FINAL REPORT

PROJECT AID-SCI 936-5442

"Development of Appropriate Technology for Overcoming Different Mechanisms of P Retention in Central American Soils

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"Development of appropriate technology for overcoming different mechanisms of P retention in Central American soils"

The basic hypothesis of this project was to develop a system of soil classification based on Phosphorus retention properties. It was hoped that because many of the properties related to P retention (clay content, clay mineralogy, and organic matter content) were used in the US Soil Taxonomy, some relation could be established between the US soil taxonomy and P retention properties. A relationship had been proposed by Fox and Searle(1978), Sanchez and Uehara (1980), and Juo and Fox (1977) for soils of the tropics but these workers did not include many of the great groups frequently found in Central America (Humitropets, Dystropepts, Haplohumults).

The project agreement signed on August 1, 1985, called for three specific activities:

1) Field sampling and characterization of mechanism of P retention of 30 soils from Costa Rica and Panama

2) Determination of germplasm of common bean (<u>Phaseolus vulgaris</u>) adapted to growth under conditions of: (1) low P availability and (2) high P retention , and (3) low levels of P application

3) Field experimentation using ten of the sites charactirized under activity (1) representing different mechanisms of P retention to see if different methods of P application were more appropriate in soils showing different mechanisms of P retention.

The first activity was mainly carried out by the University of Costa Rica. However, since equipment for mineralogical analyses is not available in Central America, this work was supplemented by mineralogical analyses carried out at the SCS laboratory in Lincoln, Nebraska, and use was made of previous mineralogical characterizations carried out by SMSS principally in relation to previous ROCAP projects in Central America. P retention isotherms were done in the soils laboratory of CATIE, using the method of Fox and Kamprath (1970). The second activity formed the basis of a CATIE-UCR M.S. thesis of Mr. Wilbert Campos Alvorado, who received support from the project. The third activity was carried out at four sites in Costa Rica by the University of Costa Rica and at Turrialba by CATIE. Experimentation at a site in Panama formed the research of a Panamanian M.S. student, Mr. Alexis Samudio, whose studies in the CATIE M.S. program were financed by the project.

The bulk of the results of the project are contained in a report submitted to CATIE by the University of Costa Rica and the two M.S. theses. All of these documents are in Spanish. It was hoped to produce a fourth document, a datebase of soils information in Central America but various difficulties related to the different forms in which this informaion is stored, have made this impossible. A manuscript was prepared from some of the University of Costa Rica work and has been submitted to the Soil Science Society of America Journal. Other manuscripts are in preparation. Four interim progress reports were submitted to AID during 1986, 1987, and 1988. Presentations based on project activities were made at meetings of the American Society of Agronomy in 1986 and 1988. A presentation was also made in Guatemala in 1988. These results are most conveniently summarized in three categories: characterization of soils with bean germplasm with respect to its adaptation to low soil phosphorus, high soil P retention, and low levels of P application; and field experimentation to determine nature of P response related to soil and germplasm characteristics.

Much of the rationale for the project can be found in the chapter on Management Considerations for Acid Soils with High Phosphorus fixation capacity by P.A. Sanchez and G. Uehara in the ASA volume on the role of Phosphorus in Agriculture (Khashwane, Sample, and Kamprath , eds. 1980), where a distinction between precipitation and sorption reactions in P retention is made and the possibility of overcomoing P retention by hoigh and low input strategies proposed. Because of the volcanic origin of many of the soils of Central America, it was thought worthwhile although many are not classified as Andepts, it was thought worthwhile to try to separate soils with precipitation and sorprtion reactions though this is probabaly an oversimplification and both processes apparently occur to some degree in most soils. As suggested by Sanchez and Uehara (1980), P sorption isotherms (Fox and Kamprath, 1970) were used to evaluate amounts of P retained. It was hoped the apparent relationship beteween the form of the isotherms and the taxonomy (Sanchez and Uehara, 1980; Fox and Searle, 1978) could be refined to distingui various integrades between Andisols and Ultisols (Dystrandepts, Dystropepts, Humitropepts, Humults) which appeared to common in Central America. While it was first thought to correlate P retention with the factors cited by Sanchez and Uehara (clay mineralogy, clay content, x-ray amorphous colloid content, exchangeable aluminum, soil organic matter, and flooding), more recent work has indicated the importance of other factors such as total surface area in highly weathered soils of West Africa (Juo and Fox,1977) and iron and aluminum bound with humus in Andosols of Japan (Wada and Gunjigake, 1979) and New Zealand (Parfitt, Hume, and Sparling, 1989). Field experiments were run to determine external P requirements. Both a high input (massive P applications and liming) and a low input (banding, cultivars adapted to low P, P imbibition by seeds) were tried as a strategy for overcoming porblems of P retention. Because of the inavailability of Phosphate rock in Central America, its use was not considered as a management alternative.

Characterization of soil properties.

The thirty six profiles characterized by the University of Costa Rica team are summarized in Table 1. The classification was revised by Dr. Ray Bryant of Cornell Univeristy who spent his sabbatical from January to July of 1988 as consultant to the project. He attempted to combine this soils information with the existing SCS database on soils of Central America. Unfortunately, there were considerable differences in the information available such as New Zealand P, bulk density, dithionate iron and aluminum, and mineralogical characterizations, making it impossible to produce a comprehensive database. Of the 36 soils, 11 were classified as ULtisols, 12 as Andepts, 7 as other Inceptisols (Dystropepts and Humitropepts), 3 as Alfisols, 1 as a Mollisol, and 2 could not be classified with the information available. A good mix of soils with andic and non-andic properties was obtained; but reclassification of the soils in the Andisol order of the 1990 revision of the Taxonomy was not attempted as this would require field and lanboratory data not obtained during the life of the project.

Table 1.CLASSIFICATION AND SOME PROPERTIES OF SOILS CHARACTERIZED IN PROJECT

	pH NaF	%Al Sat	O.M.	% Clay
1, GUARUMAL (Puriscal) -Typic Paleustult				
Ah (0-18)	9.2	40.0	3.55	64
Bt1 (18-70)	9.8	78.9	0.47	68
Bt2 (70-110)	10.1	83.2	0.13	64
C1 (110-150)	9.8	85.6	T	56
2. LA LEGUA (Puriscal, Costa Rica) -Typic Paleustult				
Ah (0-45)	9.5	9.0	4.36	48
AB (45-65)	9.7	9.3	3.02	50
Bt (65-115)	9.9	5.1	T	56
C1 (115+)	9.8	55.8	T	50
3. GRIFO ALTO (Puriscal, Costa Rica) - Typic Rhodulstalf				
Ah (0-20)	10.8	9.8	9.38	22
AB (20-47)	9.8	29.8	3.35	52
Bw (47-100)	9.6	41.2	0.87	58
C (100+)	9.7	61.5	T	50
4. AGROPECUARIO (Puriscal, Costa Rica) - Andic Humitropept				
Ah (0-30)	9.7	7.5	4.69	64
AB (30-45)	9.5	6.0	0.20	70
Bt1(45-110)	9.5	4.7	T	70
5. PARAISO (Cartago, Costa Rica) - Typic Haplohumult				
Ah (0-27)	9.9	54.8	8.04	58
AB (27-43)				
Bt1(43+)	9.7	69.2	0.54	74
6. SANATORIO DURAN (Cartago) - Typic Haplohumult				
Ah1 (0-20)	9.6	6.2	2.75	14
Ah2 (20-45)	9.5	7.1	4.02	18
Bw (45-100)	9.6	2.1	4.62	19
7. IPIS (Guadalupe, Costa Rica)- Typic Humitropept				
Ah1 (0-18)	10.6	4.7	6.30	6
Ah2 (18-36)	10.6	3.2	4.36	6
AB (36-57)	10.5	3.2	3.62	6
Bw (57-150+)	10.5	3.8	2.14	6
8.LA SOLEDAD (Heredia, Costa Rica) - Typic Dystrandept				
Ah1 (0-30)	9.8	1.4	4.36	34
Bw (30-70)	9.7	1.2	T	56
BC (70-100)	9.5	5.2	T	52
9. FRAIJANES (Fraijanes, CR) - Hydric Dystrandept				
Ah1 (0-22)	11.5	12.4	12.46	4
Ah2 (22-34)	11.2	6.3	10.32	2
Bw1 (34-80)	11.0	13.6	3.89	6
Bw2 (80-110)	11.0	6.3	2.01	2
10. NAZARETH (Upala, CR)- Aeric Tropaquept				
Ah1 (0-8)	8.7	1.2	6.00	24
Ah2 (8-20)	9.2	0.3	T	34
Bw1 (20-36)	9.1	0.5	T	50

	pH NaF	%Al Sat	O.M.	% Clay
11. SAN JOSE DE UPALA (Upala, CR) - Typic Kandhapludalf				
Ah (0-25)	9.0	2.3	0.87	68
AB (25-43)	9.0	3.2	2.21	64
Bt (43-100)	9.3	2.6	T	82
12. ROSARIO (Rosario de Upala, CR) - Oxic Dystropept				
Ah (0-22)	9.0	1.8	2.68	56
Bw (22-47)	9.2	2.4	T	72
IIA (47-70	9.2	3.5	T	74
IIBw (70-120+)	9.4	4.1	T	12
13. BIJAGUA DE UPALA (Costa Rica) - Entic Dystrandept				
A11 (0-20)	10.5	2.1	11.12	8
A12 (20-36)	10.6	2.0	5.36	20
AB (36-50)	10.6	2.4	3.35	70
Bw (50-100)	10.5	1.4	T	30
14. FORTUNA DE SAN CARLOS (Costa Rica) - Entic Dystrandept				
Ap (0-20)	10.8	3.4	6.36	4
Bw (20-40)	10.6	3.0	2.68	4
C1 (40+)	10.8	2.3	2.68	10
15. VALLE HERMOSO (Coto Brus, Costa Rica)				
Ah (0-32)	11.3	3.2	10.79	4
AB (32-50)	11.0	7.6	2.95	6
Bw1 (50-80)	10.8	7.2	1.20	2
Bw2 (80-130)	10.9	6.5	1.60	2
16. LA UNION (Coto Brus, CR) - Typic Hydrandept				
Ah (0-14)	11.0	5.1	9.85	8
AB (14-26)	11.0	6.7	8.71	14
Bw1 (26+)	10.9	12.0	3.62	2
17. SAN ANTONIO (Coto Brus, CR)- Hydric Dystrandept				
Ah (0-30)	11.4	56.8	14.07	8
Ah2 (30-50)	11.3	11.2	15.41	10
AB (50-75)	11.2	7.5	7.37	8
Bw1 (75+)	11.0	7.8	4.02	4
18. SABANILLA (Coto Brus, CR) - Typic Dystropept				
Ah (0-35)	10.0	65.1	4.62	66
AB (35-90)	10.1	72.5	0.34	70
B (90+)	9.6	40.8	T	70
19. LA PINERA (Buenos Aires, Costa Rica) - Typic Tropudult				
Ah (0-23)	9.7	9.6	3.02	58
Bt1(23-70)	10.0	4.1	0.34	70
Bt2 (70+)	9.8	6.2	T	64
20. SAN MARCOS PEJIVALLE (CR) - Typic Haplohumult				
Ah (0-13)	9.3	4.2	6.37	55
AB (13-47)				
Bt (47+)	9.8	27.2	1.84	75

	pH NaF	%Al Sat	O.M.	% Clay
21. PALMARES (PEREZ ZELEDON) (San Isidro, CR)-Typic Plinthudult				
Ah (0-25)	10.0	47.0	7.71	45
AB (25-50)	10.2	37.2	5.85	59
Bt (50+)	10.0	5.1	3.75	71
22. CALABACITO (Panama) - Typic Plinthudult				
Ap (0-15)	9.0	41.9	3.81	47
Bt1 (15-26)	9.5	77.9	2.04	49
Bt2 (26-43)	9.3	60.2	3.09	55
Bt3 (43-60)	9.1	74.2	2.11	55
23. RIO SERENO (Panama) - Hydric Dystrandept				
Ah (0-27)	11.2	11.7	5.65	2
AB (27-51)	11.3	7.6	9.86	2
Bw (51-118)	11.1	6.2	5.19	2
24. CAIZAN (Panama)- Typic Dystandept				
Ah (0-30)	11.2	2.6	14.52	2
AB (30-55)	11.3	4.1	10.84	4
Bw (55-100)	11.1	4.5	7.29	2
25. LOS ANGELES (San Carlos, Costa Rica)- Typic Argiudoll				
Ap (0-16)	9.2	3.4	4.60	44
A1 (16-27)	9.4	4.2	1.91	62
Bt1(27-65)	9.5	2.3	1.65	74
26. SAN JOSECITO (San Carlos, Costa Rica)- Typic Tropudalf				
Ap (0-17)	9.2	3.7	5.26	36
A1 (17-30)	9.7	4.9	2.30	54
Bt1(30-60)	9.2	3.9	1.91	64
27. LA LEGUA (Pital, San Carlos,CR)- Typic Hunitropept				
A11 (0-27)	9.6	66.8	3.94	44
A12 (27-40)	9.7	69.0	2.37	50
Bw (40-100)	10.0	42.6	1.45	52
28. LA TRINCHERA (Pital, San Carlos, CR)- Typic Humitropept				
Ap (0-20)	9.1	3.2	6.18	32
A3 (20-32)	9.3	3.7	3.68	42
Bw (32-120)	9.5	2.4	3.68	58
29. POCO SOL (San Carlos, CR)- Typic Tropudult				
Ah (0-25)	9.0	3.4	5.65	48
AB (25-44)	9.2	3.1	2.70	85
Bt (44-120)	8.9	3.4	1.45	87
30. ZARCERO (CR) - Hydric Dystrandept				
Ap (0-20)	10.2	3.8	9.00	11
AB (20-80)	10.4	3.0	9.40	11
A3 (80-110)	10.1	1.9	3.88	13
Bw (110-160)	10.2	1.4	3.81	9
31. SANTA CRUZ (Turrialba, CR) - Typic Hydrandept				
Ap (0-30)	11.1	10.5	19.90	2
A11 (30-66)	11.4	9.1	12.03	3
A12 (66-100)	11.3	16.1	11.12	3
Bw (100+)	11.1	5.3	6.64	3

	pH NaF	%Al Sat	O.M.	% Clay
32. SAN RAFAEL (Turrialba, CR) -Typic Dystrandept				
Ah (0-25)	10.4	2.7	9.20	4
AB (25-50)	10.7	15.8	6.18	5
Bw (50-90)	10.7	9.8	3.16	5
33. TWIS (Turrialba, CR) -Typic Haplohumult				
Ah (0-19)	9.6	40.0	5.00	57
AB (19-37)	9.8	41.8	3.75	71
B (37-97)	9.8	28.6	2.50	75
34. CERVANTES (CR) - Unclassified				
Ah (0-25)	11.2	2.5	17.87	3
35. RIO FRIO I (CR) - Andeptic Haplohumult				
Ah	10.1	19.1	8.54	23
36. RIO FRIO II (CR) - Andeptic Haplohumult				
Ah (0-20)	10.0	40.3	9.33	21
B1 (20-35)	10.4	43.0	4.93	25
Bt (35-72)	10.5	48.1	3.55	29

Twelve soils representing a broad range of characteristics from ultic (presumably high exhnageble aluminum and consequent P retention by a precipitation reaction) and andic characteristics and presumably high P retention by amorphous materials were chosen for mineralogical analyses. Various centers were contacted where these analyses could be relaized. Finally, Dr. John Kimble of the SCS laboratory in Lincoln, Nebraska, who had collaborated with CATIE on soil characterization in connection with the ROCAP projects, said he could probably accomodate the samples with no direct charge to the project. Although the clays were separated by the University of Costa Rica chemists' assistant who was paid by the project, further separation was required to obtain the fine earth fraction when the samples arrived at Lincoln. Dr. Madison Wright of Cornell University who was visiting CATIE for the Tropical Agriculture Field Laboratory which Cornell offers generously offered to hand carry the samples to the US and was very helpful in clearing them through quarantine. The results of the mineralogy on the fine earth fraction are presented in Table 2. The X-ray analyses failed to reveal much amorphous material in several of the Andepts , casting doubt on the value of mineralogical analyses for studies of P retention. The predominant mineral was generally kaolinite, which was not in accordance with the previous SCS analyses which revealed high levels of Halloysite in several Costa Rican soils. When questioned about this, Dr. Kimble expressed the opinion that what had been previously identified as Halloysite might have been "poorly crystalline kaolinite", thus casting doubt on the previous analyses. As was so often the case in this project, findings tended to open more questions than they solved.

LE 2: Classification to family level of soils for which mineralogy determined

	X-ray	DSC	TGA	Elemental Fe_2O_3	K_2O
UARUMAL - Very fine, kaolinitic, isohyperthermic Typic Paleustult					
0-18	KK2 Ge 1	KK 43;Gi 1	KK 41;Gi 3	11.9	0.2
18-70	KK2 Ge 1	KK 56;Gi 1		12.9	0.3
70-110	KK2;Mi 1; Qz 1	KK 64;Gi 1		13.2	0.3
RIFO ALTO- Fine, loamy over clayere, isohyperthermnmic Andic Humitropept					
0-20	KK2; Gi 1	KK 70; Gi 7		9.0	-
20-47	KK1; Gi 1	KK 70; Gi 7		10.4	0.1
47-100	KK3;Gi1;Ge1;Qz1	KK 90; Gi 3		8.4	-
ARAISO - Very fine, kaolinitic, isohyperthermic Typic Haplohumult					
0-27	KK2	KK 99; Gi tr		10.6	0.1
43+	KK2;Gi 1;Ge 1	KK 74; Gi 1		11.2	0.1
RAIJANES - Sandy mixed isothermic Hydric Dystrandept					
0-22	Nx 6	KK 18; Gi 5		8.3	0.1
22-34	Gi 1	GI 8		6.3	0.1
34-80	Gi 1	KK 8; Gi 4		7.3	0.1
SAN JOSE DE UPALA - Very fine, kaolinitic, isohyperthermic Typic Kanhapludalf					
0-25	KK 3; Ge 1	KK 74; Gi 1		11.2	0.1
25-43	KK 3;Ge 1;Mt 1	KK 75; Gi 2		11.2	0.1
43-100	KK 3; Ge 1	KK 79; Gi 2	KK 44 GI 2	11.7	0.1
BIJAGUA DE UPALA - Sandy, mixed,isohyperthermic Entic Dystrandept					
0-20	Ge 1;Gi 1;KK 1	KK 26; Gi 4		11.0	0.2
20-36	Le 1;Gi 1	KK 39; Gi 2	KK 28;Gi 9	7.9	0.2
36-50	KK 1; Gi 1	KK 37; Gi 4		-	-
SABANILLA -Very fine, kaolinitic,isohyperthermic Typic Dystropept					
0-35	KK 3;Ge 1	KK 60; Gi 1			
35-90	KK 3;Ge 1	KK 55; Gi tr		9.3	
90+	KK 2	KK 61; Gi tr		9.7	0.1
RIO SERENO - Sandy, mixed, isohyperthermic Hydric Dystrandept					
0-27	Gi 1	KK 9; Gi 2		5.4	0.1
27-51	Gi 2	Gi 8		6.3	0.1
51-118	Gi 1	KK 4; Gi 4		5.6	0.1

	X-ray	DSC	TGA	Elemental Fe_2O_3	K_2O
CAIZAN- Sandy, mixed, isohyperthermic Hydric Dystrandept					
0-30	Nx 6	KK tr;Gi 5		3.9	
30-55	Gi 1	KK 22;Gi 3		5.6	0.3
55-100	Gi 2	Gi 2		4.3	0.1
LA LEGUA -Fine, kaolinitic, isohyperthermic Typic Humitropept					
0-27	KK 2;Ge 1;Gi 1	KK 53; Gi 2		11.4	0.1
27-40	KK 3;Ge 1;Gi 1	KK 64; Gi 2		10.6	0.1
40-100	KK 2;Ge 1;Gi 1	KK 60; Gi 1		11.9	0.1
TWIS - Very fine, kaolinitic, isohyperthermic Typic Haplohumult					
0-19	Gi 2;KK 2;Ge 1	KK 72; Gi 5		14.3	0.1
19-37	KK 2;Gi 2;Ge 1	KK 48; Gi 4		12.3	0.1
37-97	KK 2;Gi 2;Ge 1	KK 69; Gi 5		14.3	0.1
RIO FRIO II - Sandy, mixed, isohyperthermic Andeptic Haplohumult					
0-20	GI 2;KK 1	KK 23; Gi 8		6.3	0.2
20-35	GI 2;KK 1;Ge 1	KK 19; Gi 13		5.6	0.1
35-72	GI 2;KK 1	KK 52; Gi tr		9.0	0.1

Key to minerals: KK kaolinite; GE- Goethite; GI-Gibbsite; MI-Mica
QZ- Quartz; LE- Lepidocrocit Nx- non-crystalline
Fd-Feldspar; Cr-cristobalite; FD -feldspar

Relative Peak Size: 5-very large;4-large; 3-Medium; 2-Small;
1-very small; 6- no peaks

Because the mineralogical analyses failed to provide any readily apparent differences among the soils, it was felt that more meaningful information could be obtained by determining the aluminum and iron extractable by dithionate citrate, pyrophosphate, and oxalate (Wada and Gungijake, 1978) and relate this to P retention as determined by adsorption isotherms (Fox and Kamprath, 1970) and New Zealand P retention (Blakemore, Searle, and Daly, 1981). According to Wada and Gungigake (1978), iron and aluminun extracted by Pyrophosphate should indicate the Fe and Al bound with humus although Parfitt _et al._ (1989) have shown this to be valid only for the Al. The difference between the dithionate citrate and the Pyrophosphate Fe and Al should indicate the iron and aluminum in allophane-like constituents. Finally, the oxalate contained in allophane and imogolite. The work of Wada and Gungijake indicated that the fraction least correlatable with P retention was the oxalate extractable iron and aluminum, indicating a surprisingly minor role for allophane and imogolite (Wada and Gungijake, 1978).

The results of these determinations as well as of the KOH extractable Al suggested by Kimble, Holzhey, and Holmgren (1984) are given in Table 3. Various attempts were made to correlate these results with P retention. Simple correlation coefficients were attempted by the group of the University of Costa Rica. They found good corrleation of the New Zealand ans isotherm P with all Al fractions for the soils classified as Andepts. They found no correlation for the soils classified as Ultisols or Dystropepts.

Unfortunately, work of Dr. Bryant indicated that some of the soils they classified as Andepts were not as is indicated by their low levels of Oxalate extractable aluminum.

Multiple correlations using the stepwise technique were attempted by the principal investigator. He found the following relationships for predicting P retention:

Isotherm P (P addition required to obtain 0.2 mg/kg in soil solution (mg/kg)

$$= -8697.597 + 1028.049(\text{pH in NaF}) - 99.8123(\%\text{ org C})$$

$$r^2 = 0.7883 \text{ , prob } F = 0.001$$

$$NZP = 78.5576 + 4.806(\text{Oxal Al} + \text{Dith Al}) - 4.502\ (\text{Dith Fe})$$

$$r^2 = 0.742, \text{ prob } F = 0.0001$$

Another relationship was also found to be significant for the New Zealand P (NZP)

$$NZP = -71.731 + 13.4(\text{pH in NaF}) + 3.79(\text{Oxal+Dith Al}) - 23.148(\text{Pyr Al})$$

$$r^2 = 0.801 \text{ Prob } F = 0.001$$

Table 3: Some chemical characteristics of soils used for field experiments

Soil	Horizon	1. Al in KOH	2. Acid Oxalate	3. Pyrophosphate	4 Citrate dithionite	4-3	5. Acid Oxalate	6. Citrate dithionite	7. Pyrophosphate	6-7	P retention: NZ	P retention: Isotherm (a)
		Aluminum extracted by (%)					Iron extracted by (%)					
1. Guarumal - Typic Paleustult												
	Ah	0.15	0.34	0.22	0.80	0.58	0.93	6.12	0.38	5.74	55.6	850
	Bt_1	0.18	0.16	0.20	0.84	0.64	0.31	6.42	0.08	6.34	52.7	1150
3. Grifo Alto (Typic Rhodustalf)												
	Ah	0.30	0.94	1.10	1.38	0.28	0.90	4.82	0.46	4.36	77.0	1700
	AB	0.32	0.51	0.34	0.96	0.62	0.59	5.80	0.43	5.37	59.6	1000
5. Paraiso - Typic Haplohumult												
	Ah	0.20	0.62	0.81	1.14	0.33	0.80	5.62	0.85	4.77	64.7	1100
	Bt_1	0.26	0.36	0.44	0.92	0.48	0.21	5.60	0.43	5.17	49.8	1100
9. Fraijanes - Hydric Dystrandept												
	Ah1	0.34	3.64	1.28	1.96	0.68	1.46	3.02	0.51	2.51	96.9	
	Ah2	0.42	5.16	0.76	1.72	0.96	1.62	3.18	0.34	2.82	98.3	
	Ah3	4.00	6.07	0.46	1.26	0.80	1.75	3.70	0.06	3.64	98.7	
13. Bijagua - Entic Dystrandept												
	Ah1	0.25	1.50	1.11	0.60	0.51	0.90	3.95	0.38	3.57	78.4	1250
	Ah2	0.31	2.06	1.32	0.50	0.72	1.12	4.48	0.35	4.13	81.9	1800
15. Valle Hermoso -Typic Dystrandept												
	Ah	0.42	3.00	1.88	2.02	0.14	0.87	2.15	1.40	0.75	93.6	2400
	AB	0.49	3.44	1.20	1.53	0.33	0.92	4.45	0.47	3.98	96.6	2900
17. San Antonio -Hydric Dystrandept												
	Ah1	0.40	3.66	0.76	1.86	1.10	0.73	2.38	0.24	2.14	90.7	
	Ah2	0.55	4.54	0.70	1.94	1.24	1.04	3.48	0.16	3.32	76.3	
18. Sabanilla - Typic Dystropept												
	Ah	0.20	0.50	0.35	0.96	0.61	0.46	5.62	0.60	5.02	49.7	1450
	AB	0.16	0.40	0.08	0.74	0.66	0.68	6.35	0.09	6.26	51.2	1450
22. Calabacito - Typic Plinthudult												
	Ah	0.12	0.24	0.18	0.54	0.36	0.52	5.25	0.49	4.76	51.2	750
	Bt_1	0.14	0.20	0.14	0.62	0.48	0.13	5.45	0.25	5.20	59.9	500

Soil	Horizon	Aluminum extracted by 1. Al in KOH	2. Acid Oxalate	3. Pyrophosphate	4 Citrate dithionite	4-3	Iron extracted by 5. Acid Oxalate	6. Citrate dithionite	7. Pyrophosphate	6-7	P retention: NZ	Isotherm (a)
		%										
23. Rio Sereno- Hydric Dystrandept												
	Ah	0.40	3.58	0.81	1.52	0.71	0.81	2.60	0.26	2.34	94.0	
	AB	0.49	4.51	1.56	1.94	0.38	1.08	3.18	0.18	3.00	96.6	
24. Caizan - Typic Dystrandept												
	Ah	0.34	3.04	0.78	1.56	0.78	0.70	1.65	0.33	1.32	94.4	1930
	AB	0.40	4.62	0.52	1.86	1.34	0.98	1.65	0.18	1.47	96.6	2000
27. La Legua -Typic Humitropept												
	Ah1	0.22	0.44	0.18	1.12	0.94	0.52	5.12	0.40	4.82	57.8	1230
	Ah2	0.21	0.43	0.16	1.07	0.91	0.52	6.28	0.12	6.16	75.8	1500
30. Zarcero- Hydric Dystrandept												
	Ap	0.18	0.94	0.26	0.59	0.33	1.25	4.15	0.10	4.05	62.3	800
30. Santa Cruz - Typic Hydrandept												
	Ap	0.30	1.98	0.31	1.54	1.23	0.98	1.65	0.16	1.49	92.4	1900
33. Twis - Typic Haplohumult												
	Ah	0.29	0.30	0.46	1.57	1.11	0.50	6.40	1.14	5.26	49.7	900
	AB	0.30	0.30	0.45	1.30	0.85	0.22	6.38	1.00	5.38	81.5	1100
34. Cervantes -												
	Ah	0.46	4.06	1.56	1.94	0.38	1.42	2.80	0.22	2.58	95.6	1800
35. Rio Frio I-Andeptic Haplohumult												
	Ah	0.46	0.84	1.12	1.88	0.76	1.18	5.90	0.55	5.35	57.8	1060
36. Rio Frio II - Andeptic Haplohumult												
	Ah	0.39	0.90	1.54	1.57	0.03	0.52	5.25	0.49	4.76	52.7	1000
	Bt_1	0.38	0.97	1.74	1.65	0.0	0.70	5.48	1.42	4.06	59.0	1450

a) P addition (ug/g) required to obtain 0.2 ppm P in soil solution

Finally, Dr. Ray Bryant subjected the data from 31 horizons of the eighteen soils in Table 3 to various forms of analyses. He attempted correlating New Zealand P and isotherm P (the amount of P addition required to get 0.2 ug/g of P in soil solution) with pH in NaF, organic carbon, pH in KOH, clay percentage, Al in KOH, Al in pyrophosphate, Al in citrate dithionate, ln Al in oxalate, lntot Al (sum of oxalate Al, pyrophosphate Al, and Dith-Pyr Al), Fe in pyrophosphate, Fe in citrate dithionate,Fe in oxalate. P retention by both methods was strongly correlated (r^2 values greater than 0.8) with total Al, Al in oxalate, and pH in NaF, and Al in KOH. The latter two properties have been suggested by Alvarado and Buol (1985) and Kimble, Holzhey, and Holmgren (1984) as field tests for P retention. P retention was correlated with oxalate Fe but to a lesser extent than Oxalate Al. New Zealand P gave slightly higher correlations than isotherm P. Other properties were poorly correlated with P retention.

Regression equations for those properties most strongly correlated with P retention are given in Table 4. The relationships between P retention and measures of Al are logarithmic functions. Stepwise regression resulted in relationships for P_{NZ} correlated with $lnAl_{tot}$ and a negative expression of clay percentage (R^2 = 0.825) and for isotherm (P_{2ppm}) correlated with $lnAl_{tot}$ and organic C (R^2 =0.84).

Information obtained from the regression analyses were applied to the SMS data set . The laboratory kindly assented to perform P_{NZ} on those soils in the data set for which the determination was missing. Al_{dith} data were available for 30

Table 4 . Results of regression analyses for the 31 horizons for which chemical data were determined by project personnel.

P retention		Constant	Var 1	Var. 2	R^2
P_{NZ}	=	53.9	+22.6 (LntotAl)		0.802
P_{NZ}	=	65.8	+ 16.3 (LntotAl)	-0.19 clay	0.825
P_{NZ}	=	72.1	+ 14.0 ($LnAl_{oxal}$)		0.724
P_{NZ}	=	-149.4	+ 21.4 (pH in NaF)		0.724
P_{NZ}	=	48.2	+ 1.47 ($\%Fe_{oxal}$)		0.613
P_{2ppm}	=	855.3	+ 819.5(LntotAl)		0.748
P_{2ppm}	=	992.9	+ 1052.1(LntotAl)	-83.6 OrgC	0.840
P_{2ppm}	=	1523.5	+ 486.2($LnAl_{oxal}$)		0.673
P_{2ppm}	=	-6165.5	+ 743.4(pH in NaF)		0.660
P_{2ppm}	=	806.1	+ 41.0($\%Fe_{oxal}$)		0.435

Table 5. Results of regression analyses for all available horizons from Central America

Pretention		Constant	Variable 1	Variable 2	R^2
P_{NZ}	=	47.8	+ 28.5(LnAltot)		0.811
P_{NZ}	=	83.5	+ 27.7(LnAltot)	-6.19(pH in H_2O)	0.834
P_{NZ}	=	66.2	+ 21.9($LnAl_{Oxal}$)		0.618
P_{NZ}	=	153.6	+ 22.9($LnAl_{Oxal}$)	-15.3(pH in H_2O)	0.765
P_{NZ}	=	67.9	+ 20.3		0.714
P_{NZ}	=	121.1	+ 18.0($LnAl_{Oxal}$)	-8.97(pH in H_2O)	0.774

additional samples and Al_{oxal} data were available for an additional 143 samples. The results of regression analyses on these data are presented in Table 5. Again, the strongest correlations were found for P_{NZ} related to lnAltot and $lnAl_{oxal}$. For the data set where Al_{dith} and Al_{oxal} data were available for calculating Altot, the R^2 value increased to 0.811. Using the same dataset (n=58), the relationship between P_{NZ} and $lnAl_{oxal}$ had a lower R^2, probably as a result of introducing a wider range of soil conditions. The P_{NZ} vs Al_{oxal} relationship improved when all available data (n=174) were used. For the larger data sets, stepwise regression included a term for pH measured in water to improve the correlation.

Tree diagrams resulting from cluster analyses (Wilkinson, 1988) of P retention by P_{NZ} and P_{2ppm} are shown in Figures 1 and 2. Metric distance represents Euclidean distance. The diagrams are constructed to show increasing rank as well. Some separations are enhanced as bold lines for the purpose of illustration but do not have special significance.

With the exception of site 30 (Zarcero), the foirst hierarchial separation of P_{NZ} data grouped the Andepts apart from the other suborders (Fig.1). The second separation distinguished the Entic Dystrandept from the other Andepts. The third separation distinguished the Andic Humitropept from the group of Inceptisols and Ultisols. Although the clusters at lower categories do not appear to correlate with taxonomic groups, members of the dataset containing the formative elements "hum" or "and" in the name of the taxonomic class outrank those that do not.

The first to separations based on P_{2ppm} are of no apparent taxonomic significance (Fig.2)
but the third separation distinguised the Andepts from other taxa with the exception of the Entic Dystrandept (13. Bijagua) and the Hydric Dystrandept (30. Zarcero). With the exception of site 30, the Ultisols rank lower than the Inceptisols. The results of the regression analysis show that Al is the dominant factor contolling P retention in Central American soils. Soil pH in water improves the correlation, suggestin that when factors other than Al are influencing soil pH, soil pH may control the activity of the Al and its effectiveness in retaining P. Since pH is negatively correlated with P retention, liming to raise the pH may effectively decrease the P retention in these soils. The best relationship for prediciting P retention was P_{NZ} = 83.5 + 27.7 lnAltot = 83.5 +27.7(ln Altot)-6.19(pH in HOH) (R^2 =0.834; n=58). Trends in the data suggest that the correlation might have been even higher had Al_{dith} data been available for the additional 116 samples in the SCS dataset.

A slightly higher correlation (R^2 = 0.84) was obtained for the 31 horizons sampled by the project personnel for isotherm P related to lntotAl and organic C, showing the role of organic matter in P retention, especially perhaps in soils without a much alophane (Humitropets and Humults). Similarly, the corrrelations done by the University of Costa Rica personnel showed better correlation of P_{NZ} with other soil properties for Andepts. For more highly weathered soils with high organic matter, the isotherm P may be a more useful measure, since it correlates better than the P_{NZ} with other soil properties for these soils.

Site	P_{NZ}	Taxonomic Class	
6.	49.7	Typic	Dystropept
1.	54.2	Typic	Paleustult
5.	54.9	Typic	Plinthudult
9.	55.4	Andeptic	Haplohumult
8.	57.8	Andeptic	Haplohumult
2.	61.3	Typic	Haplohumult
3.	61.9	Typic	Humitropept
7.	62.3	Hydric	Dystrandept
4.	64.2	Typic	Haplohumult
10.	69.5	Andic	Humitropept
12.	79.9	Entic	Dystrandept
13.	88.7	Hydric	Dystrandept
14.	92.4	Typic	Hydrandept
17.	93.9	Typic	Hydrandept
15.	94.6	Hydric	Dystrandept
16.	94.7	Typic	Dystrandept
18.	95.6	Typic	Dystrandept
11.	97.4	Hydric	Dystrandept

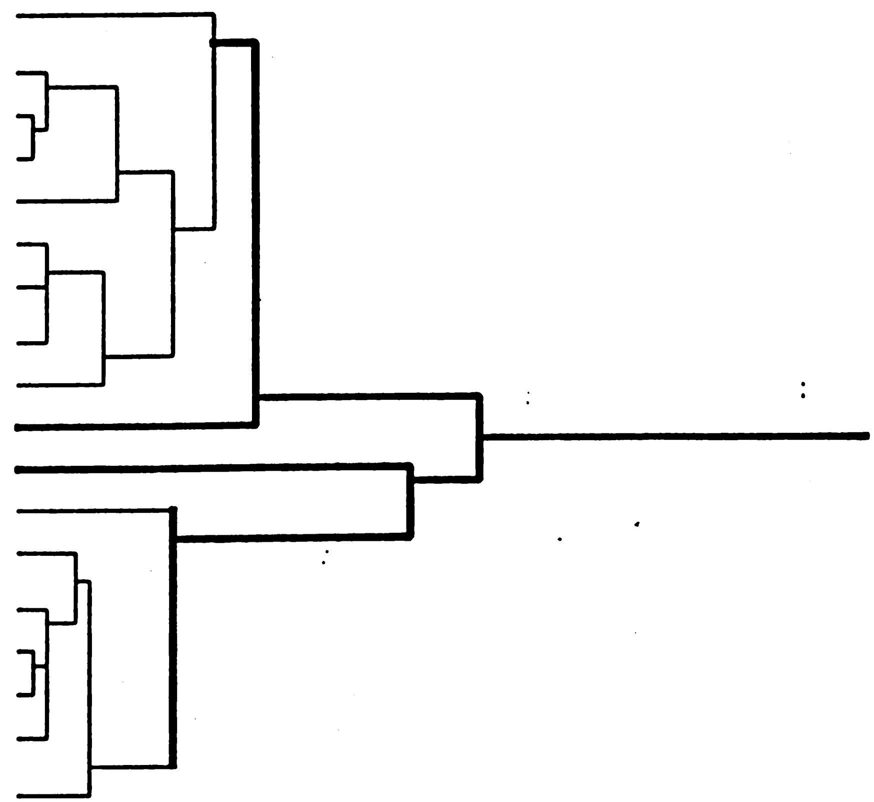

Fig. 1. Tree diagram for cluster analysis of P retention data by the New Zealand method.

Site	R_{2ppm}	Taxonomic Class	
5.	644.	Typic	Plinthudult
7.	800.	Hydric	Dystrandept
4.	991.	Typic	Haplohumult
1.	996.	Typic	Paleustult
8.	1060.	Andeptic	Haplohumult
2.	1100.	Typic	Haplohumult
9.	1193.	Andeptic	Haplohumult
3.	1292.	Typic	Humitropept
10.	1400.	Andic	Humitropept
6.	1450.	Typic	Dystropept
12.	1486.	Entic	Dystrandept
18.	1800.	Typic	Dystrandept
14.	1900.	Typic	Hydrandept
16.	1940.	Typic	Dystrandept
17.	2443.	Typic	Hydrandept
11.	3000.	Hydric	Dystrandept

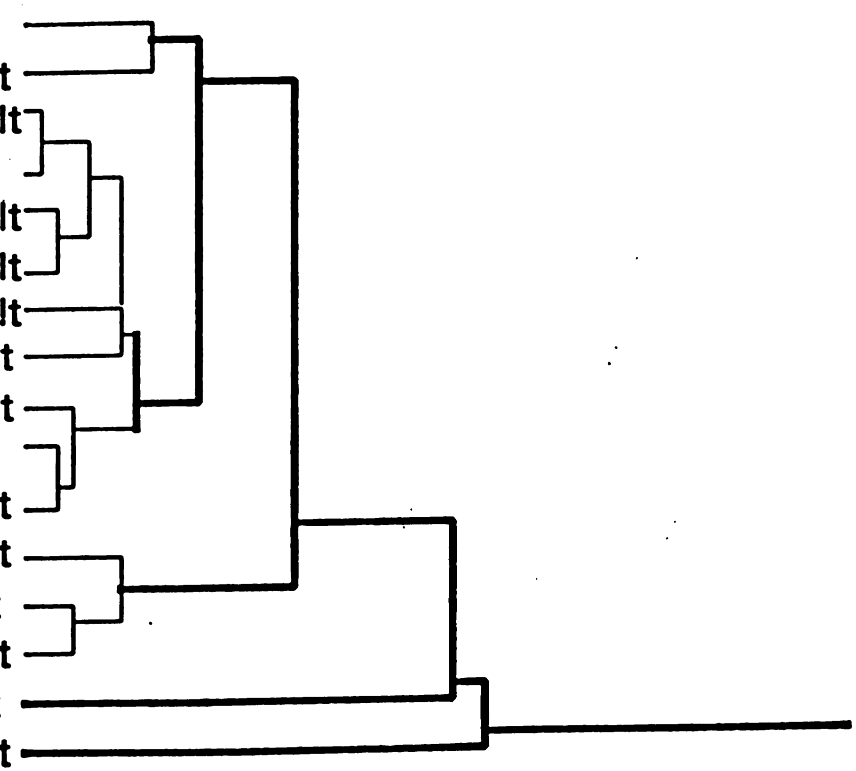

Fig. 2. Tree diagram for cluster analysis of P retention data by the adsorption isotherm method (2ppm).

II. Screening of germplasm of Phaseolus vulgaris L. for adaptation to conditions of high P retention.

Greenhouse screening of bean varieties for adaptation to soils with high P retention characteristics formed part of the research activity of the the two M.S. students, Wilbert Campos Alvarado and Alexis Samudio Patina, who were supported by the project. The results of these activities are contained in the theses, Manipulacion del cultivo de frijol(Phaseolus vulgaris L.) para superar diversos mecanismos de retencion de fosoforo en suelos de Centroamerica (Manipulation of bean culture to overcome various mecanisms of Phosphorus retention in Central American soils by Wilbert Antonio Campos Alvarado and Requerimiento externo de tres cultivares de frijol (Phaseolus vulgaris) sembrados en San Andres , Panama (External P requirement of three bean cultivars planted in San Andres, Panama) by Alexis Samudio Patino.

The activity of Mr. Campos thesis research was divided into three stages: screening of bean varieties for their ability to imbibe P from P enriched solutions, determination of P retention and other characteristics of three Costa Rican soils of differing mineralogy and presumabaly, different P retention characteristics, and finally combining the results of these studies in a greenhouse study in which four bean varieties were grown in the three different soils, with and without liming, with four methods of P application (0, seed imbibtion, foliar P, and soil applied fertilizer P). With three repetitions, there were a total of 216 pots.

In the Greenhouse screening done by A. Samudio, there were four bean varieties (Renacimiento, Rosado, Chileno, 105-R) all used in Panama, two lime levels , two zinc levels, and five P treatments (0, 200ug g^{-1}, 400 ug g^{-1}, seed imbibed P, foliar P). With three repetitions, there were a total of 240 pots. For the study, a Hydric Dystrandept from San Andres , Panama, was used.

In the preliminary study carried out by Mr. Campos, lots of 20 seeds of the bean variety ICA Pijao were imbibed in solutions of H_3PO_4, $(NaPO_3)_6$, $NH_4H_2PO_4 \cdot H_2O$ and KH_2PO_4 in concentrations of 2000, 4000, 6000, 8000, and 10,000 ug g^{-1} of P for periods of 1-12 hours. Weight was recorded hourly and germination determined. Lots in which germination was satisfactory (80%) were analyzed for total P content. The eight best treatments of the preliminary study (KH_2PO_4 at concentrations of 2000,4000,6000, 8000, and 10000 ug ml^{-1} of P and $(NH_4)_3PO_4$ at 2000,4000, and 6000 ug ml^{-1} of P and distilled water were combined with 1,2,3,4,5, or 6 hours of imbibition to give a factorial experiment with 54 treatments (9 solutions X 6 periods of imbibition) plus an untreated control to give 55 treatments with three replications. Each experimental unit consisted of 20 seeds of the ICA Pijao variety. Experimental units were evaluated for germination, survival to seedling stage and P content. Effects on P content of seedlings and germination from different concentrations of KH_2PO_4 and $NH_4H_2PO_4$ are shown in Figure 3. Germination fell off considerably with imbibition times longer than three hours or for concentrations greater than 8000 mg L^{-1} P. P content of seedlings increased with time of imbibition up to five hours for concentraltions of P greater than 4000 ug g^{-1}. Effects of P concentration and times of imbibition were significant by F tests at the 0.01 level of significance. P content and seed germinationw were thus negatively correlated at

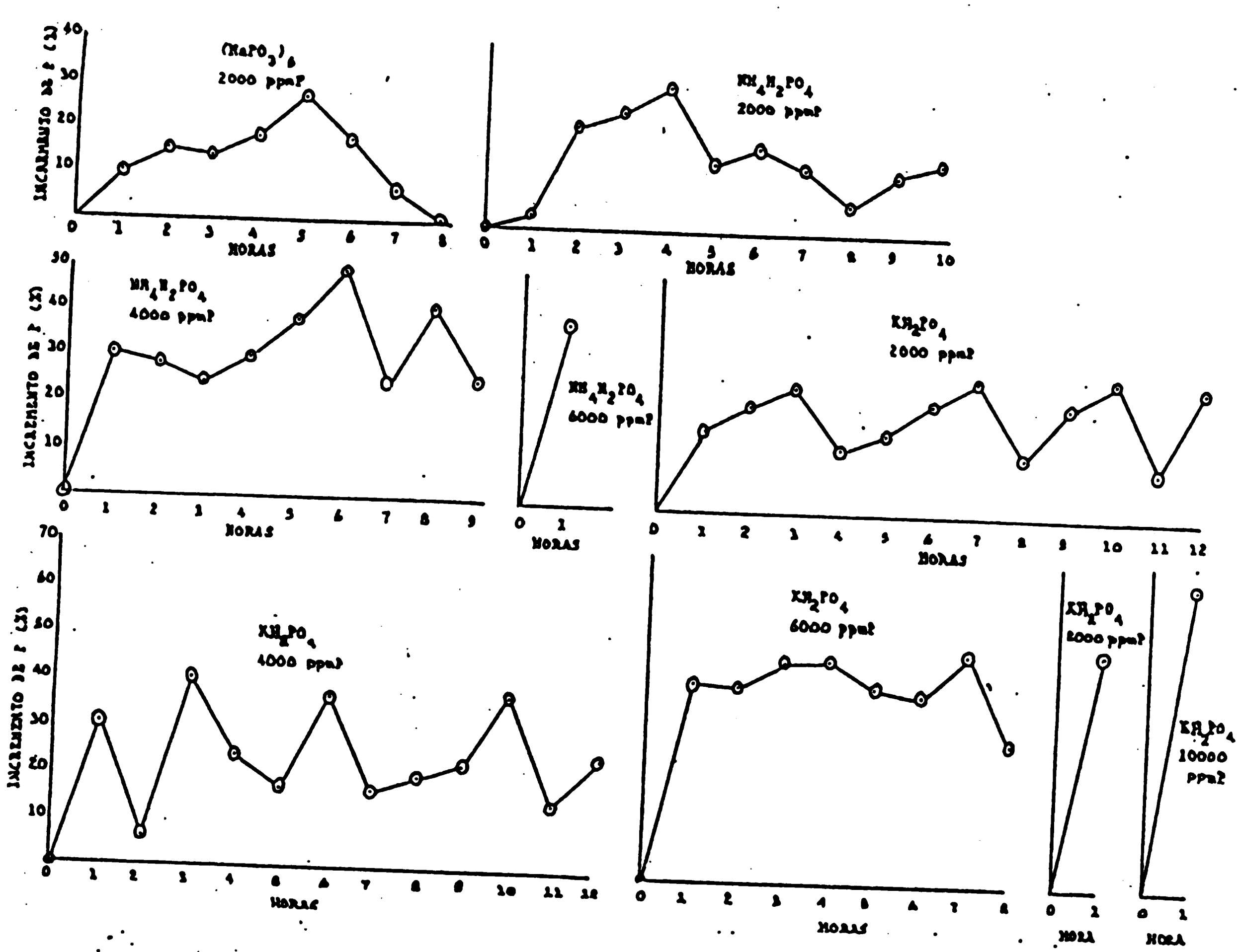

Figure 3. Increase in P content and germination percentage of bean seeds soaked for different time periods in solutions of KH_2PO_4 and NH_4PO_4 of differing concentrations

each hour of imbibition, a relationship that became more significant at longer imbibition times (Table 6). It was concluded that the best results could be obtained from an imbibition of three hours in a solution of KH_2PO_4 containing 8000 ug g^{-1} P.

The bean varieties used in the greenhouse screening done by Mr. Campos had been classified by CIAT (1979, 1983) as tolerant or susceptible to low levels of P and high levels of aluminum saturation. The cultivars Iguacu and Rio Tibaji were classified as tolerant while ICA Pijao and Puebla 152 were classified as susceptible. The soils utilized had been characterized by SCS in previous work in connection with AID supported projects in Central America. Characteristics of these soils are given in Table 7. The soils were a Typic Humitropept on the CATIE station; a Typic Hapludult from Buenos Aires, Costa Rica; and an Andeptic Dystropept from Cariari, Costa Rica (SCS, 1986). Predominant minerals in the soils were halloysite and gibbsite for the Turrialba soil; kaolinite, gibbsite, and goethite for the Buenos Aires soil, and halloysite, gibbsite, and amorphous material for the Cariari soil. Mr. Campos ran P adsorption isotherms on these soils (Fox and Kamprath, 1970) in both the limed and unlimed states. These isotherms are presented in Figures 4 and 5. For soils with such differing mineralogy and classification, the isotherms were remarkably similar. Liming had little effect on the P retention properties of these soils. P content of the leaves was affected significantly ($p = 0.05$) by soil, liming , and genotype. Effects of method of P application and the cultivar by P application method were highly signficant ($p = 0.01$). These effects and interactions are summarized in Table 8.

Table 6. Correlation coefficients between P content of seed and germination percentage for different periods of imbibition using KH_2PO_4 at 8000 ug P/ml

Imbibition time (hours)	r
1	-0.27 NS
2	-0.75**
3	-0.55**
4	-0.59**
5	-0.40**
6	-0.76**

** Indicates signficance at p = 0.01

Table 7. Characteristics of soils used by W. Campos for greenhouse screening of Phaseolus cultivars

Soil	Fine kaolinitic isohyperthermic Typic Hapludult	Coarse-loamy mixed, isohyperthermic Andeptic Dystropept	Fine, halloysitic isohyperthermic Typic humitropept
Local-	Buenos Aires de Puntarenas Costa Rica	Colonia Cariari Guapiles, Limon Costa Rica	La Montana experimental farm CATIE, Turrialba
Mineralogy (surface horizons)			
X-ray	KK3; GI 2;GE 1	KH 1; GI 1;NX 6	KH 2; GI 1
DTA	KK 55; GI 10	KH 24; GI 3	KH 32; GI 3
Al sat (surface horizons)			
	72	1	15
Organic C			
	3.07	9.06	3.27
Clay %	71.6	6.7	47.5
Bulk density (33 kPa)			
	1.15	0.67	1.23

Key to mineralogy: KK-kaolinite; KH-Halloysite; GI -Gibbsite
NX Amorphous

Scale for X-ray: 6-indeterminate; 5-dominant; 4-abundant;
3- moderate; 2- small; 1- trace

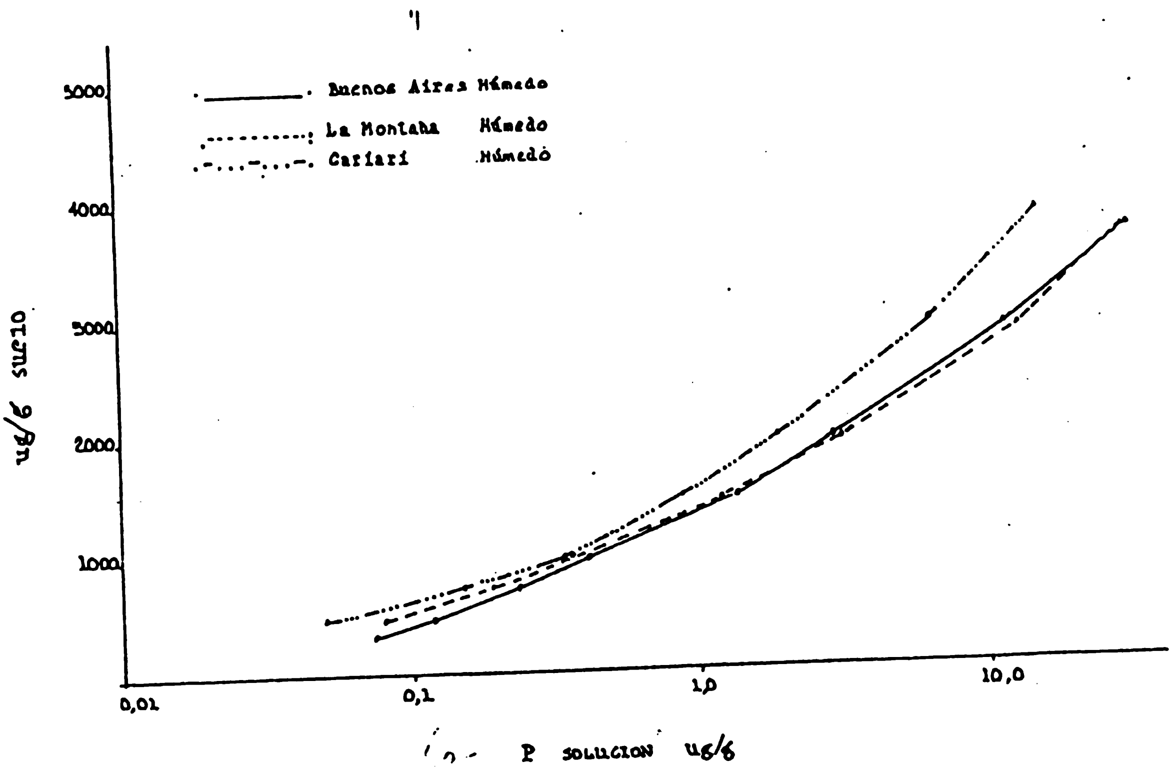

fig 4-P adsorption isotherms for soils used in W. Campos thesis, unlimed.

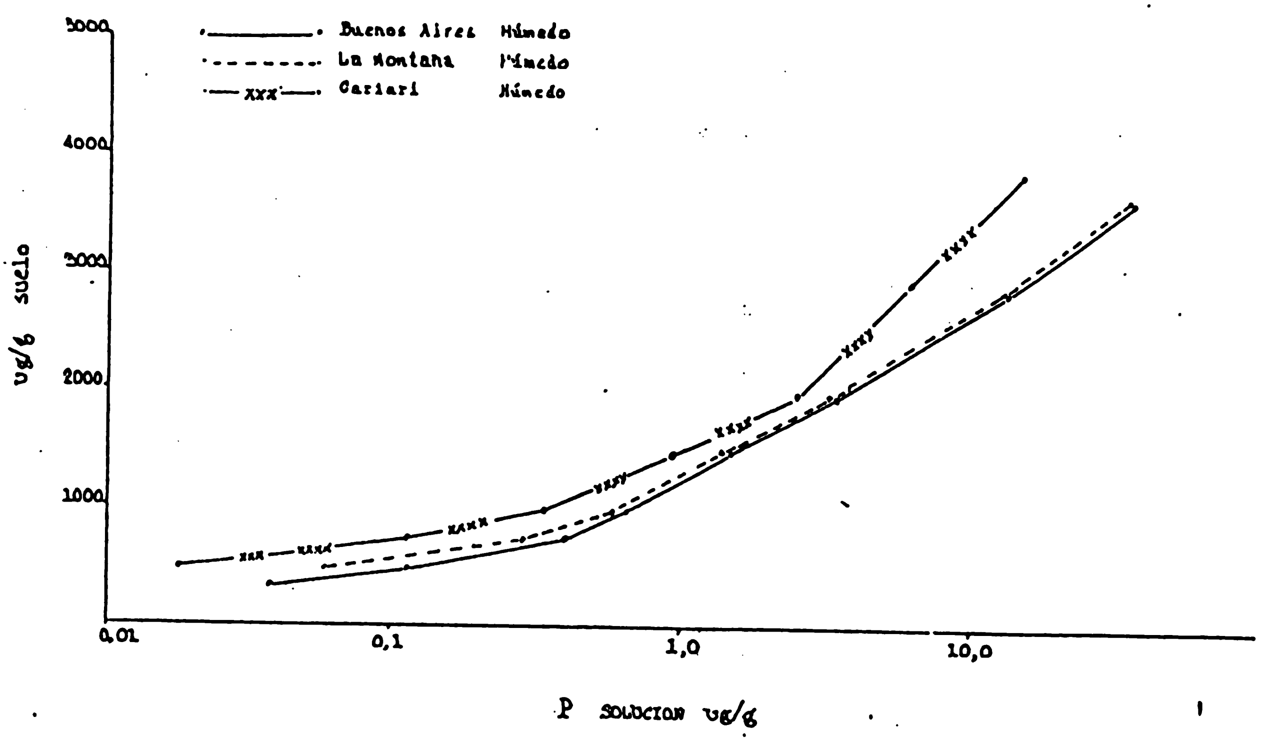

Fig. 5. P adsorption isotherms for soils used in W. Campos- thesis limed

Table 8. Biomass production per bean plant, P content, and use efficiency for different bean genotypes with different methods of P application

CULTVAR	Leaf weight (mg/plant)	Stem weight (mg/ plant)	Leaf P (mg/g)	Stem P (mg/g)	P use efficiency (mgDW/mgP)
ICA PIJAO					
No P	730	370	1.1	1.2	902
Foliar P	885	455	1.5	1.2	748
Seed imbibed P	709	383	1.2	1.3	796
IGUACU					
No P	680	355	1.2	1.2	888
Foliar P	801	449	1.9	1.4	688
Seed imbibed P	700	375	1.3	1.4	795
RIO TIBAJI					
No P	595	350	1.7	1.4	756
Foliar P	745	490	1.7	1.2	684
Seed imbibed P	635	390	1.3	1.2	809
PUEBLA 152					
No P	720	390	1.2	1.1	888
Foliar P	869	630	1.6	1.2	679
Seed imbibed P	834	551	1.3	1.3	791

Phosphorus use efficiency was calculated as the dry weight of leaves and stems divided by the P content X biomass of the leaves and stems. It can be seen that while foliar P application increased the biomass production of leaves and stems considerably, seed imbibition only had much effect in the case of the Puebla 152 cultivar. With the exception of the Rio Tibaji cultivar, both methods of P application increased the P content of leaves and stems. Efficiency of P application was always highest for the plants which did not receive P, lowest for those receiving foliar P, and intermediate for those receiving seed imbibed P.

The interaction of soil X genotype X method of P application was signficant for P efficiency and is shown in Table 9. It was highest for the Buenos Aires, intermediate for the Cariari soil, and lowest for the La Montana which is what one would expect from the Olsen P values for these soils, which were highest for the Montana soil and lowest for the Buenos Aires soil. Foliar P reduced the efficiency in all cases. Imbibition produced higher efficiency than the O P treatment for the Rio Tabaji cultivar in the Buenos Aires and Montaña soils and for the Puebla cultivar in the Cariari soil. It is well to bear these results in mind when the results of the field experiments are considered in Part 3. Although Mr. Campos concluded that there was a relationship between cultivar and ability to use P imbibed by the seed, the data did not indicate any clear relationship.

In the thesis of Alexis Samudio, four different bean cultivars, all commonly planted in Panama, were used in a soil from a bean producing area. This was classified as a Hydric Dystrandept and had a much higher P adsorption than the soils used by Wilbert Campos (Fig. 6). Seed sizes were also greater as all

Table 9. Efficiency of use of P: interaction cultivar X soil X method of P application

CULTIVAR	P treatment	SOIL Buenos Aires	 La Montaña	 Cariari
		mg DM/mg P		
ICA PIJAO	no P	970	792	945
	Foliar P	711	714	829
	Seed imbibed P	872	756	755
IGUACU	no P	1065	772	817
	Foliar P	523	624	924
	Seed imbibed P	862	729	794
RIO TIBAJI	no P	816	694	759
	Foliar P	687	632	740
	Seed imbibed P	944	726	748
PUEBLA 152	no P	1119	769	759
	Foliar P	703	599	743
	Seed imbibed P	862	677	839

Interaction signficant at $p = 0.01$

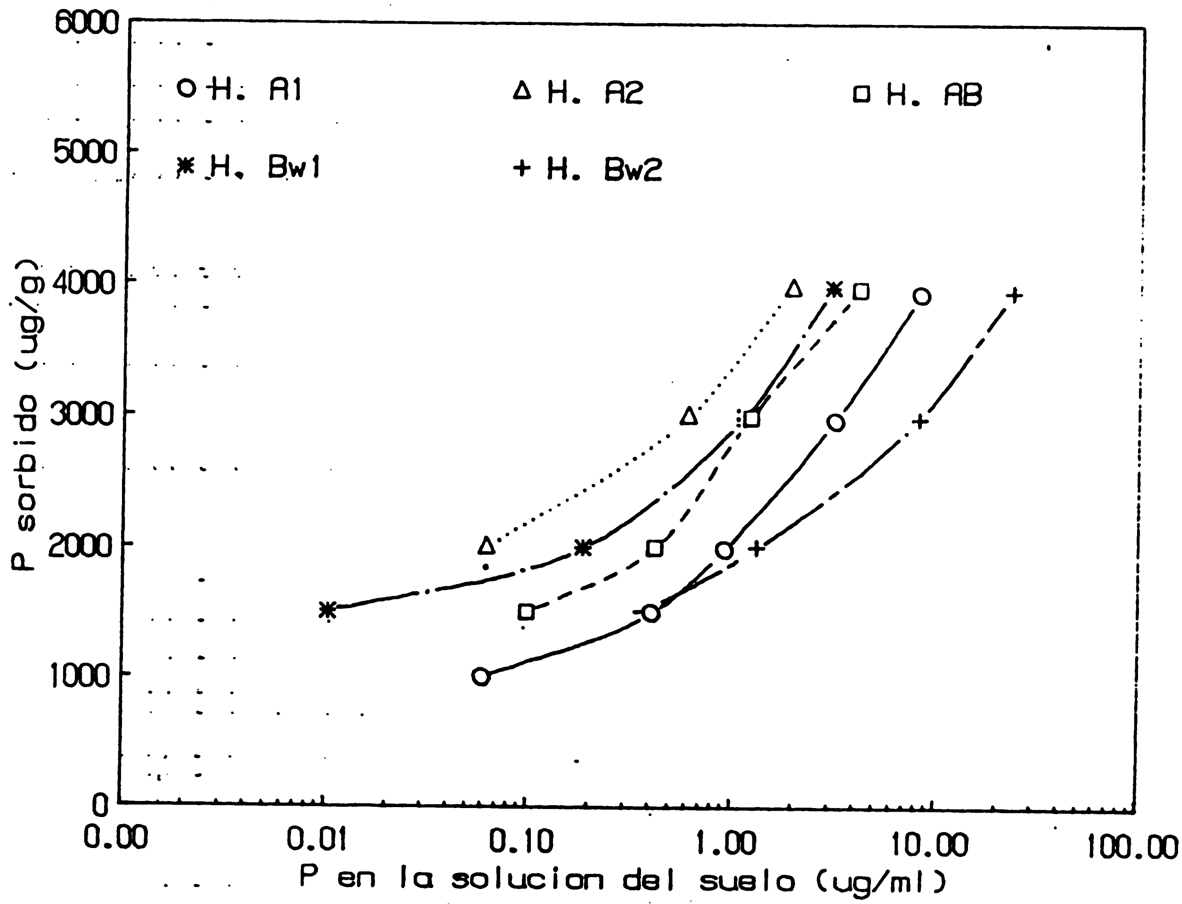

Figure 6. P adsorption isotherms for each horizon of Hydric Dystrandept used for greenhouse study in thesis of A. Samudio

cultivars had a weight of 100 seeds in excess of 35 g while the largest seeded cultivar used in the previous study was Puebla 152 with a 100 seed weight of 25 g (Table 10). In this experiment, only one seed imbibition treatment (one hour in a 6000 ug/L P solution) but two P levels (200 and 400 mg/kg) were applied to the soil in addition to the foliar P and 0 P treatments. It was thus possible to get some idea of how seed imbibition and foliar P would compare to conventional soil P application. There were a total of 80 treatments [4 bean cultivars (Renacimiento, Rosado, Chileno, and 105-R) X liming X Zn application X 5 P treatments]. There were randomized complete blocks with 3 replications. Bean plants were harvested at flowering and analyzed for dry matter, calcium, magnesium, potassium, phosphorus, zinc, copper, and manganese. The analysis of variance indicated highly significant ($p= 0.01$) effects for cultivar, P, and cal X P on bean biomass. Significant effects ($p = 0.05$) were noted for cultivar XP, ZnXP, cultXZnXP. Effects of method of P application on biomass and nutrient content of leaves are presented in Table 11. Seed imbibition of P increased foliar P levels signficanly above the control and 200 mg kg^{-1} applied to the soil but were significantly less than for foliar P or 400 mg kg^{-1} applied to the soil. Biomass production for seed imbibed P was only significantly greater than the control treatment, however. Soil application of P signficantly reduced Ca and Mg concentrations in leaves, an affect not observed when foliar or seed imbibed P were used. These results would appear to indicate that seed size may be determine the success of the seed imbibition technique. Further evidence that the method may only be successful with large seeded (over 25 g/100 seed) cultivars was obtained in a field experiment.

Table 10. Seed size of cultivars used in screening experiments

CULTIVAR	WEIGHT PER 100 SEEDS
RIO TIBAJI	19g
ICA PIJAO	20 g
IGUACU	22 g
PUEBLA 152	25 g
RENACIMIENTO	54 g
ROSADO	49 g
CHILENO	48 g
105-R	38 g

Table 11. Effect of method of P application on biomass and nutrient content of bean leaves in greenhouse experiment on a Hydric Dystrandept from San Andres, Panama.

	Method of P application				
	None	200mg/kg to soil	400mg/kg to soil	Foliar P	Seed Imbibed
P (mg/g)	1.0e	1.5d	2.2d	5.6a	1.8c
K (mg/g)	13.2a	9.7c	9.5c	13.8a	11.4b
Ca(mg/g)	21.4ab	18.1c	15.7d	20.5b	22.4a
Mg(mg/g)	3.7c	3.2d	3.1d	4.0b	4.7a
Mn(mg/kg)	208.87b	162.19d	225.54a	185.66c	184.75c
Cu(mg/kg)	15.08c	2.83e	5.42d	19.00b	44.75c
Zn(mg/kg)	32.42a	33.81a	28.02b	33.12a	33.80a
Leaf					
Dry matter(g/plant)	1.31d	2.15a	2.15a	1.90b	1.56c
Whole plant dry matter (g/plant)	2.15d	3.56a	3.60a	3.18b	2.66c
Plant height (cm)	28.72c	37.28a	38.29a	37.55a	35.39b

Values followed by the same letter do not differ signficantly by Duncan multiple range test at p=0.05

III. Field Experiments to show differing germplasm response to different methods of P application in soils with different retention characteristics.

The field experimentation part of the project was originally assigned to the University of Costa Rica because it was better located to attend sites throughout Costa Rica. Although the Turrialba valley provides excellent conditions for bean production during the dry season, it is not a very important bean producing area. It would have been well to include two further bean producing areas, the General valley, and the northern coastal plain but the fact that the project only had one vehicle limited activities somewhat. The University of Costa Rica personnel chose four sites, two Andepts, one Paleustult, thus representing extremes of mechanisms of P retention, and an Andeptic Haplohumult, which should have shown both mechanisms of P retention. Referring to the aluminum extractions in Table 3, it can be seen that the two andepts (soil 9 and 17) had very high levels of Oxalate extractable aluminum but also rather high levels of citrate-dithionate aluminum in relation to pyrophosphate extractable aluminum, indicating a fairly considerable contribution of allophane-like constituents in P retention. P retention of the other two soils was much lower.

Although the original idea of these field experiments was to apply high lime and Phosphorus levels in order to see if liming brought about some reduction of P retention (Haynes, 1984) regardless of exchangeable aluminum levels, the University of Costa Rica agronomist who was in charge of the field experiments resolved to use exchangeable aluminum as a guide to liming as suggested by Kamprath (1984). Thus, no lime was applied to the two Andepts (Fraijanes and San Antonio de Coto Brus) in spite of the fact that the latter soil had rather high levels of exchangeable aluminum. Since the levels of the exchangeable aluminum in the Rio Frio soil (Profile 35) were relatively low, only 0.7 and 1.4 t ha^{-1} of lime were applied. Although no significant response to liming was observed on this soil, there was an increase in yield associated with liming (The coefficient of variability was also high.). Still, it would have been intetresting to see the effect of liming on these soils. It will be seen that a response to lime was obtained on the Hydric Dystrandept soil in Panama with a lower level of exchangeable aluminum than these soils. In all four experiments, 5 levels of P were applied (0,100, 200, 300, and 400 kg P ha^{-1}). The Talamanca cultivar of beans was used in all sites. The Negro Huasteco cultivar was included at the Guarumal, Coto Brus, and Frainjanes sites. The Huetar cultivar was included at the Guarumal site and the Chirripo cultivar at the Fraijanes site. Thus, the only factor that was comparable in all four experiments was P level. Analyses of variance of yield data for all factors at the four sites are presented in Table 12. A significant response to P was obtained at all sites except the Coto Brus site which also had the highest coefficient of variability of all sites although at this site , the variety X P interaction was significant. the response to liming levels was significant at the Guarumal site. No other factors or interactions were significant with the exception of repititions which was highly signficant at the Coto Brus and Fraijanes sites.

Yield levels for main effects are given in Table 13 and signficant interactions are given in Table 14. The Talamanca

Table 12

Analysis of variance for bean yields in four experients carried out by the University of Costa Rica at four sites in Costa Rica (1987-88)

Source of Variation	GUARUMAL Typic Paleustult DF	MS	Signif. F	COTO BRUS Hydric Dystrandept DF	MS	Signif F	RIO FRIO Andeptic Haplohumult DF	MS	Signif F	FRAIJANES Typic Dystrandept DF	MS	Signif F
Reps	2	241582	0.32	2	56291	0.01	2	23963	0.39	2	134571	0.00
Bean variety	1	491360	0.18	2	525125	0.06				2	5924	NS
Resid	2	115530		4	83666							
Lime	2	652334	0.00				2	80459	0.11			
LimeXVar	2	104112	0.13									
Resid	8	39691										
P level	4	1872848	0.00	4	177861	0.14	4	88106	0.004	4	56636	0.009
P X Var.	4	80960	0.40	8	217954	0.05				8	9938	NS
P X Lime	8	57447	1.00				8	27678	0.171			
VarXPXLim	8	62071	1.00									
Resid	48	77835		24	92579		24	17062		28	13752	
C.V.		30.31%			43.22			37.47			39.86	

Table 13. Principal effects at the four sites (Guarumal, Coto Brus, Rio Frio, y Fraijanes) ($kg\ ha^{-1}$)

Principal effects

	Guarumal	Coto Brus	Rio Frio	Fraijanes
	--------------------	$kg\ ha^{-1}$	--------------------	
BEAN CULTIVARS:				
Talamanca	924	917	353	301
Huasteco	776	637		267
Huetar	562			
Chirripo				310
LIME				
0-	680		0 - 276	
3 T/ha	943		0.7 T/ha- 423	
6 T/ha	927		1.4 T/ha- 359	
P LEVELS ($kg\ ha^{-1}$)				
0	600	600	186	149
100	986	1300	337	277
200	947	675	407	350
300	940	1175	407	320
400	776	833	425	367

'able 14: Significant Interactions

X Variety:	Guarumal	Coto Brus	Rio Frio	Fraijanes
Talamanca:				
0	611	600		188
100	1144	1375		192
200	947	675		362
300	1033	1175		368
400	883	833		393
Huasteco:				
0	589	808		142
100	828	1000		316
200	947	275		406
300	847	500		330
400	669	600		356
Huetar:				
0		341		
100		433		
200		741		
300		558		
400		733		
Chirripo				
				116
				322
				281
				261
				353

PX Lime:

Guarumal		Rio Frio	
0 Lime X			
0 P	404	0 P	271
100 P	816	100 P	221
200 P	712	200 P	319
300 P	845	300 P	213
400 P	621	400 P	360
3T ha-1 Lime X:		**0.8 T ha-1 Cal X:**	
0 P	675	0 P	145
100 P	1191	100 P	486
200 P	1095	200 P	495
300 P	1017	300 P	527
400 P	738	400 P	458
6T ha -1 Lime X:		**1.3 T ha-1 Cal X :**	
0 P	720	0 P	143
100 P	950	100 P	302
200 P	1033	200 P	409
300 P	958	300 P	481
400 P	971	400 P	459

outperformed other cultivars at all sites and appeared to be somewhat more adapted to lower lime and P levels although at the Coto Brus site, the Huasteco cultivar performed better in the absence of P. Although P response curves are somewhat irregular, maximum yields appear to have been obtained with the application of 100-200 kg P ha^{-1}, somewhat lower than would have been expected on soils with such high P retention characteristics. In all cases, However, yields were quite low indicating that other factors may have been limiting yields. At the Fraijanes site, folair analyses were performed and also showed maximum P levels corresponding to the application of 200 kg ha^{-1} P.

Two experiments carried out at the CATIE station in Turrialba in 1986-7 permitted the evaluation of a wider range of factors and because the coffecients of variability were lower, a better evaluation of the nature of the P resonse was possible. One experiment was a 4×4^2 factorial with four bean cultivars (ICA PIJAO, IGUACU, RIO TIBAJI, and PUEBLA 152), liming, foliar P application, and seed imbibed P as treid in the greenhouse experiments previously reported. The soil was a Typic Humitropept as used in the greenhouse experiments of Wilbert Campos (Table 7) although the level of Al saturation was somewhat higher. There was a single replication but third and fourth order interactions were combined to give an effor term with 11 degrees of freedom. Plots measured 5m X 2m. Beans were planted at 200,000 seeds per hectare and subsequently thinned to 133,333 plants per hectare. AT flowering, the uppermost fully opened trifoliate leaf was sampled for analysis. At maturity, yields and harvested population were determined on a 7.65 m^2 area and ten plants taken for the determination of pods and seeds per plant.

The second experiment combined a complete factorial 2^3(liming, foliar P, and seed imbibition) with five levels of fertilizer P (0, 150,300, 450, 600 kg ha^{-1} of P) in a split plot experiment with two replicates. Thus, considerable precision was available for the P response curve which could be combined with the P adsorption isotherms to determine the external P requirements, using the method of Fox (1981). Plot size and harvest methods were the same in both experiments.

In the first experiment, the effect of seed size on the effectiveness of the P imbibition treatments was rather dramatically illustrated as the smallest seeded cultivar (Table 10), Rio Tibaji, failed to germinate in the seed imbibition treatments. Analysis of variance was thus limited to the three remaining cultivars (Table 15). The analysis of variance indicated highly significant (p 0.01) effects for cultivars, soil P application, and seed imbibition and signficant effects (p 0.05) for liming. As can be seen in Table 16, however, while soil P application and liming increased yields, imbibition and foliar P application reduced yields. Several interactions were signficant at the p 0.05 level, among them, cult X imbibition, fertilizer X imbibition, and imbibition X liming. It can be seen from Table 15 that imbibition only increased grain yield in the absence of soil P application in the Puebla 152 cultivar, the largest seeded cultivar used in the present study (Table 10). Even combining all cultivars and considering the Imbibition X Soil P interaction (Table 16), imbibition is seen to increase yields in the absence of P fertilizer and liming. It would appear thus to have value in a low input situation, i.e. where neither liming or soil P fertilization are economically viable alternatives.

Table 15. Analysis of variance of $3X\ 4^2$ experiment on a Typic Humitropept in Turrialba, with 35% aluminun saturation.

Source of variation	GL	Sum of squares	F VAlue	Prob F
Bean cultivar	2	2117459	24.2	0.0001
Fertilization(0 or 300kg/ha P)	1	5931632	136.3	0.0001
Foliar P application (FOL)	1	139665	3.1	0.1008
Seed imbibition of P (IMB)	1	641996	14.74	0.0027
Liming (0 o 5 t/ha)	1	306752	7.15	0.0224
CULT X FERT	2	466230	5.35	0.0238
CULT X FOL	2	871	0.21	0.99
CULT X IMB	2	634257	7.28	0.0097
CULT X LIME	2	24945	0.29	0.7564
FERT X FOL	1	2649	0.06	0.8097
FERT X IMB	1	418693	9.62	0.0101
FERT X CAL	1	53774	0.67	0.4313
FOL X LIME	1	967	1.24	0.2901
IMB X LIME	1	391143	8.98	0.0121
CULT X FERT X FOL	2	107348	1.23	0.3288
CULT X FERT X IMB	2	175828	2.02	0.1791
CULT X FERT X LIME	2	86152	0.99	0.4026
CULT X FERT X IMB	2	47567	0.55	0.5941
CULT X FOL X LIME	2	302055	3.47	0.0679
CULT X IMB X LIME	2	91679	1.05	0.3816
FERT X FOL X LIME	1	4332	0.10	0.7583
FERT X FOL X IMB	1	6120	0.14	0.7149
FERT X IMB X LIME	1	39307	0.90	0.3624
FOL X IMB X LIME	1	249350	5.73	0.0357
ERROR	11	478951		

C.V. 17.04 %

Table 16. Main effects and significant interactions in 3 X4^3 experiment at Turrialba (1986-7)

a) Main effects (kg ha^{-1})

CULTIVAR		FERT P		LIMING		IMBIBITION		FOLIAR P	
ICA PIJAO	1519	0	873	0	1144	0	1339	0	1278
IGUACU	1045	+	1576	+	1304	+	1109	+	1170
PUEBLA 152	1108								

b.) Interactions among cultivars ,soil P, and imbibition; and cultivars X Liming

	-P, -IMB	-P, +IMB	+P, -IMB	+P, +IMB	-Lime	+Lime	Mean per Cultivar
	----kg/ha at 14% mositure----						
ICA Pijao	1211	862	2282	1720	1448	1589	1519
IGUACU	700	735	1713	1032	934	1157	1045
PUEBLA 152	772	953	1358	1346	1049	1165	1108

c.) Interaction among Liming, soil P , and seed imbibition

	-IMB -P	+IMB -P	-IMB +P	+IMB +P
Without Lime	671	874	1668	1373
With Lime	1118	838	1902	1360

The response of the ICA PIJAO cultivar to different P levels with the appropriate response curves is presented graphically in Figure 7 . Bean yields, percent of maximum yield, P concentration in soil solution and P levels in last fully expanded trifoliate leaf at flowering are given in Table 17 for the control, liming, foliar P, and seed imbibition treatments. In Figures 8 and 9 percent maximum yields are plotted against soil P levels as calculated from the isotherm (Fox, 1981). In this manner, external P requirements (amount of P necessary in soil solution to give 95% maximum yield could be calculated. They were found to vary from 0.082 to 0.093, with a value of 0.084 for the control treatment. This would compare quite well with the value of 0.08 reported for the ICA-Huasano cultivar by CIAT (1977) on a Colombian soil pf volcanic origin.

It can be seen that liming appears to have shifted the P adsorption isotherm upward as was reported by Friesen, Juo, and Miller (1980) for a Nigerian Ultisol with similar levels of exchangeable aluminum as that used in the present study. However, the level of P fertilization required for maximum yield is lower with liming as is generally reported in the tropics (Lathwell, 1979) so that when the response curve is combined with the isotherm in order to determine the external P requirement (Figure 8), the latter is found to be 0.089 ppm, higher than in the absence of liming. If liming increases the amount of P in the soil solution, this result would appear to be reasonable since there should be a higher level of soil solution P at all levels of applied P in the limed plots. Friesen <u>et al.</u> (1980) observed this effect only at higher levels of lime such as those used in the present study (5 t ha^{-1}).

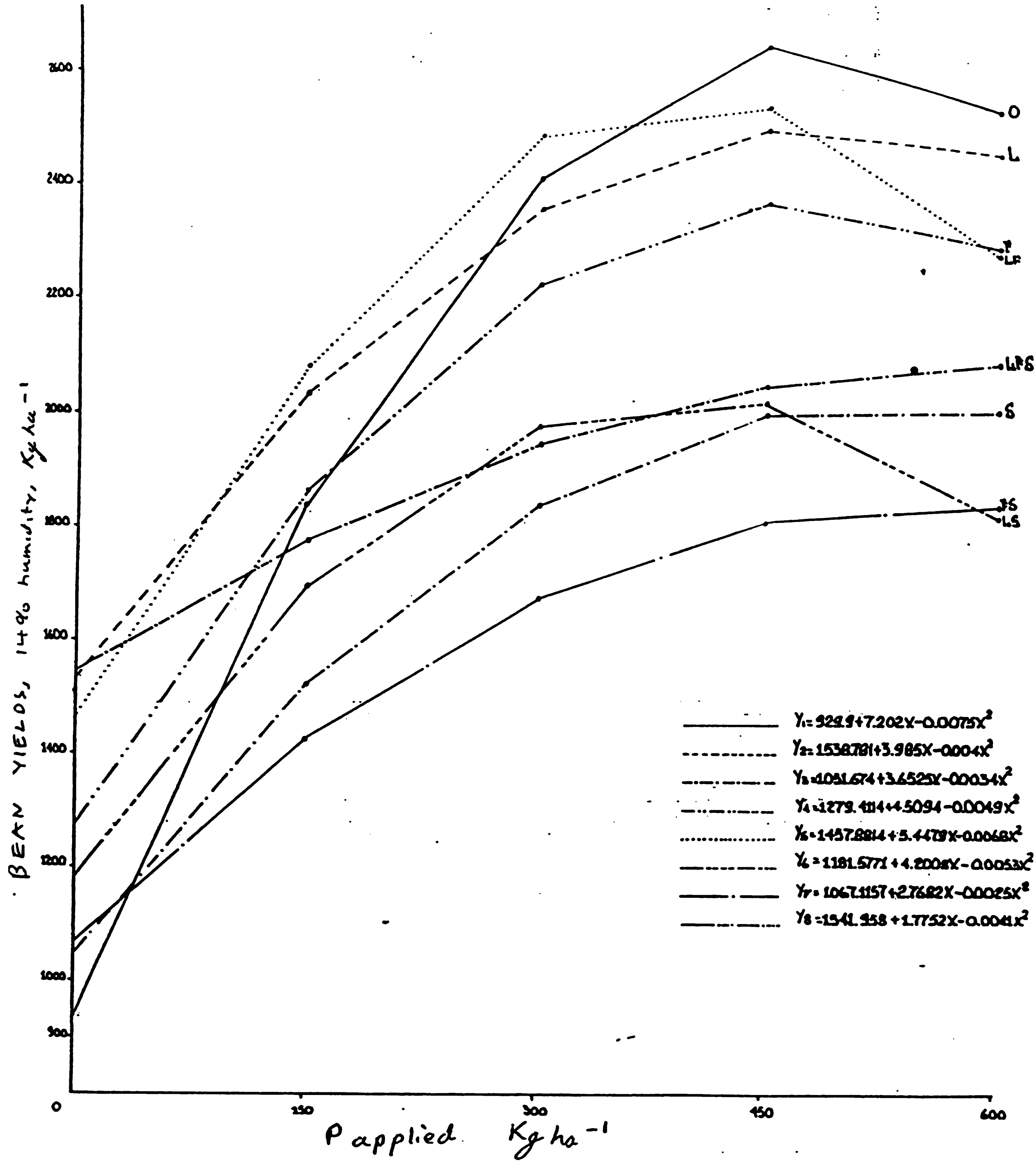

Figure 7. Response of bean cultivar ICA PIJAO to Phosphorus with different combinations of lime (L), foliar applied (F), and seed imbibed (S) P.

Table 17. Bean yields (14% moisture), percent maximum yield, P concentration in soil solution, and foliar P levels associated with different levels of P fertilization in unlimed plots, limed plots, plots receiving foliar P application, and seed imbibed P in a trial on a Typic Humitropept with 35% Al saturation in Turrialba, Costa Rica (1986-7).

Management system	Level of P applied (kg/ha)	Yield of beans (kg/ha) (14% moisture)	% of maximum yield (1)	Concentration of P in soil solution(2) (ppm)	Concentration of foliar P (%)
Control					
	0	842	34,9	0.063	0.585
	150	2064	69.2	0.072	0.605
	300	2266	90.7	0.081	0.545
	450	2609	99.3	0.093	0.570
	600	2571	95.2	0.105	0.605
Limed	(5t ha^{-1})				
	0	1479	61.3	0.068	0.510
	150	2170	81.4	0.077	0.595
	300	2325	94.1	0.088	0.645
	450	2414	99.7	0.109	0.620
	600	2508	98.1	0.114	0.610
Foliar P applied					
	0	1181	52.1	0.063	0.570
	150	2046	75.5	0.072	0.580
	300	2263	91.1	0.081	0.620
	450	2131	99.0	0.093	0.675
	600	2402	99.3	0.105	0.670
P imbibed by seed previous to planting					
	0	974	55.2	0.063	0.550
	150	1719	80.4	0.072	0.610
	300	1718	95.9	0.081	0.620
	450	1961	100.2	0.093	0.640
	600	2042	98,8	0.105	0.620
Significant F tests		Sistem Linear P Quadratic P			Linear P Quadratic P

(1) Percent maximum yield calculated from response curve (Fig 7)

(2) P concentration in soil solution calculated from P adsorption isotherm

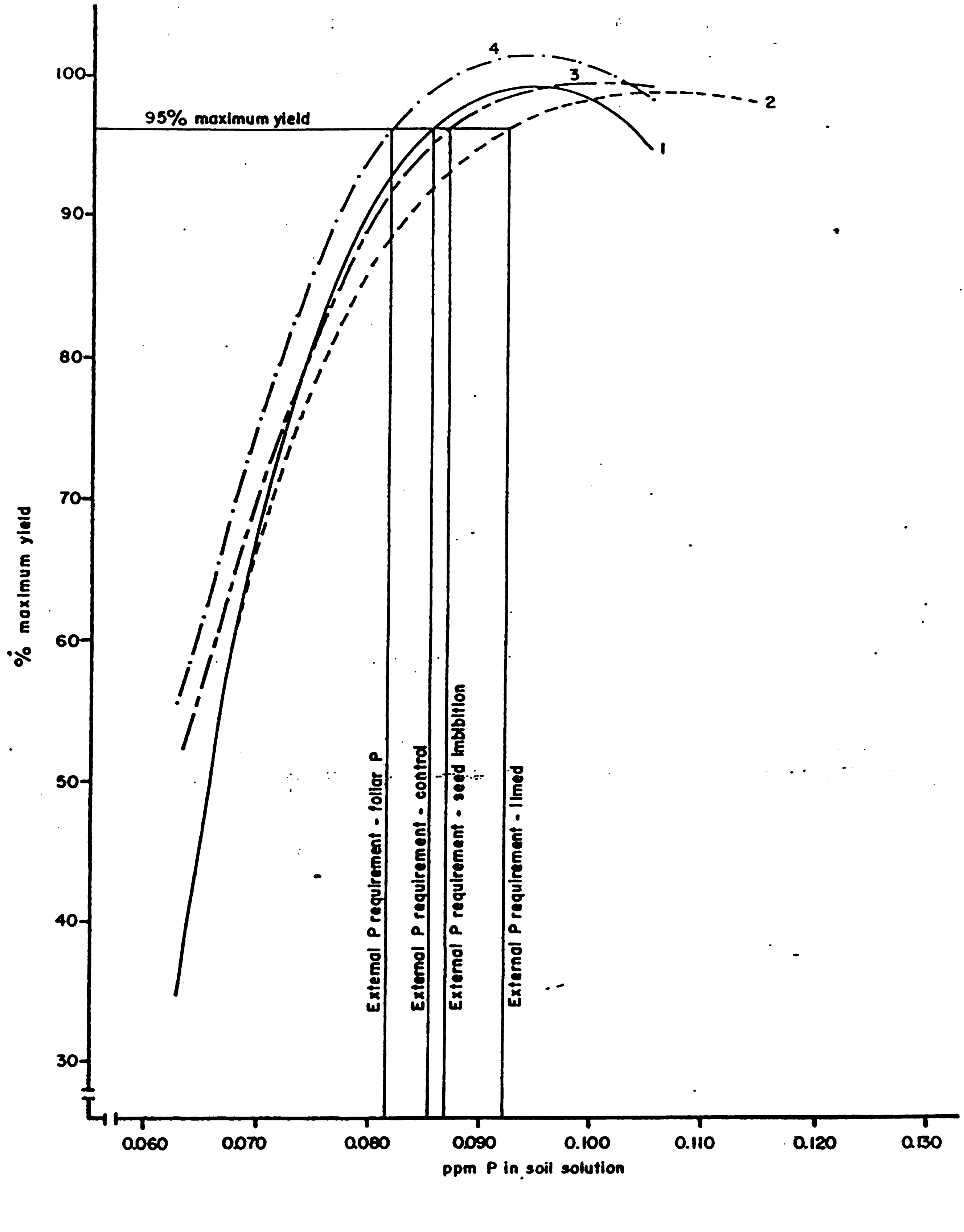

Figure 8. Determination of external Phosphorus requirement of beans under four management systems

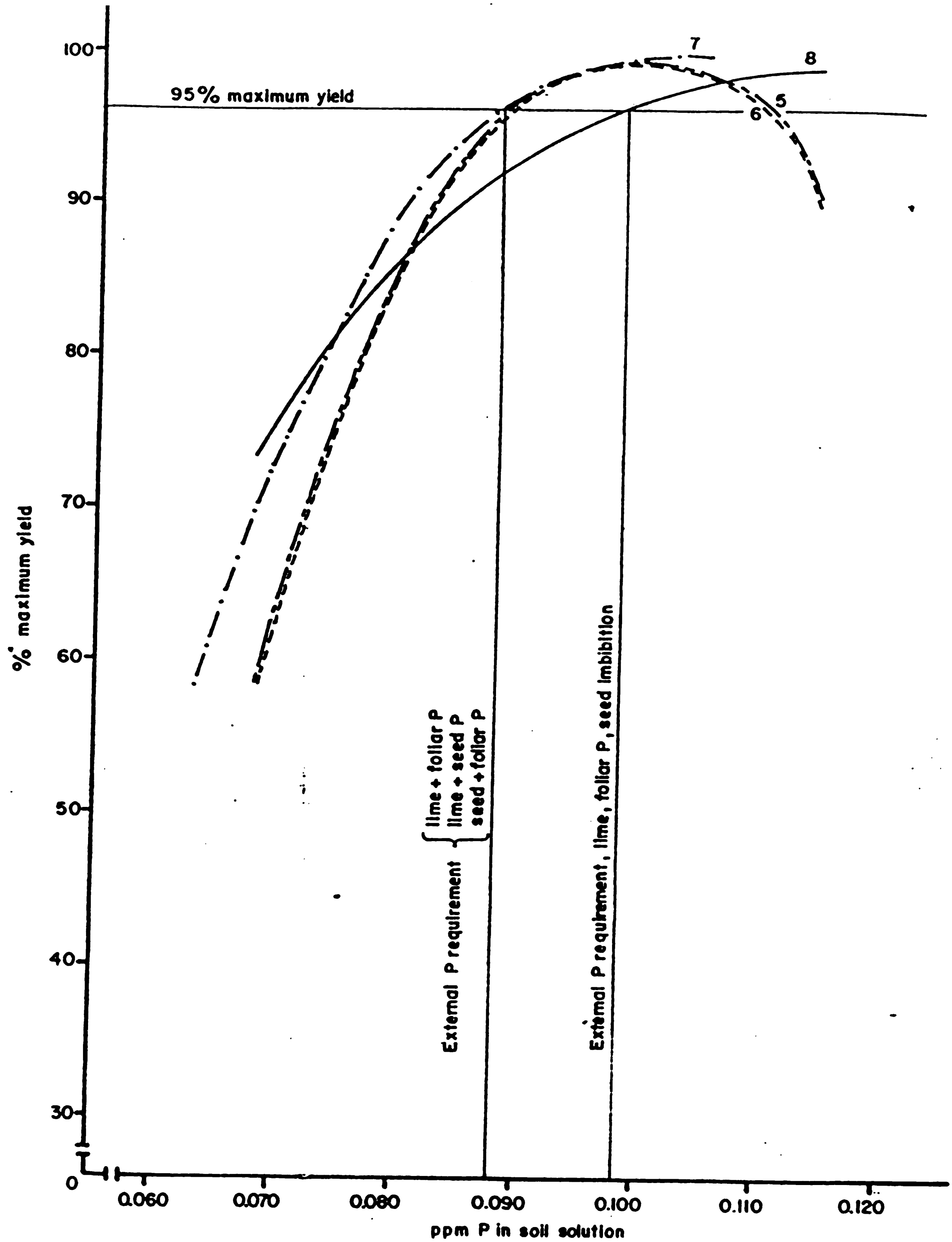

Figure 9. Determination of external Phosphorus requirements of beans with combinations of liming, seed imbibition, and foliar P.

As part of the M.S. thesis of Ing. Alexis Samudio, a Panamanian student whose M.S. program was supported by the project, an additional field experiment was run in the township of San Andres, Panama, a major bean producing region of that country, which imports more than 80% of the beans consumed (Samudio, 1988). A profile description was made by Dr. Ray Bryant who classified the soil as a Hydric Dystrandept. Analytical data are presented in Table 18. It can be seen that the aluminum saturation was rather high (33%) in the surface horizon and much lower at greater depths. Zinc levels were also low. There was considerable local interest in no tillage techniques. As a result, there were five main plot treatments: 1) no lime,no zinc, no tillage; 2)no lime, zinc, and no tillage; 3) lime, no zinc, and tillage; 4)lime, no zinc, and tillage; and 5) lime, zinc, and tillage. As in the other experiments, P was to be broadcast as this would give a mixing with the soil more analogous to the isotherms which were used to determine P :levels in the soil solution. Fox and Kang (1978) showed no difference in P response of maize to banded or broadcast P although some reduction in P requirement had been shown by previous work in Panama (De Gracia, 1985). As a compromise with the personnel of the Panamanian agricultural research organization (IDIAP), it was decided to apply 0, 100, 200, 400, and 600 kg P ha^{-1} to the plots that were tilled and 0, 50, 100, 150, and 200 kg P ha^{-1} to the plots receiving no tillage. The resulting experiment could be analyzed as two experiments, utilizing the plots which received the same levels of P for the comparison of tillage and non-tillage and utilizing the tilled plots to obtain a P response curve. There were two repetitions.

Table 18. Physico-chemical data of the soil used for experimentation in Panama.

Horizon	A_1	A_2	AB	BW_1	BW_2
Depth (cm)	0-26	26-51	51-78	78-109	109-145+
pH H_2O	5.6	6.4	6.3	6.9	6.8
KCl	4.8	5.3	5.6	5.7	5.3
NaF	10.5	10.9	10.7	10.7	10.4
Cmol (+)/kg (1)					
Ca	1.6	1.8	2.7	4.3	6.6
Mg	0.34	0.28	0.38	1.04	1.19
K	0.34	0.26	0.17	0.23	1.62
CEC	32.30	35.00	27.80	37.00	34.00
Sat bases (%)	7.1	6.7	11.7	15.00	27.7
Cmol (+)/kg (2)					
Ca	1.59	2.39	1.88	2.85	4.29
Mg	0.34	0.31	0.25	0.62	0.75
K	0.17	0.14	0.12	0.12	0.82
Exch.acidity	1.05	0.25	0.20	0.15	0.20
Effective CEC	3.15	3.09	2.45	3.74	6.06
% Al sat	33.4	8.10	8.20	4.00	3.30
Results of Olsen extraction (mg/kg)					
P	7.5	0.4	1.3	1.3	3.1
Cu	9.4	9.2	6.1	6.1	8.8
Zn	0.9	0.6	0.3	1.2	1.9
Mn	4.7	3.0	1.1	1.2	1.0
New Zealand P retention (%)					
	89.0	98.0	96.5	98.5	87.5
Organic matter (mg/kg)					
	89.0	66.0	31.0	14.0	4.0
Bulk density (tm^{-3}) (3)					
	0.82	0.83			
Particle size distribution (gg^{-1})					
Sand	0.39	0.41	0.41	0.36	0.30
Silt	0.52	0.51	0.43	0.47	0.47
Clay	0.09	0.08	0.16	0.17	0.23

1. Extraction with Ammonium Acetate, 1 N, pH 7
2. Extraction by Olsen for K, KCl for Ca, Mg, and exchangeable acidity
3. Clod method

P adsorption isotherms for this soil were presented in Figure 6. Three bean cultivars, commonly planted in the region, were used: Renacimiento, Rosado, and 105-R. There were thus fifteen main plot treatments (3 cultivars X 5 management systems) and five subplot treatments for a total of 150 subplots. Each subplot consisted of 4 bean rows, 5m in length with 50 cm between bean rows. The middle 4m of the two central rows was used to determine yields. As there were 0.1 cm between plants, yield was evaluated on approximately 80 plants per subplot, representing an area of 4 m^2. Percent germination, number of plants per harvested area, number of pods per 10 plants, number of seeds for 10 plants, and weight of 100 seeds were determined for each subplot in addition to grain yield at 14% moisture.

In the limed treatments, 1.59 t ha^{-3} of local limestone with a lime equivalent of 0.65, was applied five weeks previous to planting. Zinc was applied as ZnO_2 at a rate of 18 kg Zn ha^{-1}, applied in a band one week after seeding. One week after planting, the entire experiment received 75 kg ha^{-1} N as urea and 30 kg K ha-1 as KCl.

The experiment was located 450 m above sea level in a terrain with about 1% slope. The experiment was planted in October, 1987, and harvested in February, 1988. In October, 1988, the area was reseeded with no further application of lime, Zinc, or Phosphorus. Otherwise, management was the same as in 1987-88.

Results of the analysis of variance for all treatments at 0, 100, and 200 kg P ha^{-1} are given in Table 19. The other analysis of variance for only the tilled treatments at 0, 200, 400, and 600 kg ha^{-1} P for the determination of the response curve are given in Table 20.

Table 19. F values for analysis of variance for yield components of field experiment in San Andres, Panama, using 0, 100, and 200 kg /ha P and all management treatments

Sources of Variation	Degrees Freedom	Pods per 10 plants	Seeds per 10 plants	100 seed weight	Yield
Repetitions(1)	1	35.13*	7.24ns	0.84ns	7.91ns
Cultivars (1)	2	25.14ns	3.65ns	9.18ns	0.28ns
Reps X Cult	2	0.50ns	2.04ns	5.57**	7.12**
Management (2)	4	0.22ns	0.98ns	1.15ns	0.95ns
Manage X Cult(2)	8	1.79ns	3.01*	1.75ns	3.12*
Error (a)	14	0.44ns	0.46ns	0.65ns	1.89ns
P levels	2	14.13**	20.40**	28.59**	56.66**
PX Cults	4	1.64ns	1.73ns	0.24ns	3.15*
PX Management	8	1.01ns	0.65ns	0.67ns	2.59*
PX manageX Cult	16	0.74ns	1.31ns	1.37ns	0.92ns
Error (b)	30				
C.V.(%)		16.69	18.76	3.18	11.15

1) Reps X Cult mean square used for F test

2) Error (a) used for F test

F values of one degree of freedom contrasts for management X cultivar interaction

	Pods per 10 plants	Seeds per 10 plants	100 seed weight	Yield
Tillage vs no tillage/ Rosado vs others	0.01ns	0.61 ns	1.50ns	4.84*
Tiilage vs no tillage/ 105-R vs Renacimiento	0.46ns	0.09ns	0.42ns	0.09ns
Zn no till vs no Zn/ Rosado vs others	2.96ns	1.61 ns	3.48ns	0.00ns
Zn no till vs no Zn/ 105-R vs Renacimiento	0.21ns	0.45ns	0.04ns	3.35ns
Tillage + lime vs no lime/ Rosadovs others	5.23*	8.26*	0.71ns	13.45**
Tillage+ lime vs no lime/ 105-R vs Renacimiento	0.06ns	1.06ns	0.59ns	2.50ns
Lime +Zn vs Lime-Zn/ Rosado vs others	1.01ns	5.29*	7.14*	0.75 ns
Lime+Zn vs Lime-Zn/ 105-R vs Renacimiento	4.39ns	6.40*	0.07ns	0.00ns

* indicates significance at p = 0.05

** inidcates signficance at p = 0.01

Table 20. F values for analysis of variance for yield components of field experiment in San Andres, Panama, using only tilled management treatments and P levels of 0, 200, 400, and 600 kg P/ha.

Sources of Variation	Degrees Freedom	Pods per 10 plants	Seeds per 10 plants	100 seed weight	Yield
Repetitions(1)	1	9.55ns	10.56ns	0.10ns	15.23ns
Cultivars (1)	2	8.09ns	3.61ns	20.95*	7.41ns
Reps X Cult	2	1.30ns	2.00ns	1.02ns	1.90ns
Management (2)	2	0.23ns	0.49ns	1.18ns	1.25ns
Manage X Cult(2)	4	9.33**	4.18ns	0.64ns	4.51ns
Error (a)	8	0.17ns	0.42ns	1.02ns	1.29ns
P levels	3	3.34ns	10.09**	14.41**	23.17**
PX Cults	6	0.38ns	0.32ns	0.58ns	0.50ns
PX Management	6	0.39ns	0.60ns	1.56ns	0.62ns
PX manageX Cult	12	0.80ns	0.89ns	0.46ns	0.77ns
Error (b)	27				
C.V.(%)		17.60	18.00	4.00	13.30

1) Reps X Cult mean square used for F test

2) Error (a) used for F test

F values for one degree of freedom contrasts for P response, management systems, and cultivars.

Lineal P	5.42*	15.41**	30.48**	49.43**
Quadratic P	3.08ns	13.95**	9.96**	15.73**
Cubic P	1.51ns	0.91ns	2.80ns	4.35*
Lime *vs* no Lime	0.01 ns	0.09ns	2.35ns	1.25ns
Lime+ Zn *vs* Lime-Zn	0.07ns	0.33ns	0.04ns	1.97ns
Rosado *vs* other cults	20.74**	11.43**	10.26**	27.42**
105-R *vs* Renacimiento	0.36ns	3.05ns	32.36**	0.73ns

* indicates significance at p = 0.05

** indicates signficance at p = 0.01

Response curves for the three cultivars in the tilled, unlimed, no zinc treatment, the tilled, limed, no Zinc treatment, and the tilled, limed, zinc treatment are given in Figures 10,11, and 12 respectively. Liming improved the P response of the Rosado cultivar while zinc improved the P response of the Renacimiento cultivar. The 105-R cultivar gave about the same P response, which was quite small, in the presence or absence of lime or zinc.

Similar procedures for determining external P requirements from the P adsorption isotherms and the response curves were used as in the Turrialba experiment (Figures 13, 14, 15). These data are summarized in Table 21. As was seen from the response curve, the application of lime markedly reduced the external P requirement of the Rosado cultivar. The application of Zn in addition to lime further reduced the external P requirements of the Renacimiento and 105-R cultivars. Although the yields were higher than in the Turrialba experiment, the P response was less marked and the external P requirements were considerably lower despite the fact that the San Andres soil showed higher P retention than the Turrialba soil. One would have to conclude that these cultivars are more adapted to a soil with high P retention characteristics than the ICA PIJAO cultivar used at Turrialba. The amounts of P necessary to obtain 95% maximum yield are quite modest, being less than 300 kg P ha^{-1} for the Renacimiento and Rosado cultivars in the presence of lime and zinc. However, the actual increase in bean yield associated with the application of this amount of P was around 600 kg ha^{-1} and was only 200 kg ha^{-1} for the 105-R cultivar. Without lime and P, the Renacimiento cultivar performed best while the Rosado cultivar showed the highest yield at all P levels when the soil was limed.

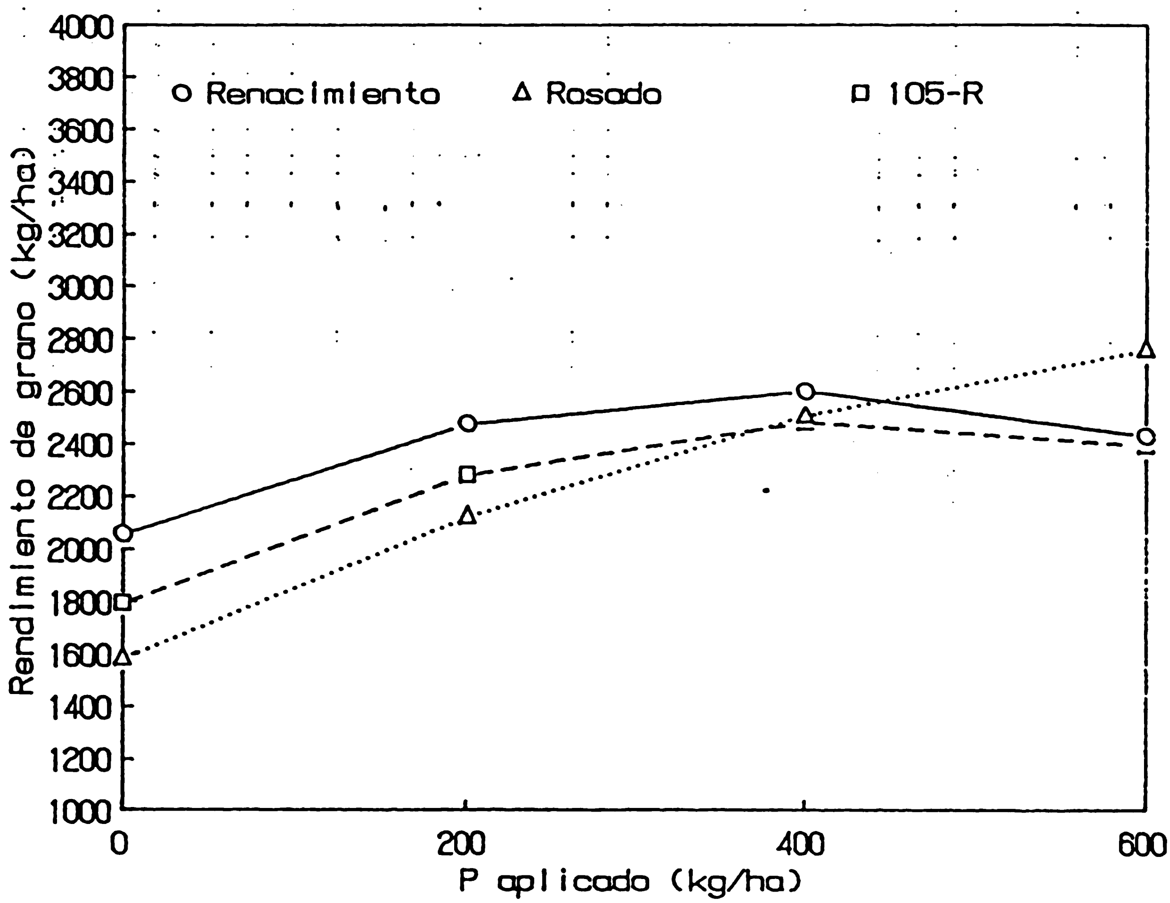

Figure 10. Response curves of three bean cultivars to P fertilization on a Hydric Dystrandept in San Andres, Panama, in tilled, unlimed plots without supplemental Zn.

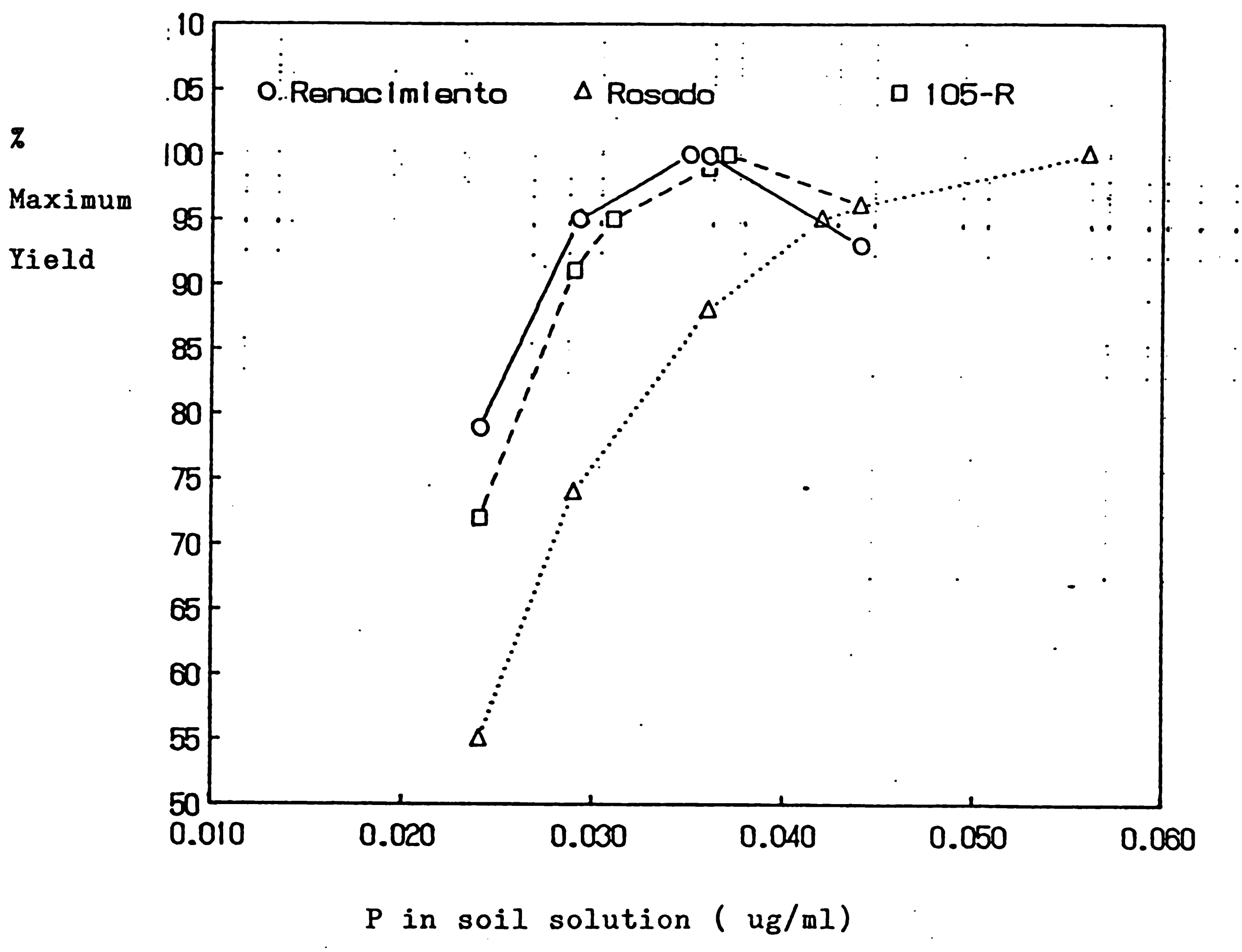

Figure 13. Determination of external P requirement for three bean cultivars in San Andres Panama in tilled plots without lime or zinc.

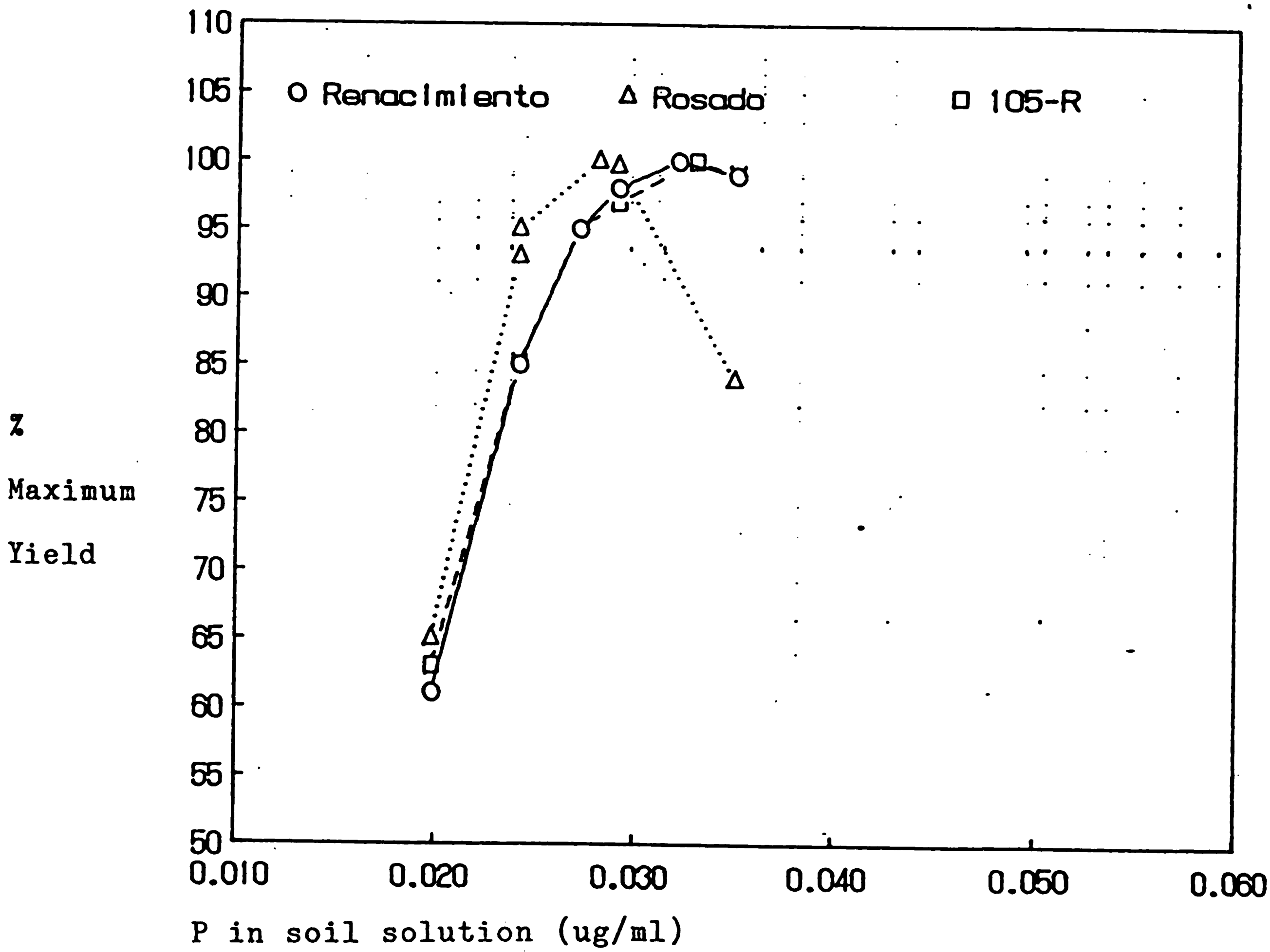

Figure 14. Determination of external P requirement for three bean cultivars on a Hydric Dystrandept in San Andres, Panama. Tilled and limed plots without Zn.

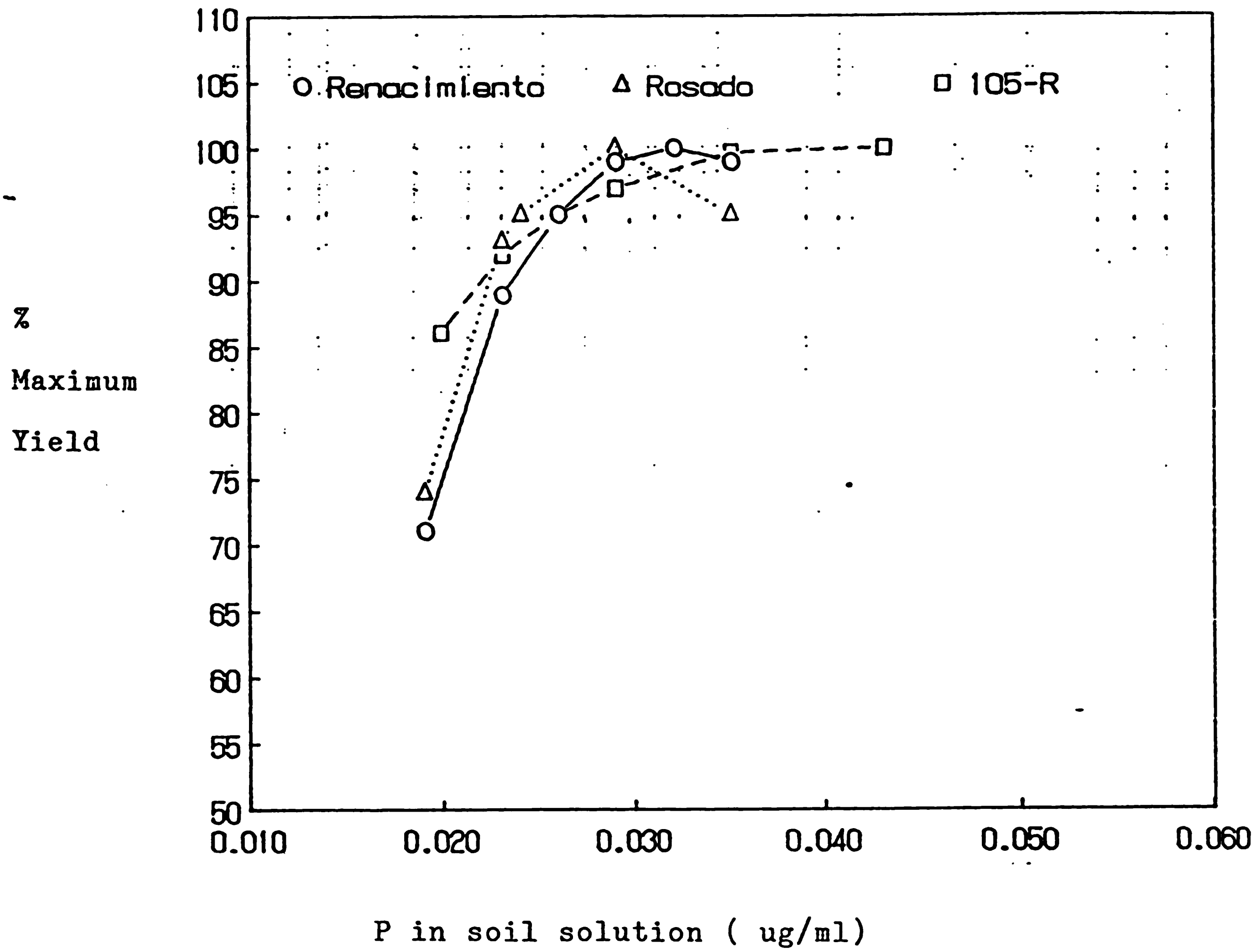

Figure 15. Determination of external P requirement for three bean cultivars on a Hydric Dystrandept in San Andres, Panama. Tilled, limed plots with Zn application.

Table 21. P response and determination of external P requirement for three bean cultivars at three different levels of management on a Hydric Dystrandept in San Andres Panama

a.) Bean yields at 14% moisture (kg ha^{-1})

Management and Cultivars	Level of P application (kg ha^{-1}) 0	200	400	600
Tillage, no lime, no Zn				
Renacimiento	1967	2735	2339	2512
Rosado	1499	2352	2271	2838
105-R	1779	2317	2443	2398
Tillage, lime, no Zn				
Renacimiento	1403	2136	2210	2383
Rosado	2190	3078	3389	2825
105-R	1465	2093	2212	2356
Tillage, lime, Zn				
Renacimiento	1843	2333	2543	2574
Rosado	2183	2960	2901	2825
105-R	2042	2303	2229	2416

b. External P requirement

	95% Maximum Yield kg ha^{-1}	Fertilizer P required kg ha^{-1}	External P requirement mg kg^{-1}
Tillage, no lime, no Zn			
Renacimiento	2471	197	0.029
Rosado	2721	559	0.042
105-R	2368	255	0.031
Tillage, lime, no Zn			
Renacimiento	2252	331	0.027
Rosado	3187	224	0.024
105-R	2333	338	0.027
Tillage, lime, Zn			
Renacimiento	2456	294	0.026
Rosado	2955	234	0.024
105-R	2272	309	0.026

Analysis of all the treatments at the 0,100, 200 kg P ha^{-1} levels failed to give much support to the hypothesis that banded application of P would be more efficient than broadcast application (Table 19) although the P X management interaction was significant at the p = 0.05 level. In the absence of P, there was no difference in bean yield among management treatments (Table 22). At 100 kg P ha^{-1}, the untilled plot without lime and zinc , in which the P was banded, outyielded the tilled plot with no lime and zinc in which the P was broadcast. Similarly, higher yields were obtained in the unlimed, untilled plot whtich received zinc than in the tilled plot which received lime and zinc. At 200 kg P ha^{-1}, all of these relations were reversed with the tilled plot without lime or zinc in which the P was broadcast outyielding both untilled treatments. Similarly, the highest yield was obtianed with tillage, lime, and zinc and the lowest yield in the untilled plot with zinc.

Application of zinc in the untilled, unlimed plots always resulted in higher levels of Zn in the foliage than application of zinc in the tilled, limed plots. At higher p levels, there was little increase in foliar Zn levels due to Zn application in both tilled and untilled plots.

At the time of bean harvest, P adsorption isotherms were again determined. The greatest effect was seen in the banded treatments where the application of 200 kg ha^{-1} of P in the band shifted the P adsorption isotherm leftward, with the result that the amount of P addition required to obtain 0.2 ug/ml in soil solution was reduced from 1400 to about 1200 ug/g. For the other treatments, the shift of the P adsorption isotherm was less marked, even when 600 kg P ha^{-1} was applied broadcast.

Table 22. Effect of P X Management Interaction on yield components of beans on a Hydric Dystrandept, San Andres, Panama

Treatment	Pods per 10 plants	Seeds per 10 plants	100 seed weight (g)	Yield kg ha^{-1}
0 kg P ha^{-1}				
no tillage,no Lime,no Zn	74.67	242.67	47.71	1887
no tillage,no Lime, +Zn	63.67	204.83	48.29	1747
tillage, no Lime, no Zn	77.00	241.33	48.66	1749
tillage, + Lime, no Zn	70.17	200.17	46.66	1686
tillage,+lime, + Zn	75.50	221.83	48.17	2023
100 kg P ha^{-1}				
no tillage,no Lime,no Zn	91.00	301.50	49.91	2391
no tillage,no Lime, +Zn	96.50	307.17	50.31	2709
tillage, no Lime, no Zn	82.00	263.17	50.73	2217
tillage, + Lime, no Zn	90.17	281.83	50.00	2206
tillage,+lime, + Zn	84.50	297.83	50.02	2338
200 kg P ha^{-1}				
no tillage,no Lime,no Zn	87.50	297.33	49.90	2459
no tillage,no Lime, +Zn	92.00	305.83	50.31	2262
tillage, no Lime, no Zn	90.33	303.17	50.64	2469
tillage, + Lime, no Zn	87.17	292.50	51.14	2436
tillage,+lime, + Zn	85.83	292.17	51.38	2532

The experiments in San Andres were harvested in February, 1988. Some funds were still available to finance a repeat of the planting with no fertilizer applied in November, 1988, to measure residual effects. It was hoped at that time that some extension of the project could be obtained to meaure long-term effects of massive P applications. When we informed in January, 1989, that there would be no extension and the final report was due in November, 1988, the experiments were already planted. However, lack of funding has made analysis of data of the results rather difficult. Bean yields for the second planting to which no fertilizer was applied are given in Table 23. Further analyses will depend upon the securing of further funding.

It can be seen that considerable response to P, especially to 200 kg P ha^{-1} was obtained in the second year, indicating that even in this relatively high fixing soil, considerable P remains available in the second year even when only 200 kg ha^{-1} is applied. When yields for the two years of the experiment are combined (table 24), it can be seen that in several cases, the application of 200 kg ha^{-1} of P resulted in an increase of 1500 to 2000 kg ha^{-1} of beans. Such an increase in bean production would readily pay for the cost of the fertilizer. As was pointed out by Sanchez and Uehara (1980), several years of such data are necessary to assess residual effects adequately and to show the true value of massive P applications. But the data available in this case would seem to indicate that relatively modest P applications may be of considerable economic benefit for several years.

Table 23. Yield of beans in second year (with no additional fertilizer applied) in experiment in San Andres, Panama
---14% mositure--
---------------------------1989------------------------------

Management and cultivars:	Level of P applied in 1987 ($kg\ ha^{-1}$) 0	200	400	600
Tillage, no lime, no Zn				
Renacimiento	1051	1788	2155	2194
Rosado	817	2398	1790	2242
105-R	983	2012	2252	2319
Tillage, lime, no Zn				
Renacimiento	1216	2237	2307	2169
Rosado	1499	2160	2125	2731
105-R	953	2002	2253	2118
Tillage, lime, Zn				
Renacimiento	1134	2109	1966	2504
Rosado	1068	1626	1744	2121
105-R	1416	1986	2154	2057

Table 24. Total bean yield resulting from fertilizer application in 1987 (sum of 1988 and 1989 harvests)

----$kg\ ha^{-1}$ at 14% moisture---

Management and cultivars:	Level of P applied in 1987 ($kg\ ha^{-1}$) 0	200	400	600
Tillage, no lime, no Zn				
Renacimiento	3018	4523	4494	4706
Rosado	2316	4750	4061	5080
105-R	2762	4329	4695	4717
Tillage, lime, no Zn				
Renacimiento	2619	4373	4517	4552
Rosado	3689	5238	5514	5556
105-R	2418	4095	4465	4474
Tillage, lime, Zn				
Renacimiento	2977	4442	4509	5078
Rosado	3251	4586	4645	4946
105-R	3458	4289	4383	4473

IV. DISCUSSION

The first project activity was somewhat limited by the size of the sample, the fact that mineralogical and analyses for characterization of Aluminum and Iron were only done on a part of the samples, and the fact that existing databases could only be used to a limited extent to supplement data determined by the project. Finally, the publication of the revision of the soil taxonomy with the Andosol order separated and reorganized some three months after funding for the project terminated (Soil Survey Staff, 1990) meant that the results were somewhat obsolete before they were analyzed. The new requirements of the Andosol order would require that most of the soils be described again in the field and New Zealand P and oxalate extractable iron and aluminum be determined on all samples, an impossible task as funding for the project ended in November, 1988. Several attempts to get the project extended and some additional funding appropriated during 1988 were not successful although the principal scientist was only informed of the non-extension in early, 1989.

Still, some of the correlations of P retention with various soil properties and with the taxonomy are of interest. The high R-squared values obtained for the regressions of New Zealand P retention on total aluminum and clay percentage and isotherm P on Total aluminum and organic carbon content are of great interest. The New Zealand P retention seems to work best in Andepts (Andisols) while the isotherm P seems to be or more signficance in the more highly weathered soils where organic matter rather than amorphous constituents are playing a more significant role in P retention. This was confirmed by the attempts to correlate P retention with the taxonomy.

In any case, a larger sample with a wider range of characteristics would probably have resulted in the emergence of other relationships. When the soils are arranged in order of increasing Andept characteristics (Table 25), the importance of the factors identified in the regression equations is apparent. Soils with less Andic properties (sites 1-10), variously classified as Paleustults, Plinthudults, Haplohumults, Humitropepts, and Dystropepts , generally have lower values of both P_{nz} and isotherm P with the difference being somewhat more marked for the P_{NZ}. Clay contents of the Andepts (Dystrandepts and Hydrandepts) is markedly lower, hence making the relation of total Al (largely influenced by Al_{oxal}) in the Andepts quite obvious. Both P_{NZ} and isotherm P were highly correlated with both ln Al_{tot} and ln Al_{oxal} (Table 26) . Thus the addition of the factors of clay content and organic carbon make a relatively small contribution to the r-square values of the correlations (Table 4).

These results correlate rather well with those of Wada and Gungijake(1979) for soils, all of which had more specifically Andic properties. These authors found a more significant role for the Aluminum extracted by pyrophosphate but they did not use a stepwise regression technique and thus were able to attribute proportional rates of P retention to different fractions of iron and aluminum. We found better correlations with the $lnAl_{tot}$ than with any component of the iron and aluminum. Other authors have been less emphatic about the role of aluminum bound with organic matter in P retention. Vijaychandrian and Carter (1975), working with US soils found little relationship while Bloom (1980) and Parfitt <u>et al.</u> (1989) have stressed the importance of the

Table 25. P retention and soil characterization data for soils used to establish correlations between P retention and soil properties

ite	Depth		P_{NZ}	P_{Alv}	P_{2ppm}	pH_{Naf}	Clay	OC	pH_{HOH}	Al_{KOH}	Al_{pyp}	Al_{oxal}	Al_{dith}	Al_{totl}	Fe_{pyp}	Fe_{oxal}	Fe_{dith}
1	0	18	55.6	90.2	850	9.2	64	2.05		0.16	0.22	0.34	0.80	1.14	0.38	0.93	6.12
1	18	70	52.7	97.6	1150	9.8	68	0.27	5.2	0.18	0.20	0.16	0.84	1.00	0.08	0.31	6.42
2	0	27	64.7	96.1	1100	9.9	58	4.65	5.1	0.20	0.81	0.62	1.14	1.76	0.85	0.80	5.65
2	43		49.8	92.0	1100	9.7	74	0.31	5.2	0.26	0.44	0.36	0.92	1.28	0.43	0.21	5.60
3	0	27	57.8	92.3	1230	9.6	44	2.28	4.9	0.22	0.18	0.44	1.12	1.56	0.40	0.52	5.12
3	27	40	75.8	95.4	1500	9.7	50	1.37	5.1	0.21	0.16	0.43	1.07	1.50	0.12	0.52	6.28
4	0	19	49.7	87.3	900	9.6	57	2.89	5.4	0.29	0.46	0.30	1.40	1.70	1.14	0.50	6.40
4	19	37	81.5	88.1	1100	9.8	71	2.17	4.8	0.30	0.45	0.30	1.30	1.60	1.00	0.22	6.38
5	0	15	51.2	71.2	750	9.0	47	2.20	5.3	0.12	0.18	0.24	0.54	0.78	0.49	0.52	5.25
5	15	26	59.9	75.7	500	9.5	49	1.18	5.2	0.14	0.14	0.20	0.62	0.82	0.25	0.13	5.48
6	0	35	49.7	96.0	1430	10.0	66	2.67	5.2	0.20	0.35	0.50	0.96	1.46	0.60	0.46	5.62
6	35	90	51.2	95.7	1450	10.1	70	0.20	5.2	0.16	0.08	0.40	0.74	1.14	0.09	0.68	6.35
7	0	20	62.3	95.6	800	10.2	11	5.20	5.9	0.18	0.26	0.94	0.59	1.53	0.10	1.25	4.15
8	0		57.8	97.2	1060	10.1	23	4.94	5.6	0.46	1.12	0.84	1.88	2.72	0.55	1.18	5.90
9	0	20	52.7	96.0	1000	10.0	21	5.39	5.2	0.39	1.54	0.90	1.57	2.47	2.20	0.90	5.22
9	35	72	59.0	98.5	1450	10.5	29	2.05	5.3	0.38	1.74	0.97	1.65	2.62	1.42	0.70	5.48
.0	0	20	77.0	98.6	1700	10.8	22	5.42	5.4	0.30	1.10	0.94	1.38	2.32	0.46	0.90	4.82
10	20	47	59.6	90.1	1000	9.8	52	1.94	5.3	0.32	0.34	0.51	0.96	1.47	0.43	0.59	5.80
1	0	22	96.9	99.8		11.5	4	7.20	6.0	0.34	1.28		1.96		0.51	1.46	3.02
.1	22	34	98.3	99.8		11.2	2	5.97	6.2	0.42	0.76		1.72		0.34	1.62	3.18
1	34	80	98.7	99.8	3000	11.0	6	2.25	6.3	0.40	0.46	6.07	1.26	7.33	0.06	1.75	3.70
2	0	20	78.4	98.3	1250	10.5	8	6.43	6.0	0.25	0.60	1.50	1.11	2.61	0.38	0.90	3.95
2	20	36	81.9	99.3	1800	10.6	20	3.10	6.2	0.31	0.50	2.06	1.32	3.38	0.35	1.12	4.48
3	0	30	90.7	97.5		11.4	8	8.13	5.8	0.40	0.76	3.66	1.86	5.52	0.24	0.73	2.38
3	50	75	76.3	98.0		11.2	8	4.26	6.4	0.55	0.70	4.54	1.94	6.48	0.16	1.04	3.48
4	0	30	92.4	99.6	1900	11.1	2	11.04	5.6	0.30	0.31	1.98	1.54	3.52	0.22	1.42	2.80
5	0	27	94.0	97.5		11.2	2	3.27	5.4	0.40	0.81	3.58	1.52	5.10	0.26	0.81	2.60
5	27	51	96.6	98.0		11.3	2	5.70	5.5	0.49	0.60	4.51	1.94	6.45	0.18	1.08	3.18
6	0	30	94.4	99.3	1930	11.2	2	8.39	5.9	0.34	0.78	3.04	1.56	4.60	0.33	0.70	1.65
6	30	55	96.6	99.8	2000	11.3	4	6.27	6.1	0.40	0.52	4.62	1.88	6.50	0.16	0.98	1.65
7	0	32	93.6	95.9	2400	11.3	4	6.24	6.2	0.42	1.88	3.00	2.02	5.02	1.40	0.87	2.15
7	32	50	96.6	99.7	2900	11.0	6	1.70	6.2	0.49	1.20	3.44	1.53	4.97	0.47	0.92	4.45
8	0	25	95.6	98.7	1800	11.2	3	10.32	6.1	0.46	1.56	4.06	1.94	6.00	0.12	1.16	3.62

Table 26. Correlation matrix for P retention and selected soil properties

P_{NZ}	P_{Alv}	P_{2ppm}	pH_{NaF}	OC	pH_{HOH}	Clay	Al_{KOH}	Al_{Pyp}	Al_{Dith}	$lnAl_{Oxal}$	$lnAl_{Totl}$	Fe_{Pyp}	Fe_{Dith}	Fe_{Oxal}
1.000														
0.551	1.000													
0.799	0.661	1.000												
0.869	0.736	0.818	1.000											
0.622	0.409	0.297	0.689	1.000										
0.444	0.283	0.451	0.577	0.296	1.000									
-0.831	-0.477	-0.654	-0.842	-0.737	-0.525	1.000								
0.815	0.542	0.802	0.805	0.446	0.475	-0.660	1.000							
0.602	0.378	0.556	0.665	0.511	0.346	-0.545	0.739	1.000						
0.793	0.552	0.687	0.806	0.645	0.391	-0.627	0.870	0.767	1.000					
0.885	0.661	0.838	0.921	0.643	0.493	-0.891	0.818	0.612	0.749	1.000				
0.910	0.679	0.863	0.923	0.623	0.491	-0.831	0.896	0.655	0.861	0.969	1.000			
-0.058	-0.216	-0.052	-0.084	0.000	-0.024	0.169	0.151	0.433	0.300	-0.120	-0.011	1.000		
-0.768	-0.434	-0.597	-0.836	-0.758	-0.463	0.884	-0.603	-0.511	-0.670	-0.846	-0.800	0.071	1.000	
0.617	0.564	0.612	0.646	0.549	0.204	-0.742	0.462	0.287	0.384	0.781	0.701	-0.290	-0.574	1.000

Al-humus, the latter authors also indicating that immobilization of P by the microbial biomass can contribute to the loss of availability of phosphate in soils.

The screening activity was also to some degree limited by premature termination of the project since the relationship between seed size and success of imbibition was only realized at the last stage of the project when large seeded bean cultivars used in Panama were tested. A further field experiment using a range of seed sizes and different low levels of P fertilization would have confirmed the results indicated by the trials carried out. Lack of funding made this impossible leaving a follow-up to other researchers the possibility of putting the findings of this study into practice. However, a significant finding might have been set back by several years by PSTC not granting another $3000 which would have permitted another field experiment.

The success of the field experiments was again to some degree limited by a time-funding factor as more years would have permitted the study of residual effects which might make in some cases high levels of P economic (Sanchez and Uehara, 1980). Again, the level of funding of the project made it difficult to carry out field experiments on the full range of soils with a variety of different P retention mentions. Still, some of the results obtained indicate that increasing yields of beans through adequate use of P fertilization and liming in Central America may not be as costly as previously considered.

Three of the soils used for the field experiments (Fraijanes, Coto Brus , and San Andres) might be considered highly P fixing (P_{NZ} values of over 90%). Still, maximum yields were associated with relatively modest levels of

P application (100-200 kg P ha^{-1}). While other factors may have limited bean production at the Fraijanes site, the response to these levels of P application at the Coto Brus and San Andres sites is sufficient to make such an application level highly economic. At the San Andres site, the increase in bean yield for a single 200 kg ha^{-1} P application was almost 2000 kg ha^{-1} for the two years which would easily pay for this level of P application.

Although the coefficients of variability were high at the two less highly P retaining sites (the Paleustult in Guarumal and the Haplohumult in Rio Frio), indicating that other factors might have been limiting bean production, the response to P was modest, leveling off at 100 kg ha^{-1} of P at Guarumal and at 200 kg ha^{-1} at Rio Frio. Response to lime was observed at both sites, indicating a lower cost alternative though highest yields were obtained with the applications of both lime and P. The yield increase due to the application of 3 t ha^{-1} of lime and 100 kg ha^{-1} of P at Guarumal was almost 800 kg ha^{-1} of beans, which would probably pay for these inputs.

At the Turrialba site, despite only moderate P retention properties of the soil, less than 1000 ug/kg of P necessary to get 0.2 ug/L P in soil solution, the response to both P and liming was more marked and somewhat higher levels of P were required to obtain 95% maximum yield. About 375 kg ha^{-1} of P were required to obtain 95% maximum yield, which was about 1500 kg ha^{-1} of beans higher than the yield obtained in the absence of lime and P. At higher levels of P, the effect of liming was practically insignificant, indicating that liming might only be necessary when only small amounts of mineral P are available. At present prices in Costa Rica, 5t of lime would cost less than 150 kg of P as triple superphosphate.

The project thus did demonstrate two low cost alternatives to Phosphorus application, soaking seeds in a concentrated P solution prior to seeding and liming. The former technique would work better with large seeded bean varieties (a 100 seed weight of over 30g) while the latter was only demonstrated in soils with over 30% aluminum saturation. Moderate applications of triple superphosphate (1 t ha^{-1}) broadcast and incorporated would appear to be more economical than previously thought, increasing bean production by as much as 1 t ha^{-1} per harvest and the results might be maintained over several harvests.

It may appear from the previous discussion that the P retention isotherms were of limited value in predicting the P response since the strongest P response was observed on the Humitropept in Turrialba with a moderate P retention (about 850 ug/g P required to get 0.2 ug/ml P in solution) . The Hydric Dystrandept from Panama required about 1200 ug/g P to get 0.2 ug/ml P in the soil solution. P retention was much higher in deeper horizons of this sol. It would appear that the San Andres soil had received some P fertilization, possibly the previous year, since the Olsen P was much higher in the surface horizon, which extended to 26 cm, than the deeper horizons. Yields in the 0 P plots were much higher in San Andres than in Turrialba about 1600 kg ha^{-1} as opposed to about 800 kg ha^{-1} (Tables 17 and 21). Maximum yields in the absence of liming were quite similar, about 2500 kg ha. Varietal differences might have affected the results somewhat since the Renacimiento and 105R cultivars, two of the three used in San Andres, showed a very small response to either P application or liming. The low yields obtained in the control plot in the second year (Table 23) also indicates that initial P levels might have been responsible for the higher yields in San Andres. Klages, Olsen , and Haby (1988) found isotherm P to be a better predictor of P response in a wide range of Montana soils, including some volcanic soils with high allophane content, than the Olsen P extraction.

The Panamanian results also indicate that proper selection of cultivars would be another promising low-income alternative to high levels of P application. The external P requirements of the bean cultivars used in Panama were much lower than that found for the ICA Pijao cultivar in Turrialba, which corresponded quite well to that found for several bean cultivars by CIAT (1978) on an Andept in Colombia. External P requirements may vary with cultivars but should not vary with soil characteristics (Fox, 1981; Lopez-Hernanadez, Coronel, and Alvarez, 1987). As can be seen in Table 21, however, the Rosado cultivar showed a higher external P requirement in the absence of liming than when soils were limed. As all of the soils used by Lopez-Hernandez et al.(1987) were limed, the effect of liming on external P requirements does not seem to have been investigated previously. As liming only affected the P adsorption isotherm slightly, the marked response to lime in the Rosado cultivar would have to be explained by a change in the external P requirement. On the Turrialba soil, the external P requirement of the ICA Pijao cultivar was increased slightly by liming (from 0.087 to 0.092 ug/ml).

The cultivar X P interaction was only signfiicant at one of the Costa Rican sites. Only at the Coto Brus site (Hydric Dystrandept) did the Huasteco cultivar outyield the Talamanca cultivar in the absence of P fertilization. With P fertilization, the Talamanca cultivar performed best at all locations with the exception of the Fraijanes site (Typic Dystrandept) where the yield levels were low in all cases (Table 14).

All of the volcanic soils used in the project were of coarse texture with low clay contents. Clay content has been shown by various authors to affect P retention (Juo and Fox, 1977; Sanchez and Uehara, 1980; Klages et al., 1988). Klages et al. (1988) found the clay content to affect the ability of the Olsen extraction to predict P response more than the isotherm procedure. Soils with low clay content should have less surface to react with phosphate (Juo and Fox, 1977) and therefore adsorb less P or adsorp it more weakly than the content of factors affecting P adsorption, such as total Al, would indicate. Parfitt et al.(1989) found somewhat higher levels than expected of P availability in some New Zealand Andepts, but did not indicate the texture of the soils studied.

The role of organic P was not considered in the present study though carbon content was shown to affect the P retention as measured by the isotherms. Organic matter levels were high in all soils studied, especially in the Andepts. Organic P can account for 60-80% of the total P in Costa Rican Andepts (Martini and Luzuriaga, 1989). The importance of aluminum bound with the humus in P retention has been emphasized by several authors (Wada and Gunjigake, 1979; Parfitt, 1989) and is included in the total Al which quite accurately predicted P retention by both the New Zealand and isotherm P methods. How much of the P applied moves into organic pools as compared to that retained by mineral constituents is yet to be elucidated. The microbial biomass appears to compete effectively with the plant for inorganic P; but some findings have indicated that the Olsen extraction includes some of the P in the microbial biomass (Parfitt et al., 1989).

Liming seems to have increased P adsorption somewhat in that generally higher levels of P were required to obtain maximum yields when lime was applied than when it wasn't. The increases in yield were not great enough to justify aplying increased levels of P, thus making the considerable literature on whether liming increases or decreases P adsorption seem rather academic (Haynes, 1984; Friesen et al., 1980). Some varietal effect was also observed. thus, the Rosado cultivar showed a somewhat greater P response when limed than when unlimed though other cultivars did not. In general, liming appears to work best in the absence or at low levels of P fertilizer. When a certain amount of mineral P is available, 150-200 kg P ha^{-1}, there does not seem to be much benefit from liming. As was pointed out earlier, application of 2-3 t of lime is generally less expensive in Central America than the application 150 kg of P as superphosphate; hence, liming can be considered a low input alternative to mineral P application although P application may be a more remunerative long-term investment (Sanchez and Uehara, 1980). It has also been pointed out that some of the agricultural limestone available in Costa Rica contains considerable amounts of Calcium silicate. Silicate anions have been shown to replace phosphate adsorbed by soils and therefore increase P availabilty (Sanchez and Uehara, 1980; Martini and Luzuriaga, 1989).

V. Conclusions

The principal findings of the project can be summarized as follows:

1. Some relationship could be established between classification at the suborder level and P retention in the soil taxonomy at least for a small group of soils from Costa Rica and Panama. Andepts showed greater P retention than Ultisols or other Inceptisols. Humic great groups of the Ultisols and Inceptisols (Haplohumults and Humitropepts)
showed somewhat higher P retention than Paleustults and Plinthudults.

2. Very good correlation was obtained between $\ln_{Altot}$ (Al_{tot} = Al_{oxal} + Al_{dith}) and P retention as measured by the New Zealand test (0.910), the amount of P addition necessary to get 0.2 ppm P in the soil solution (isotherm P) (0.863) and pH in NaF (0.921). The highest r^2 values were obtained for the following regression equations:

$$P_{NZ} = 65.8 + 16.3 \ln Al_{tot} - 0.19(\%clay) \qquad r^2 = 0.825$$

$$P_{iso} = 992.9 + 1052.1 \ln Al_{tot} - 83.6 (\% \text{ Org Carb}) \qquad r^2 = 0.840$$

3.) For a larger dataset using soils from all 5 Central American countries, the regression for New Zealand P on $\ln Al_{tot}$ was found to have an r^2 value of 0.811.

4.) Soaking of bean seed in a solution of 6000 ug/L of P for one hour previous to planting was shown to increase bean yield significantly in bean cultivars with a 100 seed weight of over 25 g. when no lime or P fertilization was applied. In a greenhouse study, using large seeded bean varieties (100 seed weight 38-54g), signficant increases in dry matter production and leaf P content were noted. Unfortunately, funds were not available for a field study using these large seeded cultivars.

5.) In three soils classified as Andepts, response of bean varieties to mineral P fertilization was surprisingly modest with 95% maximum yield being obtained when less than 250 kg ha^{-1} P was applied. In one of the soils, there was considerable residual effect in the second year, resulting in a total yield increase of 1500 -2000 kg ha^{-1} of beans from a single application of 200 kg ha^{-1} of P as triple superphosphate, broadcast and incorporated. All of these soils had relatively low clay contents which might have reduced interaction of fertilizer P with the soil. However, all Andepts in the study had clay contents of less than 15%.

6.) In the other soils used in the study, classified as Haplohumults, Paleustults, and Humitropepts, response to P was somewhat higher though 95% maximum yield was obtained with the application of less than 400 kg ha-1 of P. The increase in yield obtained on these soils was often over 1500 kg ha^{-1} of beans in a single harvest and would probabaly justify the cost of such a P application.

7.) Where lime was applied, it generally brought about a considerable yield increase in the absence of P fertilization. In the presence of P fertilization, the effect of lime was relatively insignficant. Only one of the cultivars used in Panama showed a response to lime and continued to show a response when up to 400 kg ha^{-1} of P was applied. As 5t of lime is less expensive than 150 kg ha^{-1} of P as triple superphosphate in Costa Rica, lime would have some potential as a low input alternative on soils with over 20% Aluminum saturation.

8.) Some difference in cultivars was noted in theor response to lime and P applications. The three cultivars used in Panama, all of which had 100 seed weights over 35 g, responded less to P than the ICA Pijao cultivar used in Turrialba. External P requirements for all three cultivars was less than 0.03 ug/ml as compared to 0.08 ug/ml obtained for the ICA Pijao cultivar in Turrialba. However, the relatively high Olsen P value (7.5 mg/kg) and the low clay content (.09 g/g) of the Panamanian soil may have affected the determination of the P adsorption isotherm and consequently, the external P requirement.

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VII. List of persons associated with project:

Persons not paid by project funds:

Donald L. Kass, Ph.D.,Principal Scientist; Professor of soil ; Physics and Management; Higher Education Project; CATIE; Turrialba, Costa Rica

Roberto Diaz Romeu, M.S., Head of soil analysis unit, CATIE,

Gustavo Adolfo Ortiz - laboratory assistant, CATIE

Luis Gerardo Cedeño - laboratory assistant, CATIE

Persons receiving salary complement from project funds:

Elemer Bornemisza, Ph.D., Professor of Soil Chemistry, University of Costa Rica; San Jose, Costa Rica

Freddy Sancho, M.S. Professor of Soil Management and Classification; University of Costa Rica

Persons paid by project:

Mario Jimenez, B.S., Agronomist, CATIE

Eloy Molina, B.S., Agronomist, University of Costa Rica

Consultants:

Ray Bryant, Ph.D., Associate Professor of Soil Science; Cornell University, Ithaca, NY (Jan.-June, 1988)

Graduate Students (M.S. thesis supported by Project funds):

Wilbert Campos Alvorado (1986-1987)

Alexis Samudio Patiño (1987-1988)

TITLE: Development of Appropriate Technologies for Overcoming Different Mechanisms of Phosphorus Retention in Central American Soils (5.249)

AMOUNT: $144,000

PERIOD: Three years

INSTITUTION: Centro Agronomico Tropical de Investigacion of Ensenanza (CATIE), Turrialba, Costa Rica in collaboration with the University of Costa Rica

DESCRIPTION:

The aim of the project is to devise a scheme for soil classification on the basis of their phosphorus fixation ability. It is hypothesized that different mechanisms are involved for fixing phosphorus in different soils, involving precipitation and/or sorption reactions, depending on clay mineralogy, clay content and organic matter content.

The project also includes testing of different methods of supplying phosphorus to crops according to the nature and amount of the phosphorus retention characteristics of the soils in which they are grown, and defining the most economical method of supplying phosphorus to the crop.

It is hoped that this project will lead to a greater economic efficiency with use of phosphorus fertilizer in Central America which is currently imported, resulting in a considerable saving in foreign exchange.

REVIEW COMMENTS:

The project was approved with the provisos that the investigators (1) clarify the relationship between different categories; (2) specify methods for screening; (3) relate results to soil taxonomy; and (4) justify various budget items. The principal investigator submitted a revised work plan and budget along the lines of reviewers' comments and provided a satisfactory justification for the budget request. ROCAP concurs in this proposal and will provide project management.

PROJECT OFFICER: ST/AGR, John L. Malcolm, 235-1275

CLEARANCE:

ST/AGR, James L. Walker FMerton per telecon Date 14 June 85
LAC/CAP/R, Owen Lustig per telecon Date 13 June 85
LAC/DR/EST, Paul White (info)

AGENCY FOR INTERNATIONAL DEVELOPMENT

WASHINGTON D C 20523

27 March 1985

S. V.

Dr. Donald L. Kass
CATIE
Turrialba, Costa Rica

RE: AID/SCI Proposal 5.249, "Development of Appropriate Technologies for Overcoming Different Mechanisms of Phosphorus Retention in Central American Soils"

Dear Dr. Kass:

As the PSTC Review Coordinator I have completed the review of your response to the provisos of our expert panel. With two exceptions we have found your comments generally responsive to the recommendation of the reviewers.

Given the budget allowance for a vehicle and for fuel, we do not see why additional travel money is budgeted.

In addition, we still think that the project is too ambitious with regard to the field experiments and cannot see the value of using as many as ten sites without first trying the design at one or two sites.

We would appreciate your prompt response to these comments.

Sincerely yours,

Miloslav Rechcigl, Jr., Ph.D.
Review Coordinator
Office of the Science Advisor

cc: USAID/San Jose/Costa Rica

CONVENIO DE PROYECTO DE CONTRIBUCION DE ALCANCE LIMITADO
LIMITED SCOPE PROJECT AGREEMENT

ENTRE LOS ESTADOS UNIDOS DE AMERICA,
A TRAVES DE LA AGENCIA INTERNACIONAL PARA EL DESARROLLO (AID)

BETWEEN THE UNITED STATES OF AMERICA,
ACTING THROUGH THE AGENCY FOR INTERNATIONAL DEVELOPMENT (AID)

Y
AND

EL CENTRO AGRONOMICO TROPICAL DE INVESTIGACION Y ENSEÑANZA (CATIE)
THE TROPICAL AGRICULTURE CENTER FOR TRAINING AND RESEARCH (CATIE)

---

1. Título del Proyecto
   Project Title

   INVESTIGACION CIENTIFICA INNOVADA - Desarrollo de Tecnologías Apropiadas para Vencer Diferentes Mecanismos de Retención de Fósforo en Suelos de Centro América

   INNOVATIVE SCIENTIFIC RESEARCH - Development of Appropriate Technologies for Overcoming Different Mechanisms of Phosphorus Retention in Central American Soils

2. Número del Proyecto de AID
   AID Project Number

   936-5542

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3. Por este medio las partes arriba mencionadas, de común acuerdo, convienen en llevar a cabo el proyecto descrito en este Convenio de acuerdo con (1) los términos de este convenio incluyendo los anexos adjuntos a este documento, y (2) cualquier acuerdo general con respecto a cooperación técnica o económica.

   The above named parties hereby mutually agree to carry out the program described in the Grant Agreement in accordance with (1) the terms of this Agreement including annexes attached hereto, and (2) any general agreement regarding economic or technical cooperation.

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4. Monto de la Contribución de AID
Amount of AID contribution

$134,000

5. Fecha de Finalización de la Asistencia al Proyecto (FFAP)
Project Assistance Completion Date (PACD)

30 de noviembre de 1988 | November 30, 1988

6. Propósito de la Donación | Purpose of the Grant

El propósito del proyecto es desarrollar un sistema para la clasificación de suelos basándose en su habilidad de fijar fósforo. Se tiene la hipótesis que se utilizan diferentes mecanismos para la fijación de fósforo en suelos diferentes, tomando en consideración las reacciones de precipitación y/o de absorción, según su contenido de mineral arcilloso, contenido de arcilla y contenido de materia orgánica.

The aim of the project is to devise a scheme for soil classification on the basis of their phosphorus fixation ability. It is hypothesized that different mechanisms are involved for fixing phosphorus in different soils, involving precipitation and/or sorption reactions, depending on clay mineralogy, clay content and organic matter content.

. Este Convenio consta de esta página titular, Anexo "A" Descripción del Proyecto; Anexo "B" Disposiciones Generales; Anexo "C" Disposiciones Fiscales y Administrativas; y Anexo "D" la propuesta aprobada de la investigación.

This Agreement consists of this Title page and Annex "A" Project Description; Annex "B" Standard Provisions; Annex "C" Administrative and Fiscal Provisions; and Annex "D" the Approved Research Proposal.

8. Por el CATIE For CATIE	Por la Agencia para el Desarrollo Internacional For the Agency for International Development
Rodrigo Tarté Director	John R. Eyre Acting Director
Fecha	Date 8/1/85

PROJECT DESCRIPTION

The project includes testing of different methods of supplying phosphorus to crops according to the nature and amount of the phosphorus retention characteristics of the soils in which they are grown, and defining the most economical method of supplying phosphorus to the crop.

The project will consist of three phases:

1. Field sampling and analyses of 30 soils to characterize their P fixing mechanisms.

2. Screening for common bean germ plasm adapted to growing under conditions of low P availability and high P fixation as well as for genotypes which can absorb greater amounts of foliar applied P; and

3. Field experiments, using ten of the sites representing 3 mechanisms of fixation.

Phase 1 will be carried out in the first year of the project although mineralogical characterization may take longer. Phase 2 will ba carried out in both years. Phase 3 will begin in the second year, but since the bean planting period in Costa Rica is September-November, enough information may have accumulated to start field experiments at the end of 1985.

The details of research to be conducted are more fully described in the approved research proposal attached as Annex "D", which is made part of the Grant Agreement.

RESPONSIBILITIES OF THE PARTIES

AID

AID, under the Grant Agreement, will make available up to US$134,000, to support CATIE in undertaking the research activities approved by the AID Scientific Program (Annex D).

CATIE

CATIE agrees to make available a soils management specialist and the head of soils laboratory, and will call on assistance from an Institutional Fund for Agricultural Development -IFDC- statistician and a CIAT soils specialist, in addition to 4 professional investigators partially financed by the Grant. Also, CATIE will make available existing laboratory and general administrative support necessary to implement the research.

CATIE also assumes responsibility to secure any additional resources that may be required to complete specific objectives.

EVALUATION

A final evaluation will be based on analysis of the final report and any other information deemed appropriate by the AID Project Manager. The final evaluation should be completed within ninety days of submission of the final report.

REPORTS

CATIE agrees to provide the following reports (in English) to ROCAP:

A. Interim Progress Reports (5 copies) are required every six months and are due within 30 days following each six month period. The report should document research progress and changes in research plans, key dates or benchmarks.

B. Final Report (10 copies). The principal investigator should submit to ROCAP no later than completion date of the research, currently estimated at November 30, 1988. The report should be sufficiently detailed to substantiate findings and permit scientific evaluation of the research.

The principal investigator will share the draft report with the AID Project Officer for comments prior to final submission of the document.

ADMINISTRATIVE AND FISCAL PROVISION

The administrative and fiscal provisions as stated in Annex "C" and Attachment 1 thereof are made part of this agreement.

STANDARD PROVISIONS

The Standard Provisions relevant to this Grant are attached as Annex "B" and made a part of this Agreement.

ESTIMATED GRANT BUDGET
INNOVATIVE SCIENTIFIC RESEARCH (936-5542)
DEVELOPMENT OF APPROPRIATE TECHNOLOGY FOR OVERCOMING
DIFFERENT MECHANISMS OF PHOSPHORUS RETENTION IN
CENTRAL AMERICAN SOILS
(In US$)

	YEAR 1	YEAR 2	YEAR 3	TOTAL
Staff	15,000	19,000	4,000	38,000
Equipment/Materials	7,000	4,500	---	11,500
Training/Consultation/Travel	29,000	13,500	---	42,500
Other Costs	15,000	4,000	3,000	22,000
Overhead	10,000	10,000	---	20,000
TOTAL	76,000	51,000	7,000	134,000

Within the total amount shown, budget line items may be increased or decreased not to exceed 15 percent without prior approval from AID.