



Growth and carbon partitioning of two genotypes of bean (*Phaseolus vulgaris*) grown with low phosphorus availability

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Abstract

Production of the common bean (*Phaseolus vulgaris*) is often limited by the low availability of soil phosphorus (P). Bean genotypes differ in their P efficiency, dry matter production and partitioning under low P availability. Two genotypes of bean were used in this study cv. Carioca (CNF 0554) with indeterminate growth habit (GH) and small seeds and cv. Prince (commercially available) with a determinate GH and large seeds. Plants were grown in a solution culture with either a non-limiting or low P supply and harvested at two occasions to measure dry matter production (DM), DM partitioning, and growth parameters. The determinate genotype produced a higher DM than the indeterminate genotype, due to the larger seeds. At low P supply increased the root dry weight and decreased the leaf and stem dry weight. No effect was detected on the total DM. The DM partitioning follows the same pattern as DM production. Carioca invests less dry matter in the stem, and more dry matter in the root. Low P availability also reduced the leaf area (LA), leaf area ratio (LAR) and specific leaf area (SLA). Growth was affected differently between the genotypes by low P. There was a reduction in relative growth rates (RGR) and net assimilation rates (NAR) for Carioca, but no effect was found in Prince. A genetic variation for P response exists in bean genotypes with different growth habits.

Keywords: Carbon partitioning, growth, *Phaseolus vulgaris*, phosphorus deficiency.

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INTRODUCTION

Common beans (*Phaseolus vulgaris* L.) are considered to be the most important grain legume for human consumption; and comprise 50% of the grain legumes consumed worldwide (Broughton et al. 2003, Graham et al. 2003). In several countries of Latin America and Africa, beans are staple crops serving as the primary source of protein in the diet. A range of environmental factors, such as low soil nitrogen (N) and phosphorus (P) levels, and acid soil conditions are important constraints for bean production in most areas where this crop is grown (Graham et al. 2003). Besides N, phosphorus (P) is one of the most essential elements for plant growth. Crop production of common bean (*P. vulgaris*) is often limited by low P in the soil (Hernández et al. 2007).

Systematic evaluation of bean germplasm for P deficiency at the International Centre for Tropical Agriculture (CIAT) showed genetic variation in P efficiency between cultivars. This variation probably represents general adaptation to low P and might be due to more vigorous root growth (Lynch and Beebe 1995). Youngdahl (1990) suggested that lines with large, fine root systems would have an advantage in P deficient soils. Many researches have proposed improvement of P efficiency through breeding (Whiteaker et al. 1976, Fawole et al. 1982a). One of the most important goals in plant breeding is development of P-efficient genotypes with the

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ability to grow and yield under P-deficient environments (Yan et al. 1992, Hash et al. 2002, Yan et al. 2004). Plant P efficiency has been defined in several ways. Fox and Piekielek (1978) suggested that P efficient genotypes are the ones that produce a large quantity of harvestable dry matter per unit time and area when grown in media with less than sufficient P available for maximum yield. Others (Loneragan and Asher 1967, Gerloff 1976, Gerloff and Gabelman 1983) have argued that, to be accepted as an efficient genotype under nutrient stress, this genotype must yield approximately the same as an efficient genotype under optimum supplies of the nutrient.

Beebe et al. (1997) stated that efficient genotypes are those which are able to produce superior yields under phosphorus deficiency conditions, irrespective of the mechanisms involved. In a comparison between wild and cultivated genotypes of common bean, Araujo et al. (1997) reported that cultivated genotypes have greater root dry weights and root-to-shoot ratios than wild genotypes, suggesting that selection under cultivation could have resulted in plants which invest preferentially in root production, a potentially valuable trait in low P soils. Patterns of dry matter diversion and root plasticity may therefore be important features influencing the ability of grain legume crops to cope with soil deficiencies. Plants have evolved other strategies for P acquisition and use in limiting environments that include: mycorrhizal symbioses, remobilization of internal inorganic phosphate, increased production and secretion of phosphatases, exudation of organic acids, and modification of root architecture (Plaxton 2004). Release of P-efficient genotypes would reduce the costs associated with P fertilizer applications, minimize environmental pollution, and contribute to the maintenance of P resources (Cakmak 2002, Vance et al. 2003).

The work described in this paper was designed to explore the variability of dry mass production and partitioning during the vegetative growth of two genotypes of common bean, differing in growth habits and grown in a solution culture with different P levels.

MATERIAL AND METHODS

The Plant materials were two genotypes of bean (*Phaseolus vulgaris* L.), Carioca (CNF 0554), with indeterminate growth habits and small seeds (100 seed-weight 27 g), and Prince with determinate growth habits and large seeds (100 seed weight 48 g). The research was conducted at the Experimental Gardens, University of Leeds, UK, under glasshouse conditions. Seeds were planted in trays containing perlite to germinate and then the 10-day-old seedlings were transplanted into an aerated solution culture. The plants were grown in 60-L tanks with a density of 18 plants per tank. The pH of the solution culture was adjusted to between 5.5 and 6.5 and the temperature was (22° during the day and 18° at the night). There were three replicate plants of each genotype in each tank, and 5 replicate tanks for each P level. Plants were grown under two phosphorus levels: High P (4.5 mg P plant⁻¹) and low P (3.3 mg P plant⁻¹). P was added as KH₂PO₄. The standard nutrient solutions were prepared according to the Long Ashton formula (g L⁻¹) (Hewitt 1966): 55 KNO₃, 5 Fe-EDTA, 37 MgSO₄.7H₂O, 70.8 Ca(NO₃)₂, 16 NH₄NO₃, 21.5 Na₂SO₄. 10H₂O, 0.2 MnCl₂.7 H₂O, 0.017 CuCl₂, 0.014 ZnCl₂, 0.185 H₃BO₄, and 0.008 MoO₃. P was added to the solution culture at three occasions (at transplanting, 6 days after transplanting, and 11 days after transplanting). Tanks were arranged in a randomised complete block design to counteract the temperature and light gradients. Plants were harvested on two occasions during the growth period, harvest 1 (3 weeks after germination, four plants of each genotype were harvested), and harvest 2 (4 weeks after germination, eight plants of each genotype were harvested). Plants were separated to leaves, stems and roots and dried at 80°C for 48 h for the determination of dry mass.

Leaf areas were measured with an area meter (Delta-T Devices Burwell, Cambridge). The following were calculated: specific leaf areas (SLA, ratio of leaf area to leaf dry weight (cm² g⁻¹)), leaf area ratios (LAR, ratio of leaf area to total dry weight (cm² g⁻¹)), relative growth rates (RGR) (g g⁻¹ day⁻¹), and net assimilation rates (NAR) (g cm⁻² day⁻¹). Data was analysed as a randomised complete

block design using SPSS (Anonymous 1996). Analysis of variance (ANOVA) was performed for each variable. Statements of significance indicate a 5% level of probability.

RESULTS

Because no effects of Phosphorus deficiency were detected on most plant traits at harvest 1, data was not shown. Treatment effects on root dry weight were highly significant ($P = 0.001$) for P and genotype, but the Genotype X P level interaction was not significant (Table 1). In the low P level, root dry weight was significantly higher than that in the high P level. Leaf and stem growth was influenced by genotype ($P = 0.001$) and P level ($P = 0.001$). The two-way interaction was significant ($P = 0.05$) for leaf weight, but not for stem weight. Leaf and stem dry weight increased with increasing P level. There was a highly significant effect of genotype ($P = 0.001$) on total dry weight, in contrast no effects of P levels were detected. The interaction of Genotype X P level was also not significant.

Genotypes with a large seed mass (cv. Prince) produced a larger initial mass than those with a small seed mass (cv. Carioca), thus potentially influencing the ability to yield a high final plant mass. The initial seed mass of Prince was approximately twice as large as that of the Carioca genotype and Prince had higher dry masses of root, leaf, and stem, and a higher total dry mass. A high correlation between initial seed size and total dry mass was reported using the same genotypes.

The dry matter partitioning was affected differently by genotype and P levels. A highly significant effect ($P = 0.001$) of P was found on root fractions, but no effect of genotype was observed (Table 2). The root fractions increased when the P level decreased. Leaf fractions were affected by genotype ($P = 0.05$) and P level ($P = 0.001$), and decreased at low P level. Stem fractions were also significantly affected by genotype ($P = 0.001$) and P level ($P = 0.05$), and both stem and leaf fractions were lower with low P than with high P. The two-way interactions for Genotype X P level were not significant for any of the plant part fractions.

Leaf development was greatly influenced by genotype and P level. P supply reduced the

leaf area of Carioca by 44%, but only reduced SLA in Carioca by 24%. This is because low P reduced leaf mass in Carioca by 26%, whereas in Prince it only reduced leaf mass by 6%. This big effect on leaf mass in Carioca is presumably one reason why Carioca performance decreased under P deficiency.

A highly significant effect ($P = 0.001$) of genotype was found on the leaf area (LA), but no effect was detected on the specific leaf area (SLA) or leaf area ratio (LAR) (Table 3). The leaf growth was the most responsive to the P level. The effect of the P level was highly significant ($P = 0.001$) on LA, SLA, and LAR. This effect could be seen from the big reduction (37%) of the leaf area. The decrease in leaf area, due to the low P level, was accompanied by decrease in SLA and LAR (Table 3).

Phosphorus deficiency reduced RGR significantly for Carioca plants, while no significant effect was found in Prince plants (Fig. 1). A similar pattern of effects of low P availability was observed on NAR (Fig. 2).

DISCUSSION

Considerable variation between the two genotypes for root and shoot biomass accumulation under P stress was observed. Prince (Andean genotype) had significantly greater vegetative biomass under low P conditions than Carioca (Mesoamerican genotype). The larger vegetative growth of Prince could be attributable to its greater seed size. The analysis of variance identified significant effects of P level and genotype for almost every trait.

The two genotypes showed different patterns of partitioning (Tables 1 and 2). Growth with a non-limiting supply of other nutrients was responsive to P nutrition. In P deficient plants, compared to plants given adequate P, relatively more dry matter was partitioned to roots than shoots. These results are in accordance with the findings of other researchers (Fredeen et al. 1989, Aloni et al. 1991, Ericsson et al. 1992, Jebara et al. 2005, Alkama et al. 2009). Root dry masses were generally affected positively by the reduction in the P level. The changed partitioning of carbon caused by deficient P supply resulted in higher root fractions at low P levels. Our observations show that root

Table 1. Dry matter production of bean plants of two genotypes grown with a high P or low P levels.

Genotype	Root dry weight (g plant ⁻¹)		Leaf dry weight (g plant ⁻¹)		Stem dry weight (g plant ⁻¹)		Total dry weight (g plant ⁻¹)	
	High P	Low P	High P	Low P	High P	Low P	High P	Low P
Prince	0.97	1.37	2.76	2.59	1.36	1.25	5.09	5.21
Carioca	0.61	0.81	1.86	1.37	0.72	0.57	3.20	2.75
<i>F</i> -test								
Genotype	***		***		***		***	
Phosphorus	***		**		**		ns	
G X P	ns		*		ns		ns	

*, **, *** Significant at P = 0.05, 0.01 and 0.001, respectively.

Table 2. Dry matter partitioning of bean plants of two genotypes grown with high P or low P levels.

Genotype	Root fraction		Leaf fraction		Stem fraction	
	High P	Low P	High P	Low P	High P	Low P
Prince	0.189	0.261	0.544	0.496	0.267	0.243
Carioca	0.190	0.290	0.582	0.500	0.229	0.210
<i>F</i> -test						
Genotype	ns		*		***	
Phosphorus	***		***		**	
G X P	ns		ns		ns	

Table 3. Leaf characteristics of bean plants of two genotypes grown with high P or low P levels.

Genotype	Leaf area (cm ² plant ⁻¹)		Specific leaf area (cm ² g ⁻¹)		Leaf area ratio (cm ² g ⁻¹)	
	High P	Low P	High P	Low P	High P	Low P
Prince	1403	946	510	371	276	182
Carioca	908	504	494	375	284	184
<i>F</i> -test						
Genotype	***		ns		ns	
Phosphorus	***		***		***	
G X P	ns		ns		ns	

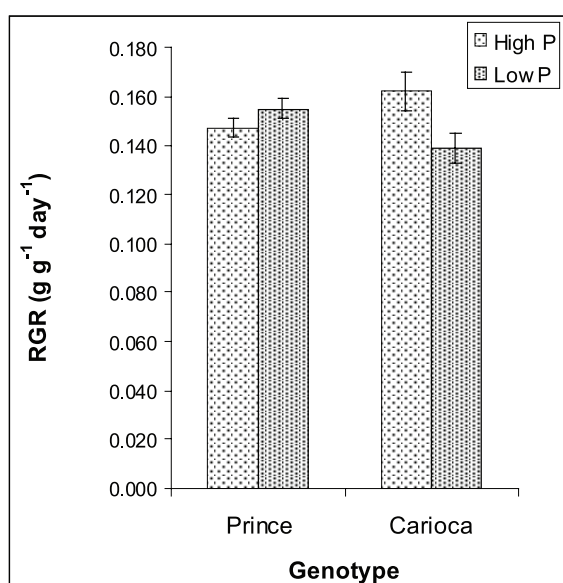


Fig. 1. Relative growth rate (RGR) of two genotypes of bean grown with high P and low P levels. Vertical bars ± SE.

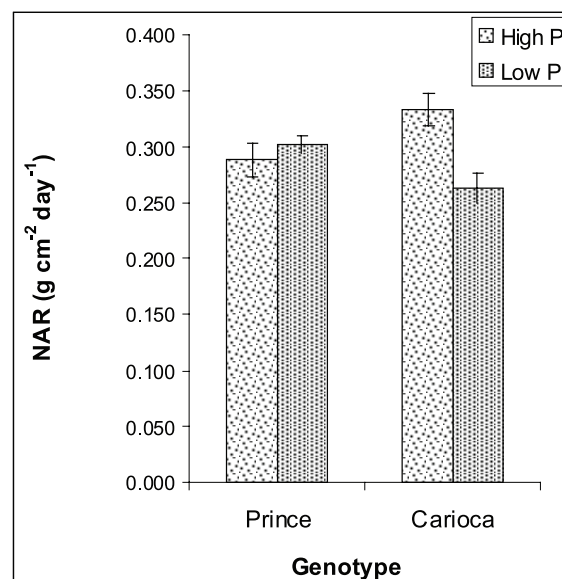


Fig. 2. Net assimilation rate (NAR) of two genotypes of bean grown with high P and low P levels.

growth is less affected by phosphorus stress than shoot growth, leading to increased root fraction. This is in agreement with many reports (Ulrich and Berry 1961, Atkinson 1973, Cassman et al. 1980, Fawole et al. 1982b, Fist and Edwards 1987, Lynch et al. 1991, Oliveira, 1995), and is also in accordance with the Brouwer hypothesis. If there is a suboptimal nutrient supply, the growth of the shoots will be checked sooner than that of roots because the latter are closer to the source of the deficient nutrient (Brouwer 1962). For bean, P stress increases the root fraction as predicted by this hypothesis (Table 2).

Carioca plants differed from Prince plants by having low stem fraction (Table 2). There appeared to be less dry matter invested in the stem and more invested in the roots. The distinct differences in root fraction seem to be related to the efficiency of these plants under low P and they are able to produce a higher number of pods and seeds compared to the Prince genotype (Boutraa 1999). In P-deficient plants, it seems therefore, that maintenance of the export of photoassimilates from the source leaves allows continued root growth and thus an increase in root fraction (Cakmak et al. 1994). The Carioca genotype in this study had much smaller root dry weights than the Prince genotype, but a similar root fraction. It might possible that larger root fraction is not an explanation for why Prince

grows better than Carioca under low P conditions.

Low P reduced leaf area is consistent with several findings, for example; Radian and Eidenbock (1984) showed that phosphorus deficiency reduced leaf expansion in cotton, and other researchers (Lynch et al. 1991, Oliveira, 1995) reported that in common bean, leaf area development was reduced by phosphorus deficiency. Fredeen et al. (1989) reported that reduction in the expansion of the leaf surface with low P was mainly due to an effect on the expansion of individual leaves, although there was also some effect on the rate of leaf emergence. They also suggested that marked reduction in leaf area expansion, which occurs with P deficiency, might be due to an insufficiency of phosphate for the expansion of leaf cells. In addition to the reduction in leaf area and leaf area ratio (LAR), low P level reduced specific leaf area (SLA) (Table 3) for both genotypes. Using common beans, Cakmak et al. (1994) found that specific leaf dry weight was higher in the control than in the P deficient plants. Smaller values of SLA denote the production of thicker leaves, and these probably have a higher photosynthetic activity on a leaf area basis. The biomass-based relative growth rate (RGR) and the biomass-based net assimilation rate (NAR) were severely reduced by P deficiency (Fig. 1).

P efficiency is defined by Yan et al. (1995)

as the ability of plants to produce relatively more yield (either biomass or grain) with suboptimal P availability. They also showed that more efficient genotypes had larger root systems (greater root biomass, greater root length, and/or higher root:shoot ratio) than the less efficient genotypes and observed considerable variability for root and shoot biomass accumulation under P stress.

Genotypes responded differently to P supply. The fact that the individual yield components responded differently to P supply (Tables 1, 2 and 3) suggests that different mechanisms may underlie tolerance to P stress (P efficiency) in the different genotypes. Other aspects, such as seed size may also influence P efficiency. This research has shown that low P availability affected the growth of bean genotypes by allowing more dry matter to be partitioned to root than shoot. On the other hand the shoot was affected by reducing leaf development, measured as leaf area. Our results confirm that bean genotypes can differ in root:shoot partitioning. We believe there is considerable potential for improvement of P efficiency in common bean through manipulation of root:shoot partitioning.

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REFERENCES

- Alkama N, Bi Bolou E, vailhe H, Roger L, Ounane SM, Drevon JJ (2009) Genotypic variability in P use efficiency for symbiotic nitrogen fixation is associated with variation of proton efflux in cowpea rhizosphere. *Soil Biology and Biochemistry* (in press).
- Aloni B, Pashkar T, Karnia L (1991) Nitrogen supply influences carbohydrates partitioning of pepper seedlings and transplant development. *Journal of the American Society for Horticultural Science* 116, 995-999.
- Anonymous (1996) SPSS for Windows Advanced Statistics Release 6.0.
- Araújo AP, Teixeira G, De Almeida DL (1997) Phosphorus efficiency of wild and cultivated genotypes of common bean (*Phaseolus vulgaris* L.) under biological nitrogen fixation. *Soil Biology and Biochemistry* 5/6, 951-957.
- Atkinson D (1973) Some general effects of phosphorus deficiency on growth and development. *New Phytologist* 72, 101-111.

- Beebe S, Lynch J, Galwey G, Tohme J, Ochoa I (1997) A geographical approach to identify phosphorus efficiency genotypes among landraces and wild ancestors of common bean. *Euphytica* 95, 325-336.
- Boutraa T (1999) Genetic manipulation of root:shoot ratio to improve stress tolerance in common bean (*Phaseolus vulgaris* L.). PhD thesis, University of Leeds, Leeds.
- Broughton WJ, Hernández G, Blair M, Beebe S, Gepts P, Vanderleyden J (2003) Beans (*Phaseolus* spp.): model food legume. *Plant and Soil* 252, 55-128.
- Brouwer R (1962) Nutritive influences on the distribution of dry matter in the plants. *Netherlands Journal of Agricultural Sciences* 10, 399-408.
- Cakmak I (2002) Plant nutrition research: Priorities to meet human needs for food in sustainable ways. *Plant and Soil* 247, 3-24.
- Cakmak I, Hengeler C, Marchner H (1994) Partitioning of shoot and root dry matter and carbohydrates in bean plants suffering from phosphorus, potassium and magnesium deficiency. *Journal of Experimental Botany* 45, 1245-1250.
- Cassman KG, Whitney AS, Stockinger KR (1980) Root growth and dry matter distributed of soybean as affected by phosphorus stress, nodulation, and nitrogen source. *Crop Science* 20, 239-244.
- Ericsson T, Rytter L, Linder S (1992) Nutritional dynamics and requirements of short rotation forests. In: Mitchell CP, Ford-Robertson JB, Hinckley T, Sennerby-Forsse L (eds), *Ecophysiology of Short Rotation Forest Crops*, Elsevier Applied Science, London.
- Fawole I, Gabelman WH, Gerloff GC (1982b) Genetic control of root development in beans (*Phaseolus vulgaris* L.) grown under phosphorus stress. *Journal of the American Society for Horticultural Science* 107, 98-100.
- Fawole I, Gabelman WH, Gerloff GC, Nordheim EV (1982a) Heritability of efficiency in phosphorus utilization in beans (*Phaseolus vulgaris* L.) grown under phosphorus stress. *Journal of the American Society for Horticultural Science* 107, 94-97.
- Fist AJ, Edwards DG (1987) External phosphorus requirements of five tropical grain legumes grown in flowing-solution culture. *Plant and Soil* 99, 75-84.
- Fox RH, Piekielek WP (1978) Field testing of several nitrogen availability indexes. *Soil Science Society of America Journal* 42, 747-750.
- Fredeen AL, Rao, IM, Terry N (1989) Influence of phosphorus nutrition on growth and carbon partitioning on *Glycine max*. *Plant Physiology* 89, 225-223.
- Gerloff GC (1976) Plant efficiencies in the use of nitrogen, phosphorus, and potassium. In: Wright MJ (ed.), *Plant Adaptation to Mineral Stress in Problem Soils*, Cornell University, Agriculture Experimental Station, Ithaca, NY.
- Gerloff GC, Gabelman WH (1983) Genetic basis of inorganic plant nutrition. In: Lauchli A, Bielecki RL (eds), *Encyclopedia of Plant Physiology, New Series, Vol. 15B*, Springer-Verlag, Berlin.
- Graham PH, Rosas JC, de Jensen EC, Peralta E, Tlusty B, Acosta-Gallegos J, Arraes Pereira PA (2003) Addressing edaphic constraints to bean production: the bean/cowpea CRSP project in perspective. *Field Crop Research* 82, 179-192.
- Hash CT, Schaffert RE, Peacock JM (2002) Prospects for using conventional techniques and molecular biological tools to enhance performance of 'orphan' crop plants on soils low in available phosphorus. *Plant and Soil* 245, 135-146.

- Hernández G, Ramírez M, Valdés-López O, Tesfaye M, Graham MA, Czechowski T, Schlereth A, Wandrey M, Erban A, Cheung F, Wu HC, Lara M, Town CD, Kopka J, Udvardi MK, Vance CP (2007) Phosphorus Stress in Common Bean: Root Transcript and Metabolic Responses. *Plant Physiology* 144, 752-767.
- Hewitt EJ (1966) Sand and water culture methods used in the study of plant nutrition. Second edition, Commonwealth Bureau of Horticulture and Plantation Crops, East Malling. Technical Communication No. 22, Farnham Royal, Commonwealth Agricultural Bureau, East Malling, Maidstone, Kent.
- Jebara M, Aouani M, Payre H, Drevon JJ (2005) Nodule conductance varied among common bean (*Phaseolus vulgaris*) genotypes under phosphorus deficiency. *Journal of Plant Physiology* 162, 309-315.
- Loneragan JF, Asher CJ (1967) Response of plants to phosphate concentration in solution culture: II. Rate of phosphate absorption and its relation to growth. *Soil Science* 103, 311-318.
- Lynch JP, Beebe SE (1995) Adaptation of bean (*Phaseolus vulgaris* L.) to low phosphorus availability. *HortScience* 30, 1165-1171.
- Lynch JP, Lauchli A, Epstein E (1991) Vegetative growth of the common bean in response to phosphorus nutrition. *Crop Science* 31, 380-387.
- Oliveira AAR (1995) Mycorrhizal effects on the growth of common bean (*Phaseolus vulgaris* L.). PhD thesis, University of Leeds, Leeds.
- Plaxton WC (2004) Plant responses to stress: biochemical adaptations to phosphate deficiency. In: Goodman RM (ed.), *Encyclopedia of Plant and Crop Science*. Marcel Dekker, New York.
- Radian JW, Eidenbock MP (1984) Hydraulic conductance as a factor limiting leaf expansion of phosphorus-deficient cotton plants. *Plant Physiology* 76, 392-394.
- Ulrich A, Berry WL (1961) Critical phosphorus levels for lima bean growth. *Plant Physiology* 36, 626-632.
- Vance CP, Uhde-Stone C, Allan DL (2003) Phosphorus acquisition and use: critical adaptations by plants for securing a nonrenewable resource. *New Phytologist* 157, 423-447.
- Whiteaker G, Gerloff GC, Gabelman WH, Lindgren DT (1976) Intraspecific differences in growth of beans at stress levels of phosphorus. *Journal of the American Society for Horticultural Science* 101, 472-475.
- Yan X, Huang ZW, Lu RJ, He YK (1992) Study on genetics of P efficiency in crops. *Soils* 24, 102-105.
- Yan X, Liao H, Beebe SE, Blair MW, Lynch JP (2004) QTL mapping of root hair and acid exudation traits and their relationship to phosphorus uptake in common bean. *Plant and Soil* 265, 17-29.
- Yan X, Lynch JP, Beebe SE (1995) Genetic variation for phosphorus efficiency of common beans in contrasting soil types: I. Vegetative responses. *Crop Science* 35, 1086-1093.
- Youngdahl LJ (1990) Differences in phosphorus efficiency in bean genotypes. *Journal of Plant Nutrition* 13, 1381-1392.

Dusuk Fosfor Kosullarında Yetisen İki Fasulye (*Phaseolus vulgaris*) Genotipinde Buyume ve Karbon Ayrisimi

Ozet

Adi fasulyenin (*Phaseolus vulgaris*) uretimi genellikle dusuk toprak fosforu (P) nedeniyle kisitlanir. Fasulye genotipleri, P etkinligi, kuru madde uretimi ve dusuk P kosullarında ayrisim konusunda farklılık gosterirler. Bu calismada iki fasulye genotipi kullanildi; sinirsiz buyume ozelligi ve kucuk tohumlari olan cv. Carioca (CNF 0554) ile sinirli buyume ozelligi ve buyuk tohumlari olan cv. Prince (ticari olarak mevcut). Bitkiler, ya sinirlandirici olmayan veya dusuk P icerikli cozelti kulturunde yetistirildi ve kuru madde (KM) uretimi, KM ayrisimi ve buyume parametrelerini olcmek icin iki kez hasat edildi. Sinirli genotip, baslangictaki tohum buyuklugu nedeniyle, sinirsiz genotipe oranla daha fazla KM uretti. Dusuk P mevcudiyeti, kok kuru agirliğini artirdi, yaprak ve govde kuru agirliğini azalatti. Toplam KM'de degisim gozlenmedi. KM ayrisimi, KM uretimi ile ayni yolu izledi. Carioca, govdede daha az, kokte daha fazla KM biriktirir. Dusuk P mevcudiyeti, yaprak alanı (YA), yaprak alan oranı (YAO) ve spesifik yaprak alanını (SYA) azalatti. Dusuk P, buyumeyi genotiplerde farklı etkiledi. Carioca'da, nispi buyume oranları (NBO) ve net asimilasyon oranlarında (NAO) azalma gozlendi, ancak Prince'de herhangi bir degisiklik yoktu. Fasulye genotiplerinde, farklı buyume ozellikleri acısından P'a verilen tepkide genetik bir farklılık mevcuttur.

Anahtar Kelimeler: Buyume, fosfor yetersizligi, karbon ayrisimi, *Phaseolus vulgaris*.