crop to result in equal doses.

These observations are similar to those obtained in the Carimagua Oxisol with production of Brachiaria decumbens (Hammond, et al., 1981; Annual Report, Pastures Program, 1980). In the Oxisol, the high residual availability of soluble phosphorus was due to the low phosphorus-retention capacity of the soil and the high phosphorus-utilization efficiency of the test crop. While the Andept from Las Guacas exhibits a much higher phosphorus-retention capacity, collaborative research conducted by Dr. P. H. Le Mare at Reading University has shown that a much higher percentage of the adsorbed phosphorus is isotopically exchangeable in the Popayan soil than in the Carimagua soil, which results in higher than expected availability of residual phosphorus in the Popayan Andosol.

The experiments established with beans in CIAT-Popayan during the first semester of 1981 were designed to determine the relative effectiveness of the locally available Huila PR (finely ground) on an Andept with a higher phosphorus retention capacity than that of Las Guacas. In addition, they were designed to determine if mixtures of the PR with varying proportions of TSP would serve to supply the initial plant requirements for water-soluble phosphorus at a cost lower than that of TSP alone. Management factors, including method of application, were also evaluated. With respect to the relative agronomic effectiveness of the finely ground Huila PR, it can be seen from combined data from two separate experiments illustrated in Figure 9, that Huila PR broadcast and incorporated resulted in a Relative Agronomic Effectiveness (RAE) of only 40% when compared with soluble phosphorus in the range between 22 and 198 kg P/ha. This is compared to an average of 65% RAE for Huila PR in the first crop following application in Las Guacas in a similar range of application rates. While these results are not directly comparable due to differences in climatic conditions, a change in bean variety, and the fact that lime was not applied in CIAT-Popayan while 4.5 t/ha of lime was applied in Las Guacas, the lower RAE of Huila PR on the soil with the higher phosphorus retention capacity does agree with the results from greenhouse experiments with eight Colombian soils. In both, a tendency toward decrease in the effectiveness of finely ground PR was shown as the phosphorus retention capacity increased to extremely high levels (unpublished).

It can also be observed from Figure 9 that the method of application greatly influences the effectiveness of Huila PR. While the broadcast and incorporated PR was 40% as effective as TSP, the same material applied in a band near the seed resulted in yields with an RAE of only 16%. While broadcasting and incorporating is always recommended for finely ground PR's, illustrating the magnitude of reduction in yield potential from PR's is important because the majority of the fertilizers applied by farmers in the Popayan region are applied with a localized placement technique, regardless of the type of fertilizer used. In the

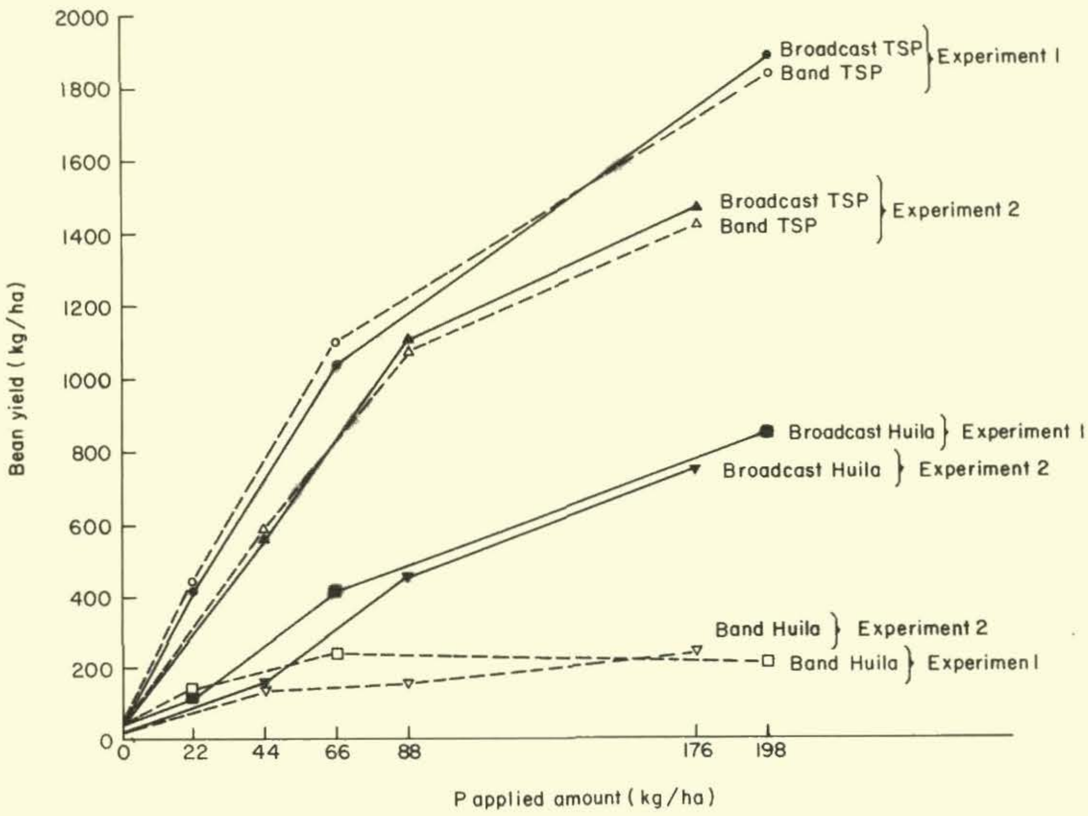

Figure 9. Response of beans (G-4000) to source, amount, and method of P application (El Refugio, Popayan, 1981A).

case of TSP, nearly identical response curves were observed regardless of the method of application. No advantage was observed due to band placement of the TSP because of the extremely low native phosphorus levels in the soil. The potential advantage of reduced contact with the soil by using localized placement was apparently not observed since the broadcast TSP increased the volume of soil from which phosphorus could be extracted. The extremely low native phosphorus status is illustrated by the fact that an average of only 46 kg beans/ha was produced in this experiment without added phosphorus while nearly 1000 kg beans/ha were produced in Las Guacas without added phosphorus.

As was previously demonstrated in the experiment conducted in Las Guacas, the availability of phosphorus from directly applied PR can be expected to increase with time. With respect to utilization of indigenous PR resources with increased initial plant available phosphorus, several material and management modifications have been tested. These include mixtures of PR in varying proportions with soluble phosphorus fertilizers (with and without cogranulation), and partial acidulation of the PR in varying proportions with either H_2SO_4 or H_3PO_4. In an experiment conducted in CIAT-Popayan during the first semester of 1981, the effectiveness of mixtures of TSP and Huila PR and the management of these mixtures were evaluated with line G-4000. It can be observed from Figure 10 that the response of beans to added phosphorus was systematically reduced as the proportion of TSP in the mixture was reduced, confirming that the major portion of applied phosphorus used by the plant was provided by the TSP in this initial cropping period. It can also be observed from this figure that, as the amount of Huila PR applied increases, the importance of incorporating the fertilizer into a large volume of soil also increases.

The theory, suggested in the past, that mixtures of TSP and PR would increase the availability of phosphorus from the PR due to the acidity produced during the dissolution of the TSP was tested by data from this experiment. Figure 11 illustrates two cases in which the modelled response of beans to mixtures of TSP and Huila PR are compared to the response expected with no interaction between sources (i.e., the yield observed with an identical amount of phosphorus from TSP as was present in the mixture when applied alone plus the response to the identical amount of phosphorus from Huila PR when applied alone). In each case, no significant interaction between the sources was observed. This may be attributed to the fact that the phosphorus concentration in the soil solution is initially increased by the rapid dissolution of TSP to a level above that of the solid phase apatite component of the PR, thereby reducing the driving force for dissolution of the PR.

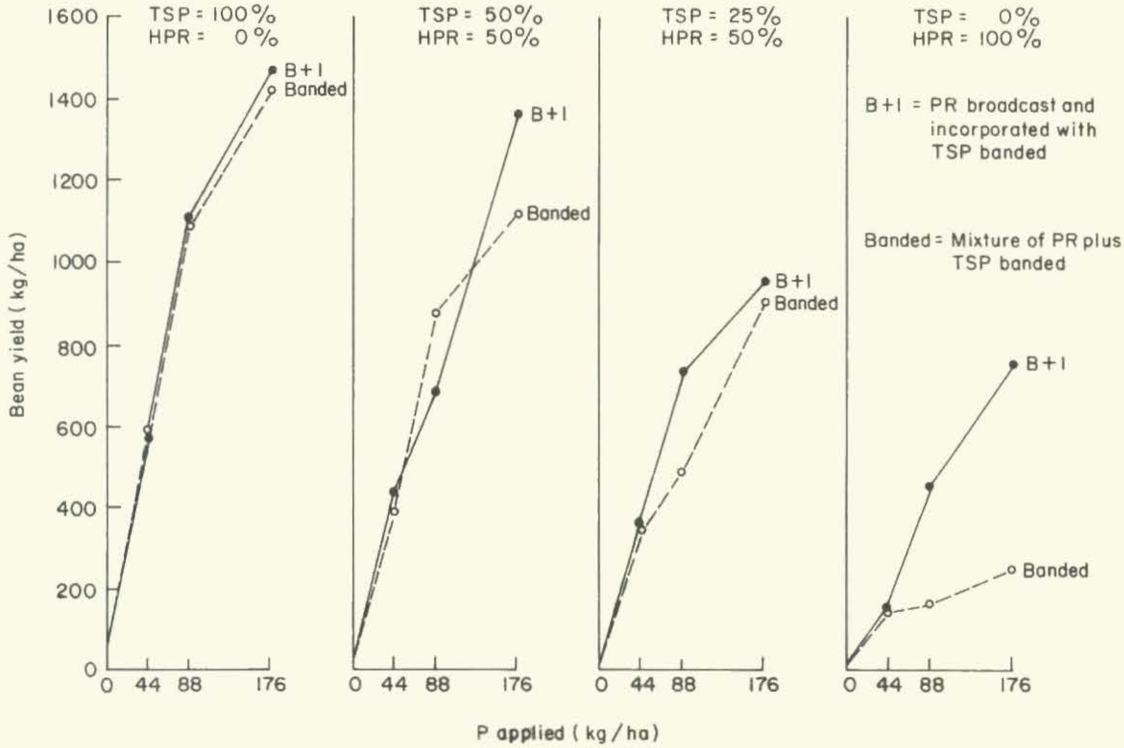

Figure 10. Response of beans (G-4000) to the proportion of total P supplied by TSP or Huila PR in mixtures and their method of application (Popayan, 1981A).

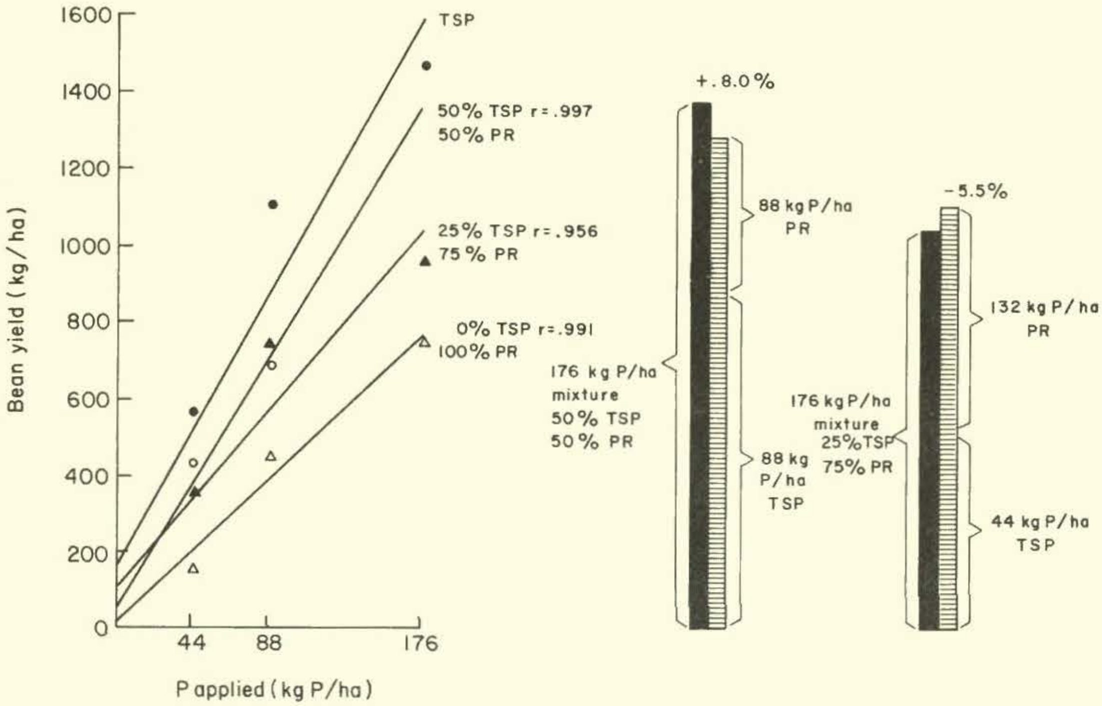

Figure 11. Comparison of response to P from mixtures of PR and TSP to response observed from the components of the mixture when applied separately (El Refugio, 1981A).

Despite this lack of interaction in the initial stages, the practical benefit of applying mixtures is still high for crops with a high phosphorus requirement since, as can be seen from Figure 12, (1) the goal of increasing initial production above that of finely ground PR alone was achieved, and (2) the phosphorus fertility level of the soil can be expected to show significant improvement, which can be drawn upon in subsequent cropping periods, through the presence of both the TSP and the lower cost indigenous material. Cropping to measure residual response is now in progress.

It can also be seen from Figure 12 that even in the initial cropping period, the distance between response curves is reduced and there is little difference between TSP and the mixtures, or even the PR alone, when considering the cost rather than the amount of phosphorus fertilizer applied. At the time the experiment was conducted, retail costs in Santander were approximately $0.93 (U.S.) per kilogram P_2O_5 from TSP as compared to only $0.50 (U.S.) per kilogram P_2O_5 from Huila PR.

Legume Comparison under Stress Conditions

Vigna sp. soybeans and Phaseolus beans were tested under nonstress, low phosphorus, and high aluminum and manganese stresses at CIAT-Quilichao Station. The species and varieties used in these experiments were as shown in Table 7.

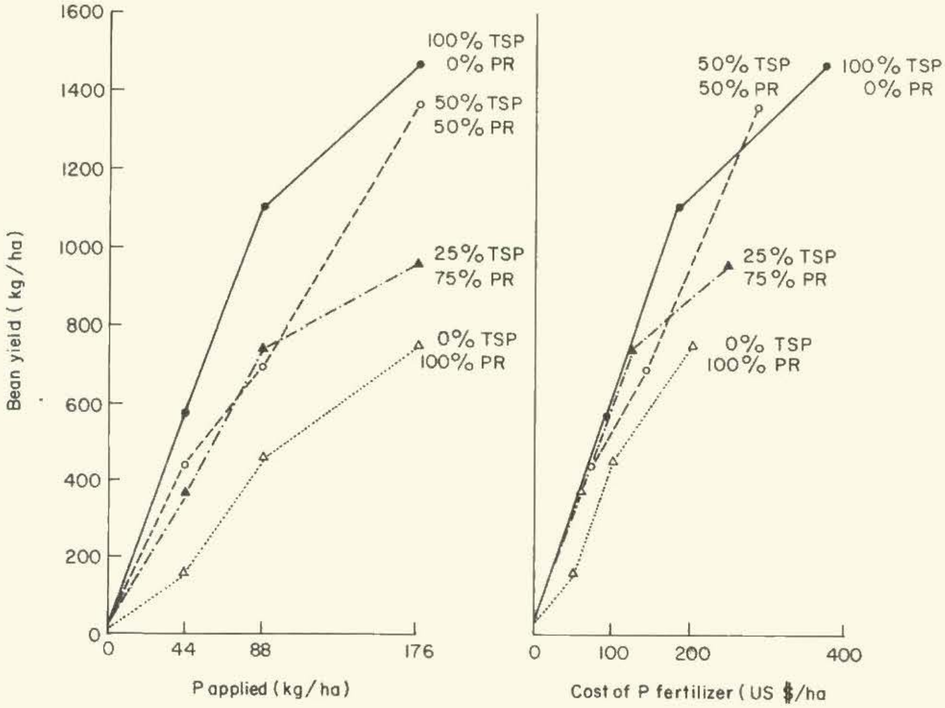

Figure 12. Response of beans (G-4000) to broadcast P from mixtures of Huila PR and TSP as related to amount of P applied vs. cost of P applied (El Refugio, Popayan, 1981A).

Table 7. Species used in legume comparison under stress conditions, Quilichao Station, 1981.

Common name	Species	Variety	Observations
Cowpea	Vigna unguiculata	CV TUV-1193-059D	
Adzuki bean	Vigna angularis	CV Shunagon	
Green gram	Vigna radiata	CV Local 2808	
Soybean	Glycine max L.	ICA-Tunia	Nontolerant to acid soil
Soybean	Glycine max L.	L 129	Tolerant to acid soil
Common bean	Phaseolus vulgaris L.	Carioca	Tolerant to acid soil
Common bean	Phaseolus vulgaris L.	G 4000	Tolerant to acid soil
Common bean	Phaseolus vulgaris L.	Puebla 152	Nontolerant to acid soil
Common bean	Phaseolus vulgaris L.	BAT 47	Nontolerant to acid soil
Tepary bean	Phaseolus acutifolius	G 40010	

Low phosphorus conditions were obtained by banding 22 kg P/ha plus an application of 5000 kg/ha $CaCO_3$ equivalent giving an aluminum saturation rate of less than 10%. High stress to aluminum and manganese (at 65% aluminum saturation) was obtained by broadcasting 1000 kg/ha $CaCO_3$ equivalent and 131 kg P/ha. Dolomitic lime and triple superphosphate were used as $CaCO_3$ and phosphorus sources, respectively. Nitrogen, potassium, and some microelements were also added to prevent deficiencies. The experimental site, previously a Zornia seed-multiplication field, had received phosphorus fertilizers, resulting in moderate phosphorus stress. The results are shown in Figures 13 and 14.

In general, stress to phosphorus is more detrimental to yield than stress to aluminum and manganese for all species, even at high aluminum saturation rates (65%), but due to high organic matter in the soil

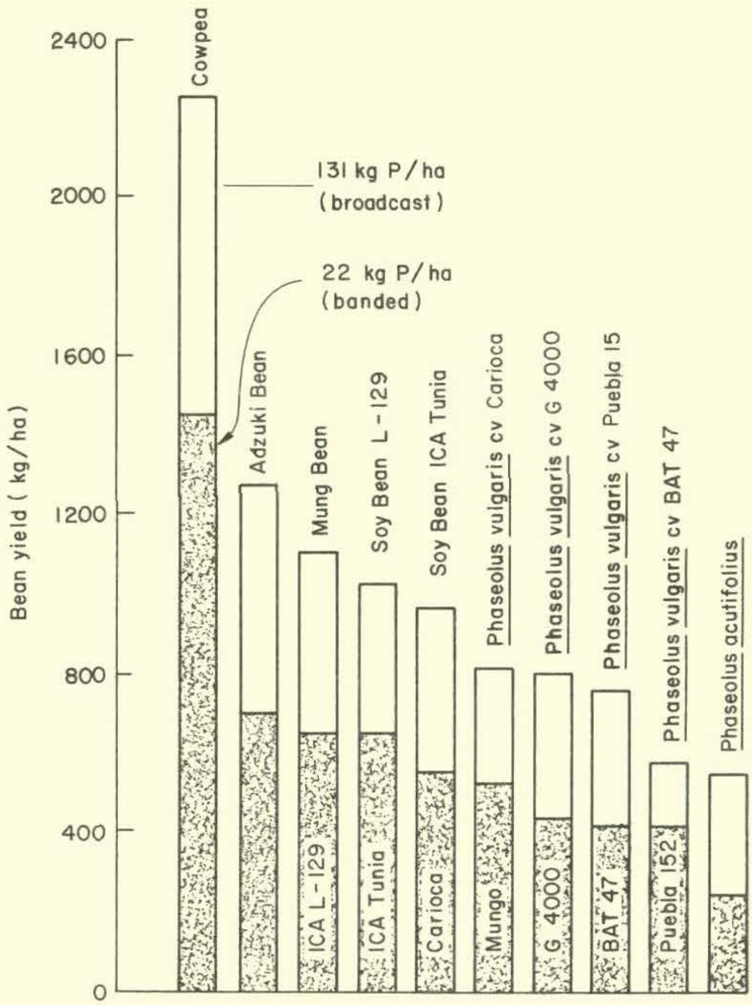

Figure 13. Yield (kg/ha 14% hum.) of various bean species under two different levels of phosphorus application (22 kg/ha and 131 kg/ha).

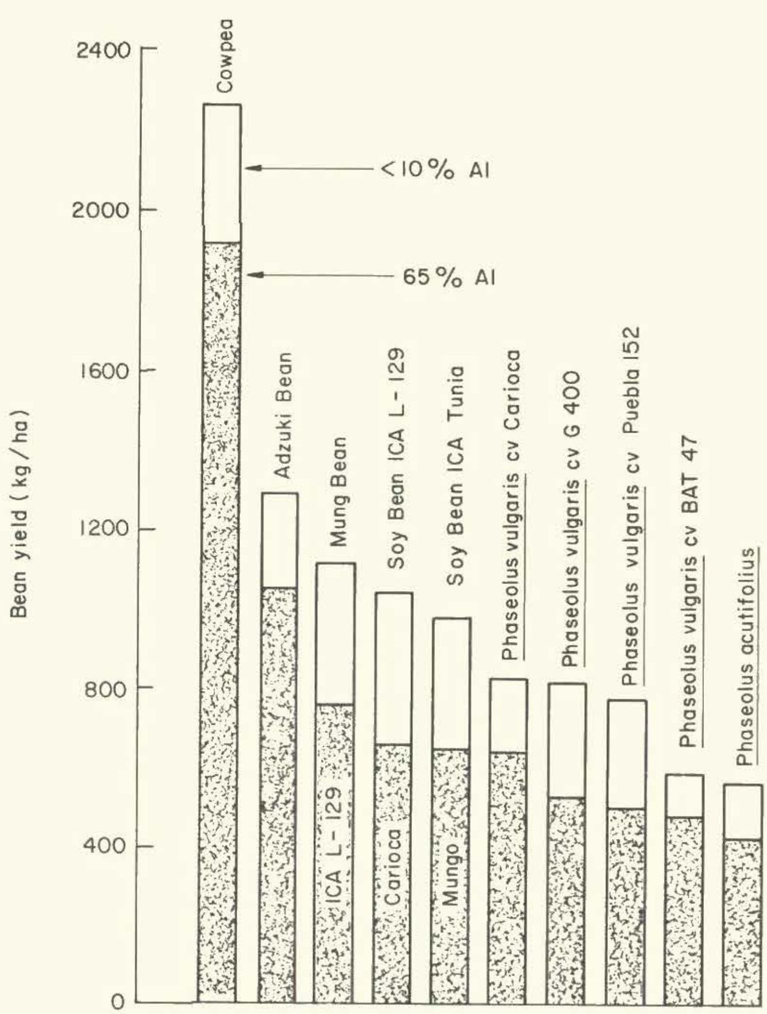

Figure 14. Yield (kg/ha 14% hum.) of various bean species under two different levels of Al saturation (65% and less than 10%).

(6.5%), the toxicity of aluminum became less severe. Cowpea and adzuki beans were the two species that performed well under any conditions of stress and nonstress, whereas Phaseolus acutifolius was the opposite. Yield of mung bean under nonstress conditions was next to cowpea and adzuki, but it performed worse than soybean and Phaseolus vulgaris cv Carioca under phosphorus, aluminum, and manganese stresses.

Under phosphorus stress, soybeans were superior to all Phaseolus vulgaris varieties. Under aluminum and manganese stress, Carioca outperformed soybean cv ICA-Tunía, which is not tolerant to acid soil conditions, but not L 129 soybean with tolerance to acid soil conditions. In general, Phaseolus vulgaris was the second least efficient species to low phosphorus among those tested: The most inefficient to low phosphorus and also the least tolerant to aluminum and manganese toxicities was Phaseolus acutifolius. Tolerant bean varieties always outperformed the nontolerant beans. These results again confirm the validity of the screening method (as described in the CIAT, Annual Report 1979) using yield as a parameter for evaluation.

Phenological data (Table 8) showed that days to flowering for all species was longer due to aluminum and manganese than to phosphorus stress conditions. The shortest days to flowering were obtained under nonstress conditions. The delay in physiological maturity was also longer in the plots with aluminum and manganese stress than in those under phosphorus stress. Changes in their phenology were greater in *Phaseolus vulgaris* than in other species due to aluminum and manganese stress, and not to phosphorus stress. This might be the effect of aluminum toxicity damaging the root system, so that the plant constantly produces new roots at the expense of overall growth. Yield reduction due to stress for phosphorus and aluminum and manganese was caused mainly by the decrease of pod number per plant in all species. The greatest loss in pod number per plant occurred in aluminum and manganese-stressed plots. The lowest pod number was found in *Phaseolus vulgaris* and cowpea under nonstress conditions, and the changes due to different stresses were also minimum. The species *Phaseolus acutifolius*, soybean, and adzuki beans have a high number of pods per plant and stresses severely affect pod numbers in these species. Grain number per pod was the least affected yield component by the stresses in all species, but there are great differences in grain number per pod among species due to length of pod. *Phaseolus vulgaris* has the highest 100-grain weight. Only adzuki beans have 100-seed weight close to *Phaseolus vulgaris*. In many cases, the 100-grain weight increased under aluminum and manganese stress in crops such as soybean, *Phaseolus acutifolius*, adzuki bean, and cowpea but not in *Phaseolus vulgaris*. This might be related to the pod length of the species: the longer the pod, the greater the number of seeds to be filled, so when a stress occurs most of the seeds are not filled or they abort (resulting in reduction of number of grains per pod); the remaining seeds in the pod would be the ones receiving all the carbohydrate supply.

At all growth stages in all species, the highest phosphorus content was observed under nonstress conditions; the root had the lowest phosphorus content, whereas the leaves had the highest. Under both stress conditions, no significant difference in phosphorus content can be detected, which means that even if there is sufficient phosphorus supply, no absorption of phosphorus occurs under aluminum and manganese toxicity pressure. At maturity, the highest phosphorus content in the grain was found in soybeans, followed by *Phaseolus acutifolius* and mung beans. The lowest phosphorus content was in cowpea and adzuki beans, *Phaseolus vulgaris* lying in between. The phosphorus-absorption pattern was the same as the phosphorus content. The highest phosphorus absorption was found in nonstress conditions by all species and at all growth stages. The roots absorbed phosphorus the least and the leaves absorbed the most under both stress and nonstress conditions. At maturity, the highest phosphorus absorption was by the grain. Under phosphorus stress conditions, cowpeas and soybeans absorbed most phosphorus and *Phaseolus vulgaris* the second lowest, and the lowest phosphorus absorption was by *Phaseolus acutifolius*. Under aluminum and manganese stress conditions, cowpeas and adzuki beans had the highest

Table 8. Phenological and yield component data of various bean species grown under three soil stress (aluminum + manganese and phosphorus) and nonstress (no) conditions.

Identification	Days to flowering (no.)			Days to physiological maturity (no.)			Pods/plant (no.)			Grain/pod (no.)			100-seed weight (g)		
	Al + Mn	P	None	Al + Mn	P	None	Al + Mn	P	None	Al + Mn	P	None	Al + Mn	P	None
Phaseolus vulgaris															
Carioca	41.0	40.0	27.8	81.3	71.8	72.8	3.3	4.0	7.0	5.2	4.8	4.6	23.7	23.4	25.6
G 4000	41.8	40.8	39.0	84.8	77.3	77.8	4.9	5.2	7.7	5.5	4.6	4.9	13.6	15.4	17.0
Puebla 152	42.3	40.8	38.0	83.3	76.5	79.0	2.9	4.2	6.5	4.2	4.0	3.9	22.2	24.3.	24.8
BAT 47	44.3	38.5	35.5	83.8	72.3	71.8	4.0	4.8	7.7	4.7	4.9	5.0	17.7	16.9	18.0
Average	42.4	40.0	37.6	83.3	74.5	75.4	3.8	4.6	7.2	4.8	4.6	4.6	14.3	20.0	21.4
Glycine max															
L 129	40.3	39.3	38.3	99.5	101.0	99.0	17.7	19.8	27.5	1.9	1.9	1.9	14.3	13.7	13.8
ICA Tunía	35.0	33.8	32.3	100.5	99.3	94.8	16.1	13.1	18.2	2.0	2.0	2.1	20.4	18.7	16.5
Average	37.7	36.7	35.3	100.0	100.2	96.9	16.9	16.5	22.9	2.0	2.0	2.0	17.4	16.2	15.2
Phaseolus acutifolius															
G 40010	38.3	38.0	35.8	71.0	67.3	67.0	10.8	7.7	16.0	4.8	4.2	4.8	9.5	7.9	8.2
Vigna radiata															
Local 2808 (Mungo bean)	44.5	42.5	40.5	82.8	72.0	70.5	5.0	8.1	14.7	12.9	12.7	12.4	2.8	3.0	3.4
Vigna angularis															
Adzuki Shunagon	45.8	44.8	42.8	91.0	14.0	89.0	16.9	6.4	11.4	6.4	6.8	6.8	9.8	7.8	7.9
Vigna unguiculata															
CV TUV-1193-059-D (Cowpea)	52.3	51.3	50.0	86.0	84.3	82.0	7.8	4.6	7.1	12.5	14.1	14.5	16.7	11.5	13.0

values in phosphorus absorption and Phaseolus beans the second lowest. The lowest absorption of phosphorus was by mung beans. This indicates that cowpea and adzuki beans removed the highest quantity of phosphorus from the soil; Phaseolus vulgaris was the second lowest. Thus, quantitatively, Phaseolus beans absorbed less phosphorus than the other species. Cowpea absorbed the highest quantities of phosphorus, but cowpea yielded at least three times higher than Phaseolus beans under CIAT-Quilichao conditions.

Growth Habit Competition

The objective of this experiment was to evaluate the competition of beans of different growth habits, planted on ridges of 0.6 m, one adjacent to the other. The row spacing of 0.6 m with 20 plants/m^2 was chosen because it is the most common planting pattern used at CIAT.

In 1980B, three varieties, Diacol Calima, Porrillo Sintético, and Puebla 152, which represent growth habits I, II, and III, respectively, were planted each in a randomized block design. Puebla 152 was not harvested due to severe tropical mite (Polyphagotarsonemus latus Banks) attack. The experiment was repeated in 1981A, with L 24, Porrillo Sintético, and G 02959 representing growth habits I, II, and III, respectively. In general, the yield reduction due to competition by growth habit was statistically nonsignificant, but some tendencies can be seen in Figures 15 and 16 for the two consecutive semesters.

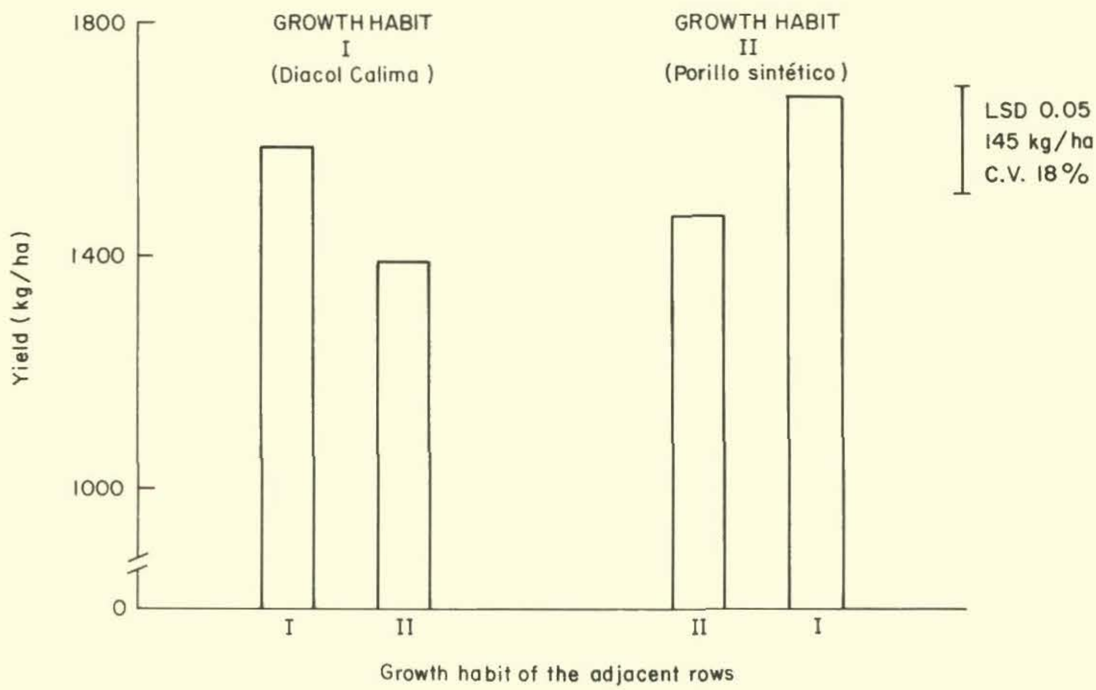

Figure 15. Effect of competition from adjacent rows with different growth habits on bean yield on ridges of 0.6 m, 1980B.

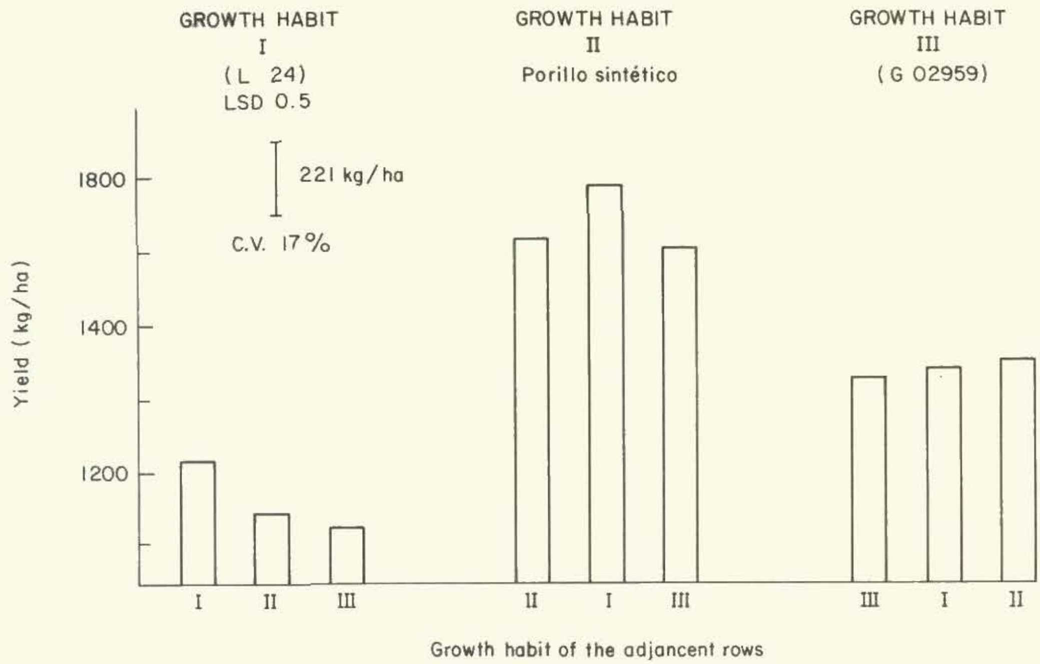

Figure 16. Effect of competition from adjacent rows with different growth habits on bean yield on ridges of 0.6 m, 1981A.

Growth habit I gave the highest yield when planted adjacent to the same growth habit. The competition effect causing yield reduction was observed when the neighboring rows were of a different growth habit. Growth habit III suppressed the yield of growth habit I most. The highest yield of growth habit II was obtained when it was planted next to growth habit I, and no yield differences were observed when it was planted with growth habit III. No yield difference was observed in growth habit III due to competition from adjacent rows of growth habit I and II; the lowest yield was obtained when its adjacent rows were of the same growth habit, suggesting that growth habit III needs a wider space for planting than the 20 plants/m^3 density. These results indicate that randomization of plots with different growth habits using 0.6 m can be done with no major effect on yield of the adjacent rows. Plots with more than two rows will give more homogeneous yields because the inner rows are not affected.

Cropping System Interactions

The objective of this experiment was to study the yield and adaptation of some advanced bush bean breeding lines when cultivated under monoculture, relay, and direct association with maize. Twenty advanced breeding lines with different yields, ranking from the best to the poorest yielders, were planted in randomized block design on fertile soil at Ingenio Providencia, located in Palmira, Colombia. For relay planting, the maize was planted 5 months earlier. Two treatments with and without plant protection were chosen. Bean population was around 20 plants/m^2. Mean yield differed significantly among cropping systems; the highest yield was obtained using monoculture; yields from relay cropping were second (Figure 17).

Plant protection gave a significant yield increase in monoculture and direct association, but not in relay cropping. Insect incidence, of such pests as Empoasca sp., tropical mites, and Chrysomelids, was more severe in monoculture and direct association than in relay (CIAT 1979). Outstanding varieties under protected conditions also performed well under nonprotected conditions. Combined analysis of variance of these three cropping systems showed a highly significant interaction of variety by cropping system, but the variance of the main effect of varieties was still dominant. By computing the relative contribution of each variety to the variance of variety by cropping system, it was found that variety Rojo 011 was the largest contributor to this interaction. If this particular variety was not included, there was no significant interaction of variety by cropping system. In Figure 18 where yields are ranked, it is shown that only one out of three outstanding varieties (within LSD 0.05) in the monoculture system was found within the group of outstanding varieties in relay planting, and three varieties were among the best in direct association. This means that outstanding materials selected in the monoculture system can be identified as outstanding in direct association but not in relay planting. This suggests that selection of varieties for relay planting could not be done under a monoculture system. It appears that the climbing ability

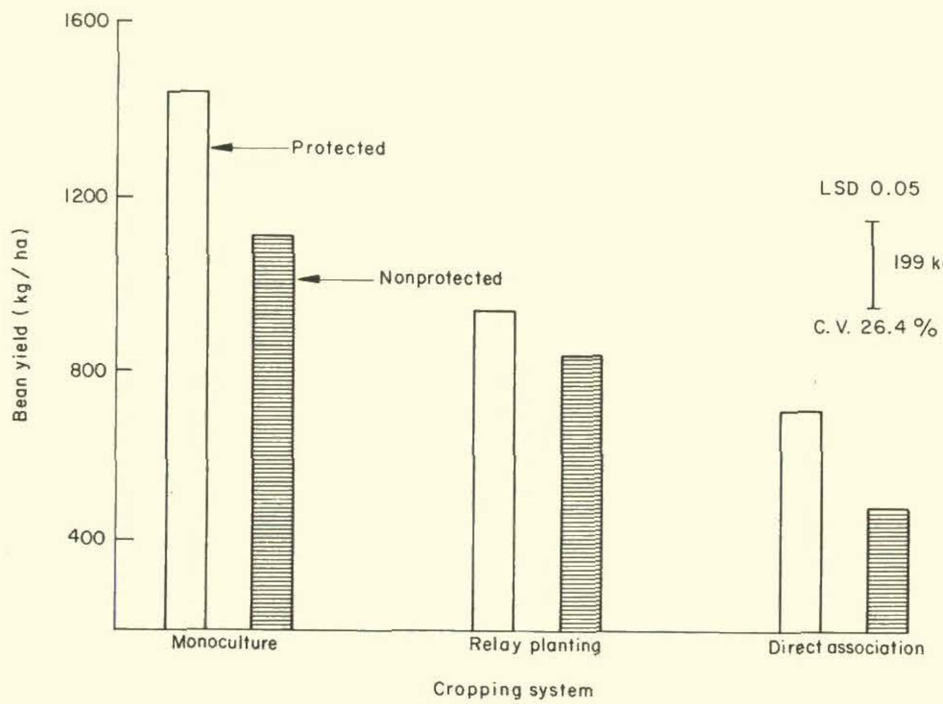

Figure 17. Mean bean yields (14% hum.) within various cropping systems, under protected and nonprotected conditions.

of a particular line is responsible for the interactions. Lines with a guide climb in relay systems and increase yields, while those without guides do not show this effect. Further studies are needed to confirm the above results.

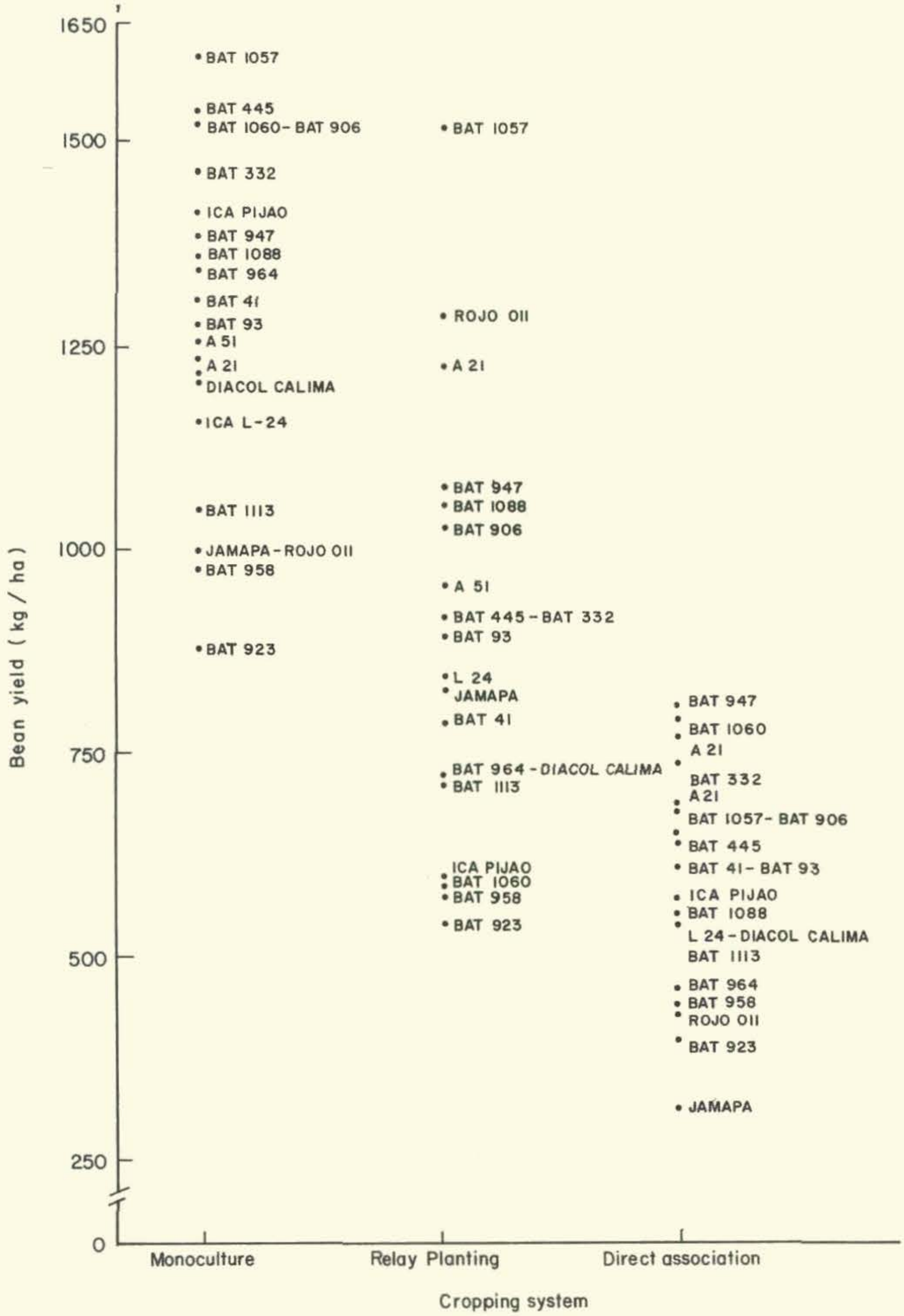

Figure 18. Yield of 20 bean varieties grown in different cropping systems.