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Selection for seed yield (visual in the F_2, visual and plot yield from the F_3 to F_5, and yield tests in F_6) was carried out in two crosses of common bean (*Phaseolus vulgaris* L.) in high and low soil fertility environments at CIAT-Quilichao, Colombia. Parents were small-seeded and tolerant to low soil phosphorus, possessed indeterminate bush growth habit, and belonged to lowland tropical gene pools of Middle America. The mean yield of selected lines from low (LFS) and high (HFS) soil fertility environments was significantly higher than the mean of the parents in both crosses when tested in high fertility (HF) but not in low fertility (LF). The highest yielding LFS and HFS lines from A 286 × (G 5059 × A 80) and the LFS line from A 286 × ICA Pijao outyielded the best check cultivar, Carioca, in HF. No line yielded significantly more than A 286, the best parent used in both crosses. The mean effect of fertilizer levels on selection for seed yield was nonsignificant. Lines selected under two environments showed similar but average response and high stability of performance under variable environments. Low soil fertility accelerated maturity and reduced 100-seed weight and seed yield.

Key words: *Phaseolus vulgaris*, bean (small-seeded common), selection for yield, soil fertility, Middle American gene pools, regression coefficient

[Sélection fondée sur le rendement à deux niveaux de fertilisation, chez le haricot à petites graines.]
Titre abrégé: Rendement et niveaux de fertilisation chez le haricot.
Nous avons procédé à une sélection pour le rendement grainier (de visu dans la F_2, de visu et fondée sur le rendement des parcelles de la F_3 à la F_5, et fondée sur des tests de rendement dans la F_6) chez deux hybrides du haricot commun (*Phaseolus vulgaris* L.) dans des milieux caractérisés par une fertilité du sol élevée ou faible, au centre du CIAT de Quilichao, en Colombie. Les parents étaient des variétés à petites graines, présentant une tolérance pour les sols à faible teneur en phosphore, à croissance arbustive indéterminée et appartenant au fonds génétique des basses terres tropicales de l'Amérique centrale. Le rendement moyen des lignées sélectionnées provenant des milieux à fertilité du sol faible (LFS) et élevée (HFS) était significativement plus élevé que la moyenne des parents des deux croisements. lors des essais en condition de fertilité élevée (HF) mais non en condition de fertilité faible (LF). Les lignées LFS et HFS présentant le rendement le plus élevé et provenant du croisement A 286 × (G 5059 × A 80) et la lignée LFS provenant du croisement A 286 × ICA Pijao ont donné un rendement supérieur à celui du meilleur cultivar témoin, Carioca, en conditions de fertilité élevée. Aucune des lignées n'a donné un rendement significativement supérieur à A 286, le meilleur des parents utilisés dans les deux croisements. Le principal effet des niveaux de fertilisation sur la sélection fondée sur le rendement grainier n'était pas significatif. Les lignées sélectionnées dans les deux milieux ont montré des réactions semblables mais moyennes, ainsi

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qu'un rendement très stable sous des conditions du milieu variables. Les sols moins fertiles ont accéléré la maturation et réduit le poids de 100 graines et le rendement grainier.

Mots clés: *Phaseolus vulgaris*, haricot à petites graines, sélection pour le rendement, fertilité du sol, fonds génétique centraméricain, coefficient de régression

Diseases, poor soil fertility, and drought are probably the most important constraints limiting production of common bean (*Phaseolus vulgaris* L.), especially in Latin America and Africa. Poor soils, especially ones deficient in phosphorus and nitrogen, are found in large parts of the bean-producing regions of Latin America, central and eastern Africa, and other parts of the world. In these poor soils, the use of adequate lime and phosphorus-rich fertilizer is essential for bean cultivation. Common bean is largely grown as a subsistence crop, farmers rarely use fertilizers or pesticides, and fluctuation in yield is common. Cultivars tolerant to these soils would help reduce the use of lime and fertilizer and thus reduce production costs, permitting the resource-limited farmers to produce more bean and stabilize production.

Cultivar differences in utilization of and tolerance to low soil phosphorus have been reported for common bean (Whiteaker et al. 1976; Salinas 1978; Fawole et al. 1982; Centro Internacional de Agricultura Tropical (CIAT) 1983). In tropical environments of Latin America, the highest levels of field tolerance to soils deficient in phosphorus have been found in small-seeded bush common bean cultivars (CIAT 1983) of growth habits II and III (Singh 1982) belonging to the Middle American lowland tropical gene pools 2 and 3 (Singh 1988, 1989), respectively. Two such cultivars, Carioca and Rio Tibagi, occupy large hectarage in Brazil.

Frey (1964) achieved small but similar increases in yield from selection in stress and nonstress environments in oats (*Avena sativa* L.). But nonstress conditions permitted retention of more widely adapted strains. Gotoh and Osanai (1959), however, found that wheat (*Triticum aestivum* L.) lines were higher yielding and more broadly adapted when selected in environments receiving one-half the recommended rate of fertilizers. This paper compares the effectiveness of selection for seed yield in common bean under contrasting conditions of soil fertility.

MATERIALS AND METHODS

Cultivars Carioca and Rio Tibagi were crossed together and their highest yielding progeny, line A 286, was then used as a common female parent to cross with other sources of low soil phosphorus tolerance. Thus, crosses A 286 × ICA Pijao and A 286 × (G 5059 × A 80) were used for the present study. Accession G 5059 was found to be tolerant to low soil phosphorus in repeated screenings at CIAT-Quilichao, Colombia. Line A 80 was selected from the cross G 4000 × Carioca, both parents of which are also tolerant to low soil phosphorus. Cultivar ICA Pijao has been the highest yielding genotype at CIAT-Palmira (1000 m elevation with mean growing temperature of 24°C) and is commercially grown in Argentina, Bolivia, Cuba, and Guatemala.

Selection was conducted at CIAT-Quilichao, Colombia. This site is located at 990 m elevation with a mean growing temperature of 24°C and annual rainfall of 1750 mm. Soil is an Oxisol (Oxic Dystropept) with pH 4.5. It has low phosphorus availability (< 15 ppm) and contains toxic levels of aluminum. Without added lime and fertilizer, common bean cannot be grown at this site.

High-fertility (HF) and low-fertility (LF) plots were established adjacent to each other. The two plots received 1000 kg ha^{-1} of lime in each cropping season. In addition, the LF plot received 20, 20, and 17 kg of N, P, and K per ha, respectively. The HF plots received three times the dosages of fertilizers applied in the LF plots. Lime in each season was incorporated into the upper 15 cm of soil profile one month prior to sowing and fertilizer was band-applied at the time of sowing.

The F_2 seed of each cross was randomly divided into two equal parts for selection in high and low fertility plots. The F_2 populations were planted, seven plants per linear meter, in plots of eight rows, each 7 m long with two replications. The spacing between rows was 60 cm. A large number (> 40%)

of single plants was harvested from each plot. These were progeny-tested the subsequent season in single-row plots, 3 m long without replications. The F_3 progeny-rows were scored on a 1 to 9 scale (1 = excellent and 9 = poor) for overall performance. An area of 1 m^2 was harvested from the center of plots receiving scores from 1 to 6 for yield measurements. About 25% of selected progeny-rows were then harvested in bulk after visual mass selection for seed yield in individual plants within selected plots. In F_4 and F_5, a similar procedure to that of the F_3 of selection was practiced between and within plots. But, in F_4 and F_5, each plot consisted of 3 rows, 3 m long without replications, and an area of 4.5 m^2 was used for yield measurements. Parents and check cultivars were planted every 20 plots in the nursery in order to facilitate the selection process. Twenty-three lines thus derived from each cross and each fertility environment and parents were yield-tested in separate trials in F_6. A randomized complete block design with two replications was used for each trial. Each plot consisted of three rows, 3 m long, and an area of 4.5 m^2 was harvested for yield estimates. From the F_2 to the F_6, high fertility selections (HFS) were grown only in high fertility (HF) environments and low fertility selections (LFS) were grown only in low fertility (LF) environments. Fourteen lines from each environment and each cross were selected for comparative yield trials.

Fifty-six selected lines (F_7), four parents, and four checks were evaluated in four cropping seasons over a period of 3 yr (1985–1987). An 8 × 8 partially balanced lattice design with two replications in each high and low fertility environment was used for the trials. Each plot consisted of three rows, each 4 m long. The spacing between rows was 60 cm. An average density of 25 plants m^{-2} was obtained. The length of 3.5 m, leaving 25 cm head borders on either end, of the three rows was harvested (net area 6.3 m^2) for yield measurements. Pods were threshed and seed cleaned, dried, weighed, and converted into kg ha^{-1} at a constant moisture of 14% by weight. Days to physiological maturity and 100-seed weight were also recorded. Combined analysis of variance was performed according to standard statistical procedures, using a fixed model (McIntosh 1983). Regression analysis for yield stability for all entries was performed according to Eberhart and Russell (1966). The regression coefficient, which measures genotypic response to varying environments, and coefficient of determination, which measures the proportion of variation due to linear regression, were estimated for stability analysis. Each trial and each fertility level was considered a separate environment.

RESULTS

The effects of seasons, soil fertility levels, and crosses were highly significant ($P<0.01$) for seed yield, 100-seed weight, and days to maturity (Table 1). Significant differences were noted for all traits among selected lines and parents. Mean square due to origin of selected lines (i.e., whether selected under low or high soil fertility) for seed yield was nonsignificant ($P>0.05$). But for 100-seed weight and days to maturity, mean squares due to origin of lines were significant. Among the four checks, differences were significant ($P<0.01$) for seed yield and 100-seed weight but not for days to maturity.

There was a general reduction in seed weight and seed yield, and maturity was ac-

Table 1. Portion of mean squares from analysis of variance of common bean lines selected for seed yield in high and low soil fertility and tested in high and low fertility environments at CIAT-Quilichao, Colombia, over four seasons (1985–1987)

Source	df	Seed yield	100-seed weight	Days to maturity
Season	3	112 813 721**	789.27**	939.39**
Fertility level	1	345 200 143**	973.44**	520.98**
Crosses (C)	1	2 368 800**	267.96**	283.27**
Origin of lines (O)	1	122 438	15.23**	19.04*
Lines/ (C, O)	52	277 816**	17.51**	10.95**
Parents	3	884 419**	66.88**	22.80**
Checks	3	686 776**	114.98**	4.33
Error	392	50 215	0.91	2.31

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

Table 2. Mean values for days to maturity, 100-seed weight, and seed yield for 28 selected lines, parents and check cultivars in high soil fertility (HF) and low soil fertility (LF) environments at CIAT-Quilichao, Colombia, over four seasons (1985–1987)

	Days to maturity		100-seed weight (g)		Seed yield (kg ha^{-1})	
Identification	HF	LF	HF	LF	HF	LF
A 286 × ICA Pijao						
Selected lines	72.7	71.8	20.7	18.9	1897	716
Parents	72.4	71.1	19.8	18.4	1768	747
LSD (0.05)	0.7	0.9	0.4	0.5	121	105
A 286 × (G 5059 × A 80)						
Selected lines	74.3	72.4	20.0	19.7	1999	820
Parents	73.8	71.6	21.3	20.0	1850	802
LSD (0.05)	0.5	0.7	0.4	0.4	101	87
LSD (0.05)†	0.2	0.3	0.2	0.2	44	37
LSD (0.05)‡	2.3	3.1	1.5	1.9	428	372
Checks	74.0	72.2	20.5	18.8	1925	857
LSD (0.05) (crosses vs. checks)	0.5	0.6	0.3	0.4	89	77

† For comparison of selected lines.
‡ For comparison of parents.

celerated in LF compared to the HF environment (Table 2). In the HF environment, mean performance of lines selected from both crosses was significantly higher than the mean yield of their respective parents. But in LF, mean of the parents and selected lines did not differ significantly. Cross A 286 × (G 5059 × A 80) was significantly higher yielding than A 286 × ICA Pijao in both test environments. Differences in the mean performance of the parents of two crosses, however, were not significant for any character studied.

Mean values for days to maturity, 100-seed weight, and seed yield for 14 lines selected under each LF and HF environment for two crosses are given in Table 3. For the low-yielding cross, A 286 × ICA Pijao, difference in yield of LFS and HFS in both test environments was significant. Seed yield of HFS was significantly more than LFS lines in LF environment. But LFS yielded more than HFS in HF environment. In the high-yielding cross, A 286 × (G 5059 × A 80), yield of LFS and HFS lines did not differ significantly in either low or high fertility environment.

Among four parents, A 286 was the highest yielding and ICA Pijao the lowest yielding in both LF and HF environments (Table 4). Line A 286 yielded significantly more than the check cultivar Carioca in high fertility environment. Carioca yielded more than Rio Tibagi under both environments. Although the two elite checks, namely BZ 2515-1 and BZ 2515-2, yielded significantly more than Rio Tibagi and Carioca, their values were not significantly different from those of A 286. In a high fertility environment, the highest yielding HFS and LFS lines from the cross A 286 × (G5059 × A 80) and the LFS line from A 286 × ICA Pijao yielded significantly more than Carioca but not more than A 286. In the low fertility environment, yield differences among the highest yielding selected lines, the highest yielding parent, and the best check were nonsignificant. In similar environments, the LFS line from A 286 × ICA Pijao yielded significantly less than HFS and LFS lines from A 286 × (G 5059 × A 80) but its yield was not significantly different from that of its sister HFS line, A 286, and Carioca.

In general, the values for regression coefficient and coefficient of determination for all selected lines were similar ($P > 0.05$), indicating average response and high stability of yield in varying environments (Table 4).

Simple correlation coefficient between

Table 3. Mean of 14 bean lines selected in each high (HFS) and low (LFS) fertility and tested in high soil fertility (HF) and low soil fertility (LF) environments at CIAT-Quilichao, Colombia, over four seasons (1985–1987)

Identification	Days to maturity		100-seed weight (g)		Seed yield (kg ha^{-1})	
	HF	LF	HF	LF	HF	LF
A 286 × ICA Pijao						
HFS	72.5	71.6	20.9	19.2	1861	777
LFS	72.9	72.1	20.4	18.6	1933	656
A 286 × (G 5059 × A 80)						
HFS	74.3	72.4	22.1	19.6	2021	821
LFS	74.4	72.5	21.9	19.9	1978	819
LSD (0.05)	0.3	0.5	0.2	0.3	63	54

yield in low and high fertility environments for 64 genotypes was positive (0.44) and highly significant ($P<0.01$).

DISCUSSION

By examining the mean yield of selected lines and parents involved in two crosses it is apparent that selection for seed yield was effective in increasing yield when tested in a high fertility environment (Table 2). But none of the selected lines yielded significantly more than the highest yielding parent, A 286 (Table 4). Also, in low fertility conditions, yield differences were nonsignificant. Coyne (1968), Duarte (1966), Patiño and Singh (1989), Sullivan and Bliss (1983), and Tolla (1978) also found selection for seed yield to be ineffective in common bean crosses. It is likely that parents utilized in the present study had similar genetic bases for seed yield, lacked favorable alleles for tolerance to low soil fertility, or the screening method used did not permit differentiation among genotypes during the selection process.

Nienhuis and Singh (1988) found that high-yielding cultivars and landraces (including Carioca, G 5059, ICA Pijao, and Rio Tibagi), characterized by small seeds and indeterminate growth habits II and III belonging to Middle American gene pools, possessed zero or negative general combining ability for seed yield. This supports our results that no substantial yield increases could be made from crosses within this germplasm. Other sources of tolerance to low soil phosphorus, preferably belonging to distantly related gene pools, must be identified and utilized. Whiteaker et al. (1976) identified PI 206002, an indeterminate snap bean cultivar from Sweden, as efficient for phosphorus utilization. Schettini et al. (1987) were able to successfully transfer this desirable trait from PI 206002 into Sanilac, a small-seeded dry bean cultivar of determinate growth habit.

Overall differences between yield of lines selected in high versus low soil fertility were nonsignificant (Table 1). But when comparisons were made for each cross separately (Table 3), differences in HFS and LFS lines were significant for low-yielding cross A 286 × ICA Pijao. Also, differences in the highest yielding HFS and LFS lines of both crosses were significant in HF environment (Table 4). But the mean yield of these lines across environments did not differ significantly. Bisen et al. (1984, 1985) reported similar results in chickpea (*Cicer arietinum*), where effects of fertility levels and spacing on selection for yield were nonsignificant.

All germplasm materials (selected lines, parents, and checks) of this experiment were small-seeded indeterminate type II or III growth habits. All except A 80 and Rio Tibagi showed an average response (regression coefficient not significantly different from unity) and stable performance (high values for coefficient of determination) under varying growing conditions (Table 4). Beaver et al. (1985) arrived at a similar conclusion regarding small-seeded indeterminate bush bean cultivars of common bean.

Table 4. Mean values for the highest yielding bean lines selected in high (HFS) and low (LFS) soil fertility environments, and evaluated in high (HF) and low (LF) soil fertility at CIAT-Quilichao, Colombia, over four seasons (1985–1987)

Identification	Days to maturity		100-seed weight (g)		Seed yield (kg ha^{-1})		Regression coefficient†	Coefficient of determination
	HF	LF	HF	LF	HF	LF		
A 286 × ICA Pijao								
HFS	73.0	72.0	21.0	19.1	2052	908	0.97	0.98
LFS	73.0	73.2	20.0	18.1	2300	742	1.28	0.98
A 286 × (G 5059 × A 80)								
HFS	74.7	73.0	22.2	19.5	2350	1001	1.11	0.98
LFS	73.6	72.5	22.8	19.9	2112	1016	1.00	0.98
Parents								
A 80	73.4	70.2	19.6	18.6	1504	705	0.72‡	0.96
A 286	73.6	71.9	20.8	19.7	2131	899	0.82	0.88
G 5059	74.4	72.7	23.5	21.8	1916	801	1.12	0.96
ICA Pijao	71.2	70.4	18.7	17.1	1405	594	0.82	0.94
Checks								
Carioca	73.4	71.2	24.1	21.9	1852	863	0.98	0.94
Rio Tibagi	74.7	72.3	17.0	15.9	1493	731	0.59‡	0.95
BZ 2515-1	73.5	73.0	20.4	18.3	2122	925	0.86	0.92
BZ 2515-2	74.3	72.2	20.3	18.9	2233	909	1.22	0.98
LSD (0.05)	0.9	1.7	0.8	1.0	235	204		

† Coefficient from regression of the variety yield in an environment on the environmental index (i.e., mean of all entries in an environment minus overall mean across eight environments).
‡ Significantly different from unity at the 0.05 probability level.

Beaver, J. S., Paniagua, C. V., Coyne, D. P. and Freytag, G. F. 1985. Yield stability of dry bean genotypes in the Dominican Republic. Crop Sci. **25**: 923–926.

Bisen, M. S., Singh, S. P., Sharma, S. M. and Rao, S. K. 1984. Effectiveness of breeding-methods under different fertility levels and spacing in two crosses of chickpea. Legume Res. **7**: 101–106.

Bisen, M. S., Singh, S. P. and Rao, S. K. 1985. Effectiveness of selection methods in chickpea *Cicer arietinum* under different environments. Theor. Appl. Genet. **70**: 661–666.

Centro Internacional de Agricultura Tropical. 1983. 1982 bean program annual report. CIAT, Cali, Colombia.

Coyne, D. P. 1968. Correlation, heritability, and selection of yield components in field beans, *Phaseolus vulgaris* L. Proc. Am. Soc. Hortic. Sci. **93**: 388–396.

Duarte, R. A. 1966. Responses in yield and yield components from recurrent selection practiced in bean hybrid population at three locations in North and South America. Diss. Abstr. **27**: 1339B–1340B.

Eberhart, S.A. and Russell, W. A. 1966. Stability parameters for comparing varieties. Crop Sci. **6**: 36–40.

Fawole, I., Gabelman, W. H. and Gerloff, G. C. 1982. Genetic control of root development in beans (*Phaseolus vulgaris* L.) grown under phosphorus stress. J. Am. Soc. Hortic. Sci. **107**: 98–100.

Frey, K. J. 1964. Adaptation reaction of oat strains selected under water stress and non-stress environmental conditions. Crop Sci. **4**: 55–58.

Gotoh, K. and Osanai, S. 1959. Efficiency of selection for yield under different fertilizer levels in a wheat cross. Jap. J. Breed. **9**: 101–106.

McIntosh, M. S. 1983. Analysis of combined experiments. Agron. J. **75**: 153–155.

Nienhuis, J. and Singh, S. P. 1988. Genetics of seed yield and its components in common bean (*Phaseolus vulgaris* L.) of Middle-American origin. I. General combining ability. Plant Breed. **101**: 143–154.

Patiño, H. and Singh, S. P. 1989. Visual selection for seed yield in the F_2 and F_3 generations of nine common bean crosses. Annu. Rep. Bean Improv. Coop. **32**: 79–80.

Salinas, J. G. 1978. Differential response of some cereal and bean cultivars to aluminum and phosphorus stress in an Oxisol in Central Brazil. Ph.D. dissertation. N.C. State University, Raleigh, N.C.

Schettini, T. M., Gabelman, W. H. and Gerloff, G. C. 1987. Incorporation of phosphorus efficiency from exotic germplasm into agriculturally adapted germplasm of common bean (*Phaseolus vulgaris* L.). Plant Soil **99**: 175–184.

Singh, S. P. 1982. A key for identification of different growth habits of *Phaseolus vulgaris* L. Annu. Rep. Bean Improv. Coop. **25**: 92–95.

Singh, S. P. 1988. Gene pools in cultivated dry bean. Annu. Rep. Bean Improv. Coop. **31**: 180–182.

Singh, S. P. 1989. Patterns of variation in cultivated common bean (*Phaseolus vulgaris*, Fabaceae). Econ. Bot. **41**: 39–54.

Sullivan, J. G. and Bliss, F. A. 1983. Recurrent selection for increased seed yield and seed protein percentage in the common bean (*Phaseolus vulgaris* L.) using a selection index. J. Am. Soc. Hortic. Sci. **108**: 42–46.

Tolla, G. E. 1978. Effect of post-bloom nutrient applications and recurrent selection on seed yield and seed protein in common bean (*Phaseolus vulgaris* L.). Ph.D. dissertation. University of Wisconsin, Madison, Wis.

Whiteaker, G., Gerloff, G. C., Gabelman, W. H. and Lindgren, D. 1976. Intraspecific differences in growth of beans at stress levels of phosphorus. J. Am. Soc. Hortic. Sci. **101**: 472–475.