GROWTH AND YIELD OF COMMON BEAN CULTIVARS AT TWO SOIL PHOSPHORUS LEVELS UNDER BIOLOGICAL NITROGEN FIXATION[1]

ADELSON PAULO ARAÚJO[2], MARCELO GRANDI TEIXEIRA[3] and DEJAIR LOPES DE ALMEIDA[3]

ABSTRACT - The genotypic differences on growth and yield of common bean (*Phaseolus vulgaris* L.) in response to P supply were evaluated in a field experiment under biological N_2 fixation. Eight cultivars were grown at two levels of applied P (12 and 50 kg ha^{-1} of P – P_1 and P_2 respectively), in randomized block design in factorial arrangement. Vegetative biomass was sampled at three ontogenetic stages. The effects of genotype and phosphorus were significant for most traits, but not the genotype × phosphorus interaction. The cultivars presented different patterns of biomass production and nutrient accumulation, particularly on root system. At P_1, P accumulation persisted after the beginning of pod filling, and P translocation from roots to shoots was lower. The nodule senescence observed after flowering might have reduced N_2 fixation during pod filling. The responses of vegetative growth to the higher P supply did not reflect with the same magnitude on yield, which increased only 6% at P_2; hence the harvest index was lower at P_2. The cultivars with highest yields also presented lower grain P concentrations. A sub-optimal supply of N could have limited the expression of the yield potential of cultivars, reducing the genotypic variability of responses to P levels.

Index terms: genotype, harvest index, nodulation, *Phaseolus vulgaris*.

CRESCIMENTO E PRODUÇÃO DE CULTIVARES DE FEIJOEIRO EM DOIS NÍVEIS DE FÓSFORO NO SOLO SOB FIXAÇÃO BIOLÓGICA DE NITROGÊNIO

RESUMO - As diferenças genotípicas no crescimento e produção do feijoeiro (*Phaseolus vulgaris* L.), em resposta ao suprimento de P, foram avaliadas em experimento de campo sob fixação biológica de N_2. Foram cultivadas oito cultivares em duas doses de P (12 e 50 kg ha^{-1} de P, respectivamente P_1 e P_2), em arranjo fatorial em blocos ao acaso, efetuando-se três amostragens de biomassa, em estágios ontogenéticos. Os efeitos de genótipo e fósforo foram significativos na maioria dos caracteres, mas não a interação genótipo × fósforo. As cultivares apresentaram diferentes padrões de produção de biomassa e acumulação de nutrientes, particularmente nas raízes. Em P_1 a acumulação de P manteve-se após o início de formação das vagens, e a translocação de P da raiz para a parte aérea foi menor. A senescência de nódulos após a floração pode ter reduzido a fixação de N_2 durante o enchimento das vagens. As respostas do crescimento vegetativo ao maior suprimento de P não se refletiram com a mesma magnitude na produção de grãos, que aumentou apenas 6% em P_2; por isso, o índice de colheita foi menor em P_2. As cultivares com maiores rendimentos apresentaram menores teores de P no grão. Um suprimento subótimo de N pode ter limitado a expressão do potencial produtivo das cultivares, reduzindo a variabilidade genotípica das respostas ao P.

Termos para indexação: feijão, genótipo, índice de colheita, nodulação, *Phaseolus vulgaris*.

INTRODUCTION

Phosphorus deficiency is the most widespread soil constraint to agricultural production in Tropical America (Sánchez & Salinas, 1981). Common bean (*Phaseolus vulgaris* L.) crop exhibits a generalized response to P fertilization, as demonstrated by sev-

[1] Accepted for publication on June 11, 1999.

[2] Agronomist, Ph.D., Dep. de Solos, Universidade Federal Rural do Rio de Janeiro (UFRRJ), CEP 23890-000 Seropédica, RJ, Brazil. E-mail: aparaujo@ufrrj.br

[3] Agronomist, Ph.D., Embrapa-Centro Nacional de Pesquisa de Agrobiologia (CNPAB), CEP 23851-970 Seropédica, RJ, Brazil.

eral trials in Brazil (Oliveira et al., 1982). Combined analysis of seven experiments showed that the maximal economic fertilizer level for bean production was equal to 47 kg ha^{-1} of P (Barbosa Filho & Silva, 1994).

Some works have noticed the genotypic variability for responses to P fertilization of bean yield (Haag et al., 1978; Graham & Rosas, 1979; Informe ..., 1985, 1986; Oliveira et al., 1987; Pereira & Bliss, 1989; Youngdahl, 1990; Yan et al., 1995a). Owing to such genotypic differences, fertilizer recommendation must consider the crop technological level, in order to obtain the maximal potential of a specific cultivar (Oliveira et al., 1987).

Yield has been considered as a quantitative character, i.e., influenced by many genes with the effects of individual genes normally unidentified, its expression depending upon interaction of many physiological component processes (Wallace et al., 1972). Therefore, grain yield would not be sufficient as unique criterion for evaluating efficiency of P use of bean genotypes: as yield integrates many edaphic and climatic variables, it would likely to conceal the efficient germplasm (Informe ..., 1985). The identification of morphological traits and a specific period on crop development, regarded critical for establishment of cultivars under low P, could enhance the ability of manipulating the germplasm (Informe ..., 1985). The lack of significance on the interaction between growth under low P and three soil types might mean that bean adaptation to low P is stable across different environments, making the selection and breeding relatively easier (Yan et al., 1995b).

The failure to establish effective nodulation is often considered the main reason for poor N_2 fixation by common bean in the field, but the species may be genetically predisposed to poor fixation because of ineffective symbiosis and the short vegetative fixation period (Piha & Munns, 1987). Most studies on adaptation of beans to low P availability were carried out under conditions of combined N, and studies to ensure that tolerance to low P is compatible with N_2 fixation are needed, since attempts to select bean genotypes tolerant to low P are likely to be affected by the symbiosis established with rizobia (Graham & Rosas, 1979). Genotypic variability in N_2 fixation at low soil P levels indicates that breeding to enhance these traits simultaneously would be possible (Pereira & Bliss, 1989).

The objective of this work was to evaluate the differences of common bean cultivars in the responses to P supply of the vegetative growth, N and P accumulation, and yield, in a field experiment under conditions of biological N_2 fixation.

MATERIAL AND METHODS

The experiment was carried out at the Embrapa-Centro Nacional de Pesquisa de Agrobiologia (CNPAB), in a complete randomized block design in 8×2 factorial arrangement with four replicates. Eight bean cultivars (BAT 76, Carioca, Goiano Precoce, ICA Pijao, Ouro Negro, Puebla 152, Rico 23, Rio Tibagi) were cropped at two levels of applied P (12 and 50 kg ha^{-1} of P — P_1 and P_2 respectively).

The soil was a Typic Haplustult, presenting at 0-20 cm depth (Embrapa, 1979): 30 $mmol_c$ kg^{-1} of Ca, 10 $mmol_c$ kg^{-1} of Mg, 1.9 $mmol_c$ kg^{-1} of K, 1 $mmol_c$ kg^{-1} of Al, 5 mg kg^{-1} of available P, water pH 4.9, 7.7 g kg^{-1} of C, sandy loam texture. The soil was plowed and harrowed, and 800 kg ha^{-1} of calcareous and 200 kg ha^{-1} of gypsum were applied and incorporated. Rows were marked 0.5 m apart and plots were delimited, each one having four lines 6 m long. The following fertilizers were applied in the rows: 30 kg ha^{-1} of K (as potassium chloride), 40 kg ha^{-1} of fritted trace elements, 12 and 50 kg ha^{-1} of P (as triple superphosphate).

The seeds, provided by Embrapa-Centro Nacional de Pesquisa de Arroz e Feijão (CNPAF), were coated with inoculant containing the strains BR10049 of *Rhizobium leguminosarum* biovar *phaseoli* and BR10050 of *R. tropici* (CIAT 899). The sowing density of 12 seed m^{-1} resulted in a final stand of 22.3 plant m^{-2}. Due to leaf symptoms of N deficiency, 30 kg ha^{-1} of N as urea was banded 10 days after emergence. During the course of experiment, from April to July 1995, the climatic data were (mean ± standard error): mean temperature 21.6 ± 0.2ºC, relative humidity 69.3 ± 1.4%, pan evaporation 3.1 ± 0.2 mm day^{-1}, rainfall (including irrigation) 220 mm.

Vegetative biomass was sampled at the stages V4, R6 and R7 of plant development (Fernández et al., 1985) (Table 1). The sample unit consisted of 6 plants harvested from the two middle rows of each plot, being roots taken off by hoeing. Roots were washed and nodules were detached and counted. Shoots, roots and nodules were separately dried and weighed. Roots plus nodules and shoots were ground, and N concentration was measured by Kjeldahl procedure, and P concentration by nitro-perchloric digestion and molybdenum-ascorbic acid dosage. At grain maturity, an area of 1 m^2 within each plot provided the number of pods and seeds, seed yield, and seed N and P concentrations. The remaining area of 3 m^2 in each plot provided seed yield, that was standardized to 14% humidity. At the end of the experiment, soil analysis showed 6 and 20 mg kg^{-1} of available P, respectively at P_1 and P_2.

The following ratios and yield components were calculated: root:shoot dry weight ratio, shoot N:P ratio (N content/P content), proportion of P in roots (root/total P content), pods per plant, seeds per pod, 100 seeds weight, harvest index (seed dry weight at maturity/shoot dry weight at third time of sampling), N harvest index (seed/shoot N content), P harvest index (seed/shoot P content). The homogeneity of variances of biomass data was verified by Hartley's test (Neter et al., 1990). For most of these traits, analysis of variance was performed on natural logarithmic (ln) transformed data in order to homogenize variances. Analysis of variance evaluated the main effects of factors (genotype, P level and time of sampling) and their interactions, considering sampling as sub-plots. For data of seed yield and yield components, analysis of variance evaluated the effects of genotype, phosphorus and their interaction.

RESULTS

The analysis of variance identified significant effects of genotype, phosphorus and time of sampling for almost all the traits of accumulation of biomass and nutrients, but the genotype x phosphorus interaction was not significant. The genotype x time interaction was in general significant, whereas the phosphorus x time interaction was significant for few traits. For most traits associated to yield components, the effects of phosphorus and genotype were significant, but not the genotype x phosphorus interaction.

TABLE 1. Sampling time of bean cultivars.

Name	Growth habit	Time of sampling[1]			
		1	2	3	4
		-----(days after emergence)-----			
BAT 76	II	30	37	46	74
Carioca	III	30	37	46	67
Goiano Precoce	I	21	28	37	60
ICA Pijao	II	28	35	44	78
Ouro Negro	III	28	35	44	67
Puebla 152	III	28	35	44	78
Rico 23	II	30	37	46	74
Rio Tibagi	II	30	37	46	74

[1] 1: third trifoliate fully expanded; 2: plentiful flowering; 3: beginning of pod filling; 4: maturity.

Biomass production and nutrient accumulation

Considering the average of the three samples, the higher P supply stimulated the vegetative growth of bean cultivars, increasing shoot dry weight (from 5.34 to 7.10 g $plant^{-1}$), root dry weight (from 0.41 to 0.51 g $plant^{-1}$), nodule dry weight (from 5.0 to 16.6 mg $plant^{-1}$) and number of nodules (from 8.0 to 16.9 $plant^{-1}$).

Patterns of biomass accumulation differed among cultivars. Goiano Precoce and Ouro Negro cultivars had significant increases in shoot dry weight after flowering, whereas in the other genotypes such increases were not significant (Fig. 1). Goiano Precoce,

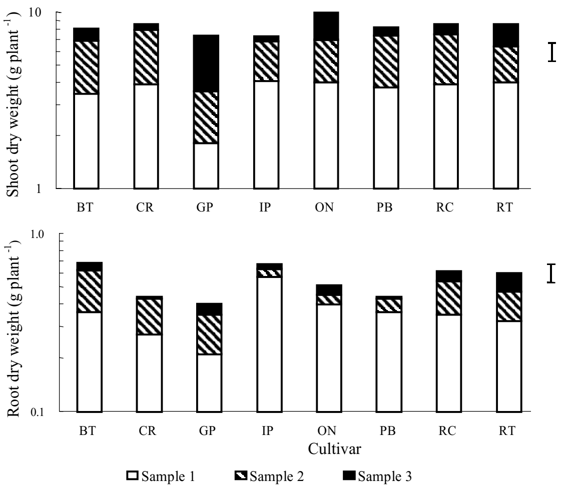

FIG. 1. Shoot and root dry weight of bean cultivars at three times of sampling (means of two soil P levels). Values on logarithmic scale; vertical bars represent the least significant difference (Tukey test 5%), and compare cultivars within each sample. Cultivars: BT - BAT 76; CR - Carioca; GP - Goiano Precoce; IP - ICA Pijao; ON - Ouro Negro; PB - Puebla 152; RC - Rico 23; RT - Rio Tibagi. Time of sampling: sample 1: third trifoliate fully expanded; sample 2: plentiful flowering; sample 3: beginning of pod filling.

sampled about one week before the other cultivars, presented the lowest shoot dry weight at first and second samplings, but at third sampling it did not differ significantly from the others (Fig. 1). At first sampling ICA Pijao cultivar showed the greatest root dry weight and root:shoot ratio, demonstrating a vigorous initial rooting (Fig. 1 and Table 2). BAT 76 and Rio Tibagi, unlike the other cultivars, kept similar root:shoot ratio with time (Table 2), indicating a stable pattern of carbon allocation between root and shoot.

All cultivars presented a reduction in the number of nodules after flowering, such effect being less intense in Goiano Precoce and Rio Tibagi, which showed poor nodulation (Table 2). At first sampling ICA Pijao and Ouro Negro cultivars had the greatest number of nodules, but at second sampling Carioca and Rico 23 were superior (Table 2).

Ontogeny reduced continuously shoot and root P concentrations in every cultivar except Rio Tibagi, which maintained shoot P concentration almost stable with time (Table 2). Rio Tibagi cultivar presented the smallest mean values of shoot and root P concentrations (Table 2), hence a lower internal P requirement. The reduction of shoot P concentration with time was more intense at P_1, whereas the reduction of root P concentration was more intense at P_2 (Table 3).

Shoot P content increased with time, more intensively before flowering than after flowering, but in ICA Pijao cultivar there was no significant difference between samplings (Table 2). Rates of P accu-

TABLE 2. Nodulation, root:shoot dry weight ratio, N and P accumulation of bean cultivars at three times of sampling (means of two soil P levels)[1].

Cultivar	Sample	Number of nodules per plant	Nodule dry weight (mg plant^{-1})	Root:shoot ratio (mg g^{-1})	Shoot P conc. (mg g^{-1})	Shoot P content (mg plant^{-1})	Root P conc. (mg g^{-1})	Root P content (mg plant^{-1})	Shoot N content (mg plant^{-1})
BAT 76	1	13.2ab	7.2	106a	2.88a	10.1b	2.15	0.81a	110b
	2	19.6a	24.9	95a	2.34b	16.0a	1.64	1.04a	175a
	3	3.5b	2.6	88a	2.13b	17.1a	1.19	0.80a	150ab
Carioca	1	13.7ab	5.5	72a	2.89a	11.5b	2.04	0.57a	113b
	2	22.8a	16.2	58b	2.52b	20.5a	1.60	0.72a	195a
	3	4.1b	3.0	50b	2.63ab	22.9a	1.24	0.52a	200a
Goiano Precoce	1	3.9a	2.3	119a	3.47a	6.4c	1.75	0.38b	66c
	2	6.8a	9.9	105a	3.22a	11.6b	1.72	0.63a	116b
	3	6.0a	7.0	56b	2.79b	21.0a	1.31	0.54ab	179a
ICA Pijao	1	30.3a	16.4	148a	3.25a	13.6a	1.72	1.03a	139a
	2	21.0b	34.9	96b	2.32b	15.8a	1.44	1.00ab	183a
	3	3.4b	4.9	91b	2.19b	17.1a	1.05	0.70b	146a
Ouro Negro	1	28.8a	19.2	104a	3.12a	13.0b	1.82	0.79a	128b
	2	21.9a	28.4	69b	2.76ab	19.5a	1.46	0.70a	172a
	3	5.3b	9.1	51c	2.44b	24.3a	1.29	0.66a	210a
Puebla 152	1	11.0a	3.3	101a	3.49a	13.7b	1.68	0.64a	132b
	2	12.4a	5.9	62b	2.84b	21.5a	1.60	0.70a	203a
	3	6.2a	4.7	51c	2.32c	19.2a	1.29	0.52a	192a
Rico 23	1	21.1ab	16.2	98a	2.91a	11.4b	2.09	0.79a	119b
	2	23.7a	23.2	76b	2.49b	18.4a	1.29	0.77a	187a
	3	6.1b	6.5	73b	2.53b	21.9a	1.23	0.76a	167a
Rio Tibagi	1	9.1a	4.1	82a	2.59a	10.2b	1.65	0.56a	115b
	2	3.7ab	3.4	75a	2.30a	15.1a	1.24	0.59a	150ab
	3	1.1b	0.6	73a	2.27a	19.9a	1.10	0.68a	177a

[1] Data ln-transformed prior to analysis of variance; means followed by the same letter, within each cultivar, did not differ (Tukey test 5%); means without letters represent nonsignificant interaction.

mulation in roots were influenced by P supply. At P_1, root P content increased between first and second samplings and thereafter stabilized, whereas at P_2 it decreased after flowering (Table 3). Proportion of P in roots diminished continuously with time at P_2, but at P_1 there was no significant reduction after flowering (Table 3). The reduction in root P content after flowering was more intense in ICA Pijao cultivar, which presented a concomitant strong reduction in root P concentration (Table 2).

Shoot N concentration decreased with time at both P levels (Table 3). The higher P supply reduced shoot N concentration at first and second samplings, but not at third sampling (Table 3). In most of the cultivars, shoot N content increased from the first to the second samplings, without significant increases after flowering; yet in Goiano Precoce shoot N content increased after flowering, and in ICA Pijao there was no significant difference between samplings (Table 2).

Goiano Precoce had the lowest shoot P and N contents at first and second samplings, but it did not differ from the other cultivars at third sampling, when Ouro Negro was superior to all of them (Table 2). While at P_2 shoot N:P ratio remained stable with ontogeny, at P_1 it decreased with time (Table 3), indicating that the lower P supply reduced the rates of N accumulation as compared with P absorption. Rates of N and P accumulation of each cultivar were similar (Table 2).

Grain yield

Regardless the significant effect of P levels on grain production, yield increased only 6% at P_2 (Table 4). Ouro Negro Cultivar had the greatest mean yield, followed by Carioca, Rio Tibagi and Goiano Precoce (Table 4). The genotype × phosphorus interaction being not significant means that P supply did not affect the rank of cultivars for yield, and also indicates a low genotypic variability for P responses. However, it may be pointed out that whereas most of the cultivars presented increments of yield less than 10% at P_2, Rico 23 had an increase of 27% (Table 4), being more responsive to P. Genotypic differences in grain yield resulted from distinct combinations of yield components: Rio Tibagi showed the greatest number of pods per plant, Goiano Precoce, the highest 100 seeds weight, while Ouro Negro and Carioca intermediate values of these components (Table 5).

At P_2 seed N and P concentrations, and seed N and P contents per unit of land area, were increased, but N and P harvest indexes decreased (Table 5). Goiano Precoce Cultivar showed the highest seed N and P concentrations, while Carioca and Ouro Negro had the lowest seed P concentration and Rio Tibagi the lowest seed N concentration (Table 5). The genotypic differences in harvest index and in N and P harvest indexes were not significant (Table 5), in part due to high coefficients of variation for these variables. Values of N and P harvest indexes superior to 1.0 (Table 5) suggest that N and P accumulation continued after the beginning of pod filling, particularly

TABLE 3. Shoot and root P concentrations, root P content, proportion of P in roots, shoot N concentration, and shoot N:P ratio, of common bean cultivars at three times of sampling and at two soil P levels (means of eight cultivars)[1].

Time of sampling[2]	Shoot P concentration[3] (mg g^{-1})		Root P concentration[3] (mg g^{-1})		Root P content[3] (mg plant^{-1})		Proportion of P in roots (mg g^{-1})		Shoot N concentration (mg g^{-1})		Shoot N: P ratio[3] (g g^{-1})	
	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
1	2.62aB	3.53aA	1.45aB	2.28aA	0.46bB	0.94abA	56.8aA	59.8aA	33.8aA	31.3aB	13.1aA	9.0aB
2	2.39bB	2.81bA	1.20bB	1.79bA	0.54aB	1.00aA	39.4bB	48.6bA	27.3bA	25.1bB	11.6bA	9.1aB
3	2.19cB	2.63bA	1.09bB	1.33cA	0.52abB	0.78bA	34.0bA	31.4cA	20.7cA	21.7cA	9.7cA	8.4aB
Mean	2.40B	2.99A	1.25B	1.80A	0.50B	0.90A	43.4A	46.6A	27.3A	26.0A	11.4A	8.8B

[1] Lowercase letters compare samples, and capital letters compare P levels; means followed by the same letter did not differ (Tukey test 5%); P_1: 12 kg ha^{-1} of P; P_2: 50 kg ha^{-1} of P.
[2] 1: third trifoliate fully expanded; 2: plentiful flowering; 3: beginning of pod filling.
[3] Data ln-transformed prior to analysis of variance.

under low P supply. ICA Pijao and Puebla 152, cultivars with latest maturity (Table 1), presented the greatest N and P harvest indexes (Table 5), indicating that the third sampling did not represent the maximal growth of them. It seems that an additional sampling, at the end of pod filling, should have been done to ensure the stage of maximal biomass production of the cultivars.

DISCUSSION

The cultivars evaluated have different growth habits and days to maturity (Table 1), and were previously selected as contrasting in regard to some traits associated with efficiency of P absorption and utilization (Araújo, 1996). Notwithstanding, the non significance of genotype × phosphorus interaction indicates a relatively similar growth pattern of each cultivar at both P levels, and a narrow genotypic variability of P responses under field conditions (Haag et al., 1978; Informe ..., 1986).

Carioca and Rio Tibagi cultivars have been used as controls of adequate yield under low P supply (Informe ..., 1985, 1986; Yan et al., 1995a), and confirmed such efficiency. Goiano Precoce, despite its lower initial biomass and nutrient accumulation (Fig. 1 and Table 2), yielded as much grain as the best cultivars (Table 4), demonstrating a rapid translocation of assimilates to grain. Carioca and Ouro Negro, the most grain yielding cultivars, presented the lowest seed P concentrations, suggesting a relationship between productivity and P utilization by grain. More efficient P utilization should be achieved by genotypes which retain P in the vegetative tissues, maintaining the rate and duration of photosynthesis and minimizing grain P concentration (Batten, 1986).

Linear regressions obtained by covariance indicated significant correlation between grain yield and number of pods per plant ($r = 0.378$, $P < 0.001$) and 100 seeds weight ($r = 0.538$, $P < 0.001$). Pods per plant is one of the yield components most affected by P deficiency, explaining the superiority of efficient lines under low P (Informe ..., 1986), and it has a predominant influence on yield either at low or high fertility levels (Haag et al., 1978). Rio Tibagi Cultivar had the greatest number of pods per plant, and also a relatively high grain yield at both P levels (Tables 4 and 5), confirming the importance of this component under low P. However, seed weight also contributed, since Ouro Negro and Carioca, the most grain yielding cultivars, brought together intermediate values of pods per plant and 100 seeds weight (Table 5).

The genotypic differences observed in the patterns of root production may be useful for nutritional breeding programs, since growth and P accumulation of bean in low P soils were associated to larger root dry weight and root:shoot ratio (Yan et al., 1995b). ICA Pijao, Ouro Negro and Puebla 152 cultivars showed a vigorous initial root growth (Fig. 1), that can be advantageous under conditions of low soil fertility or low soil moisture. Bean root growth is heritable, which makes possible the selection of plants with larger root system (Fawole et al., 1982). However, the significance of genotype x time interaction may compromise the usefulness of these traits as selection criteria, unless some physiological basis can be established for selection at specific points in crop development (Lynch & Beem, 1993).

Under low P supply roots retained more P after flowering, whereas the high P supply stimulated the translocation of P from roots to shoots, since root P concentration and content, and also proportion of P in roots, decreased after flowering at P_2 unlike at P_1 (Table 3). A large proportion of P on bean plants was initially invested in roots, and this allocation de-

TABLE 4. Grain yield of common bean cultivars at two soil P levels (means of 4 replicates)[1].

Cultivar	Grain yield (g m^{-2})		
	P_1	P_2	Mean
BAT 76	66.7	69.1	67.9c
Carioca	90.9	92.3	91.6ab
Goiano Precoce	85.4	94.2	89.8ab
ICA Pijao	78.4	82.9	80.6bc
Ouro Negro	106.2	107.6	106.9a
Puebla 152	85.1	92.4	88.8b
Rico 23	68.0	86.5	77.2bc
Rio Tibagi	91.3	89.8	90.6ab
Mean	84.0B	89.3A	

[1] Lowercase letters compare cultivars, and capital letters compare P levels; means followed by the same letter did not differ (Tukey test 5%); P_1: 12 kg ha^{-1} of P; P_2: 50 kg ha^{-1} of P.

creased with time, more intensively in plants under high than under low P supply (Snapp & Lynch, 1996). In addition, P harvest index superior to 1.0 at P_1 (Table 5) indicates that P accumulation persisted after early pod filling, when the third sampling was done. Bean roots under low P did not remobilize P or senesce with ontogeny, suggesting that retention of P in roots may allow nutrient and water uptake late in ontogeny (Snapp & Lynch, 1996). Therefore, the maintenance of P absorption at late growth stages may be an important factor on establishment of bean crop under low soil fertility.

Relationships between seed yield and data of biomass and nutrient accumulation were difficult to establish, since linear regressions were not significant. The responses of vegetative growth to the higher P supply did not reflect with the same magnitude on yield. Whereas shoot dry weight increased 33% at P_2 (mean of three samples), seed yield increased only 6% (Table 4). The lower harvest index at P_2 (Table 5) suggests that the cultivars did not fully express their yield potential, and yield was also limited by another factor than P supply.

Silveira & Moreira (1990) observed that P response of bean yield was small under a water level of 204 mm in an Oxisol, but there was no evidence of a water deficit during the experiment. Nodule number and weight were inferior to values verified in the same cultivars in a pot experiment (Araújo, 1996). In addition, the reduced nodulation after flowering indicates a process of nodule senescence, noticed in every genotype but at different degrees (Table 2). With the onset of bean pod filling, competition for photosynthates between nodules and pods becomes important, thus reducing nodule growth and activity (Piha & Munns, 1987). Nodule initiation and complete nodule development can be restricted in parts of bean root system at pod filling (Vikman & Vessey, 1993).

Maximum bean uptake of mineral N was observed in the period of 15 days between flowering and mid-pod filling (Hungria & Neves, 1987), and allocation of N to seed dominates the reproductive N budget of common bean (Lynch & White, 1992). The intense nodule senescence observed could have lessened N_2 fixation during a stage of high N demand, and the crop requirement was likely to be not satisfied by the symbiosis. Leaf N concentrations at flowering below 30 and 47 mg g^{-1}, respectively by critical nutrient level and by diagnosis and recommendation integrated system criteria, predicted significant responses of bean yields to applied N (Wortmann et al., 1992). Hence, shoot N concentration at second sampling confirms a sub-optimal N supply at both P levels (Table 3). The poor N_2 fixation after flowering could have limited the expression of the yield potential and the efficiency of P use, justifying in part the lack of significance of genotype x phosphorus interaction for measured traits. The low number of pods

TABLE 5. Yield components, seed P concentration and content, seed N concentration and content, and N and P harvest indexes of bean cultivars at two soil P levels[1].

Treatment	Pods per plant	Seeds per pod	100 seeds dry weight (g)	Harvest index[2] ($g\ g^{-1}$)	Seed P conc. ($mg\ g^{-1}$)	Seed P content ($mg\ m^{-2}$)	P harvest index[2] ($g\ g^{-1}$)	Seed N conc. ($mg\ g^{-1}$)	Seed N content ($g\ m^{-2}$)	N harvest index[2] ($g\ g^{-1}$)
BAT 76	3.96c	4.32b	16.4f	0.40a	5.44ab	368d	1.08a	40.2ab	2.74c	0.93a
Carioca	4.15bc	4.39b	20.7d	0.47a	4.70c	427bcd	0.89a	38.5ab	3.53abc	0.81a
Goiano Precoce	4.90abc	2.53d	29.5a	0.51a	5.64a	505ab	1.15a	41.0a	3.71ab	0.96a
ICA Pijao	4.45abc	4.54ab	18.0ef	0.48a	4.95abc	399cd	1.35a	37.0ab	2.99bc	1.04a
Ouro Negro	4.81abc	4.29b	22.7c	0.46a	4.84bc	516a	0.98a	37.2ab	3.98a	0.86a
Puebla 152	5.19ab	3.30c	24.8b	0.47a	5.09abc	449abcd	1.22a	37.8ab	3.35abc	0.91a
Rico 23	4.20bc	4.73a	18.9e	0.42a	5.03abc	388cd	0.88a	38.3ab	2.96bc	0.87a
Rio Tibagi	5.54a	4.42ab	16.2f	0.45a	5.04abc	454abc	1.15a	36.3b	3.28abc	0.91a
12 kg ha^{-1} of P	4.53A	3.99B	20.7B	0.50A	4.89B	408B	1.28A	37.2B	3.12B	1.00A
50 kg ha^{-1} of P	4.77A	4.14A	21.2A	0.41B	5.29A	468A	0.90B	39.4A	3.51A	0.82B

[1] Lowercase letters compare cultivars, and capital letters compare P levels; means followed by the same letter did not differ (Tukey test 5%).
[2] Calculated based on shoot biomass at third time of sampling.

per plant (Table 5), as compared to Informe ... (1986) or Youngdahl (1990), also confirms some restriction to seed yield.

According to Adams (1967), in selection for genetic merit of some character, it should be sought to remove the constraints of limited input to permit the full expression of whatever genes were involved in such component. Therefore, the identification of bean genotypes tolerant to low P soils and efficient in N_2 fixation can be difficult (Graham & Rosas, 1979), due to constraints to growth and yield caused by an inefficient symbiosis, which can be confounded with a small genotypic adaptation to low P. However, towards efforts for obtaining bean cultivars more productive under conditions of low inputs in a sustainable agriculture, the challenge of making compatible P efficiency and biological N_2 fixation must be faced.

CONCLUSIONS

1. The bean cultivars present different patterns of biomass production and of N and P accumulation, particularly on root system.
2. The responses of vegetative growth to the higher P supply do not reflect with the same magnitude on seed yield.
3. A sub-optimal supply of N may limit the expression of the yield potential of cultivars, reducing the genotypic variability of responses to P levels.

REFERENCES

ADAMS, M.W. Basis of yield component compensation in crop plants with special reference to the field bean, *Phaseolus vulgaris*. **Crop Science**, Madison, v.7, p.505-510, 1967.

ARAÚJO, A.P. **Eficiência de absorção e utilização de fósforo em genótipos de feijoeiro (*Phaseolus vulgaris* L.) sob fixação biológica de nitrogênio**. Seropédica : UFRRJ, 1996. 341p. Tese de Doutorado.

BARBOSA FILHO, M.P.; SILVA, O.F. Aspectos agro-econômicos da calagem e da adubação nas culturas de arroz e feijão irrigados por aspersão. **Pesquisa Agropecuária Brasileira**, Brasília, v.29, n.11, p.1657-1667, nov. 1994.

BATTEN, G.D. The uptake and utilization of phosphorus and nitrogen by diploid, tetraploid and hexaploid wheats (*Triticum* spp.). **Annals of Botany**, London, v.58, n.1, p.49-59, 1986.

EMBRAPA. Serviço Nacional de Levantamento e Conservação de Solos (Rio de Janeiro, RJ). **Manual de métodos de análise de solo**. Rio de Janeiro, 1979. Não paginado.

FAWOLE, I.; GABELMAN, W.H.; GERLOFF, G.C. Genetic control of root development in beans (*Phaseolus vulgaris* L.) grown under phosphorus stress. **American Society for Horticultural Science. Journal**, Alexandria, v.107, n.1, p.98-100, 1982.

FERNÁNDEZ, F.; GEPTS, P.; LÓPEZ, M. Etapas de desarrollo en la planta de frijol. In: LÓPEZ, M.; FERNÁNDEZ, F.; SCHOONHOVEN, A. van. (Eds.). **Frijol:** investigación y producción. Cali : CIAT, 1985. p.61-78.

GRAHAM, P.H.; ROSAS, J.C. Phosphorus fertilization and symbiotic nitrogen fixation in common bean. **Agronomy Journal**, Madison, v.71, n.6, p.925-926, 1979.

HAAG, W.L.; ADAMS, M.W.; WIERSMA, J.V. Differential responses of dry bean genotypes to N and P fertilization of a Central American soil. **Agronomy Journal**, Madison, v.70, n.4, p.565-568, 1978.

HUNGRIA, M.; NEVES, M.C.P. Partitioning of nitrogen from biological fixation and fertilizer in *Phaseolus vulgaris*. **Physiologia Plantarum**, Copenhagen, v.69, n.1, p.55-63, 1987.

INFORME ANUAL DEL PROGRAMA DE FRIJOL. Cali : CIAT, 1985. 372p.

INFORME ANUAL DEL PROGRAMA DE FRIJOL. Cali : CIAT, 1986. 341p.

LYNCH, J.; BEEM, J.J. Growth and architecture of seedling roots of common bean genotypes. **Crop Science**, Madison, v.33, n.6, p.1253-1257, 1993.

LYNCH, J.; WHITE, J.W. Shoot nitrogen dynamics in tropical common bean. **Crop Science**, Madison, v.32, n.2, p.392-397, 1992.

NETER, J.; WASSERMAN, W.; KUTNER, M.H. **Applied linear statistical models**. 3.ed. Burr Ridge : R.D. Irwin, 1990. 1181p.

OLIVEIRA, A.J.; LOURENÇO, S.; GOEDERT, W.J. (Eds.). **Adubação fosfatada no Brasil**. Brasília : Embrapa-DID, 1982. 326p. (Embrapa-DID. Documentos, 21).

OLIVEIRA, I.P.; THUNG, M.; KLUTHCOUSKI, J.; AIDAR, H.; CARVALHO, J.R.P. Avaliação de cultivares de feijão quanto à eficiência no uso de fósforo. **Pesquisa Agropecuária Brasileira**, Brasília, v.22, n.1, p.39-45, jan. 1987.

PEREIRA, P.A.A.; BLISS, F.A. Selection of common bean (*Phaseolus vulgaris* L.) for N_2 fixation at different levels of available phosphorus under field and environmentally-controlled conditions. **Plant and Soil**, Dordrecht, v.115, n.1, p.75-82, 1989.

PIHA, M.I.; MUNNS, D.N. Nitrogen fixation potential of beans (*Phaseolus vulgaris* L.) compared with other grain legumes under controlled conditions. **Plant and Soil**, Dordrecht, v.98, n.2, p.169-182, 1987.

SÁNCHEZ, P.A.; SALINAS, J.G. Low-input technology for managing Oxisols and Ultisols in Tropical America. **Advances in Agronomy**, San Diego, v.34, p.279-406, 1981.

SILVEIRA, P.M.; MOREIRA, J.A.A. Resposta do feijoeiro a doses de fósforo e lâminas de água de irrigação. **Revista Brasileira de Ciência do Solo**, Campinas, v.14, n.1, p.63-67, 1990.

SNAPP, S.S.; LYNCH, J.P. Phosphorus distribution and remobilization in bean plants as influenced by phosphorus nutrition. **Crop Science**, Madison, v.36, n.4, p.929-935, 1996.

VIKMAN, P.A.; VESSEY, J.K. Ontogenetic changes in root nodule subpopulations of common bean (*Phaseolus vulgaris* L.). III. Nodule formation, growth and degradation. **Journal of Experimental Botany**, Oxford, v.44, n.260, p.579-586, 1993.

WALLACE, D.H.; OZBUN, J.L.; MUNGER, H.M. Physiological genetics of crop yield. **Advances in Agronomy**, San Diego, v.24, p.97-146, 1972.

WORTMANN, C.S.; KISAKYE, J.; EDJE, O.T. The diagnosis and recommendation integrated system for dry bean: Determination and validation of norms. **Journal of Plant Nutrition**, New York, v.15, n.11, p.2369-2379, 1992.

YAN, X.; BEEBE, S.E.; LYNCH, J.P. Genetic variation for phosphorus efficiency of common bean in contrasting soil types. II. Yield response. **Crop Science**, Madison, v.35, n.4, p.1094-1099, 1995a.

YAN, X.; LYNCH, J.P.; BEEBE, S.E. Genetic variation for phosphorus efficiency of common bean in contrasting soil types. I. Vegetative response. **Crop Science**, Madison, v.35, n.4, p.1086-1093, 1995b.

YOUNGDAHL, L.J. Differences in phosphorus efficiency in bean genotypes. **Journal of Plant Nutrition**, New York, v.13, n.11, p.1381-1392, 1990.