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Agronomic performance of common bean (*Phaseolus vulgaris* L.) lines in an Oxisol

Ronald Dorcinvil[a], David Sotomayor-Ramírez[b,*], James Beaver[b]

[a] Department of Plant Sciences, North Dakota State University, PO Box 6050, Fargo, ND 58108, United States

[b] Department of Crop and Agroenvironmental Sciences, College of Agricultural Sciences, University of Puerto Rico, PO Box 9000, Mayagüez 00680, Puerto Rico

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ABSTRACT

Soil acidity and low nitrogen (N) and phosphorus (P) availability are the most important constraints for common bean (*Phaseolus vulgaris* L.) production in highly weathered soils of the humid tropics. The objective of this study was to identify bean lines capable of producing higher yields as the result of greater N and P use efficiency under conditions of intermediate soil N and P availability. Selection for adaptation to low soil fertility can be used by plant breeding programs to improve bean seed yields. The performance of 33 bean lines and the varieties 'Morales' and 'Verano' from Puerto Rico and 'Salagnac 90' from Haiti were evaluated under three fertilization regimes in an Oxisol (very-fine, kaolinitic, isohyperthermic Typic Eutrustox): (i) 50 kg N/ha (+N), 57 kg P_2O_5/ha (+P), 54 kg K_2O/ha (+K), (ii) −N, +P and +K, and (iii) +N, −P and +K in two field plantings of June 2007 and January 2008. The black bean line PR0443-151 and red bean line PR0340-3-31 had consistently higher seed yields under nutrient non-limiting conditions (+N +P +K). The low N tolerant lines and those that consistently had the highest N use efficiencies were PR0443-151, VAX 3, RBF 11-33 and RBF 19-63. Lines that were both efficient in N utilization and responsive to N application were PR0443-151, IBC 309-23, and A774. PR0340-3-31, PR0443-151, A774 and VAX 3 had the highest seed yields under soil P limiting conditions and expressed high soil P use efficiency. The identification of the bean lines with high relative yields under both nutrient limiting and non-limiting conditions, high nutrient use efficiency, and tolerance to low soil N and P, can help breeding programs and eventual sustainability of bean production in the Caribbean.

1. Introduction

The common bean (*Phaseolus vulgaris* L.) is an important grain legume in the Americas and parts of Africa where it serves as a vital cheap source of protein, vitamins and mineral nutrients (Broughton et al., 2003). Soil acidity and low nitrogen (N) and phosphorus (P) availability are important bean production constraints in highly weathered soils of the tropics (Sanchez and Logan, 1992; Lynch et al., 2003). It is estimated that at least 55% of the bean production area in Latin America and 62% in Central America are severely P and N deficient (Lynch et al., 2003). Increased use of fertilizer N and P to improve crop yield in developing countries is limited by costs, availability, and potential negative environmental impact (Sanchez, 1976; Hinsinger, 2001; Brathwaite, 2008).

An alternative approach is the selection of bean lines with improved adaptation to low N and P availability (high nutrient use efficiency) with higher yields in low-input agro-ecosystems or lines that would require reduced fertilization in higher input systems (Lynch, 1998; Beaver et al., 2003; Singh et al., 2003). Selection for greater tolerance to abiotic stress such as low fertility, via the identification of high yielding genotypes with high nutrient use efficiency is an important element in the development of sustainable agriculture systems (Nielsen et al., 1999; Beaver et al., 2003). Selection for adaptation to low soil fertility is expected to gain importance in response to climate change and increased use of marginal land for bean production (Beaver and Osorno, 2009). The occurrence of genotype × environment interaction complicates the selection of lines that perform well over a wide range of stress environments and soil types. Hence, the identification of breeding lines with superior performance often requires that breeders work with large populations and replicated field trials as tolerance to abiotic stress tends to be a quantitatively inherited trait. Genetic progress may require several cycles of selection and the use of multiple parents (Singh et al., 2003).

Different adaptations can be used by beans to improve efficiency of use and acquisition of N and P from the soil (Yan et al., 1995; Lynch and Brown, 2001; Ochoa et al., 2006). Some bean lines have the capacity to modify the rhizosphere through surface root architecture, acid exudation, and longer basal root hairs (particularly under stressed conditions) which can increase absorption of P several fold (Cisse and Amar, 2000). For example, Beebe et al. (2006) reported that the P efficient dry bean line G19833 produced

Abbreviations: N, nitrogen; P, phosphorus; AE, agronomic efficiency; UE, utilization efficiency.

* Corresponding author. Tel.: +787 832 4040x5819; fax: +787 265 0860.
E-mail address: david.sotomayor@upr.edu (D. Sotomayor-Ramírez).

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Table 1
Soil fertility characteristics of the experimental site in June 2007 and January 2008[a].

Season	pH	OM	mg/kg		cmol$_c$/kg				mg/kg			
			NO_3^--N	P	Ca	Mg	K	CEC	Fe	Mn	Zn	Cu
June 2007	5.47	4.0	15.7	20.7	3.9	0.58	0.26	6.7	23.1	8.6	0.49	2.7
Soil level[b]	M	H	M	H	M	L	M	M	H	H	M	H
January 2008	5.91	3.6	9.7	19.1	5.0	0.64	0.26	6.8	35.4	33.0	0.72	3.0
Soil level[b]	M	M	L	M	M	L	M	M	H	H	H	H

[a] OM is soil organic matter by loss on ignition; NO_3-N is 1 M KCL extractable; P is Bray 1 extractable; Ca, Mg and K were extracted with NH_4OAC; CEC is the soil cation exchange capacity as measured by sum of bases and acids; Fe, Mn, Zn, and Cu were extracted with DTPA-TEA.
[b] Soil fertility level according to Sotomayor-Ramírez and Martínez (2006): L = low, M = medium, and H = high.

greater root biomass and with greater seed P concentration than the inefficient line DOR 364 under low soil P availability. Nutrient efficient bean lines tend to have shallow root system under nutrient stress and acquire more P from the soil solution by producing more adventitious roots (Miller et al., 2003). Bean lines with greater P use efficiency have been reported to have increased root and shoot biomass, root length and higher yields than lines that are inefficient under P-stressed conditions (Araujo et al., 2000; Ho et al., 2005; Kimani et al., 2007). Kimani and Tongoona (2008) evaluated three tolerant and five sensitive dry bean lines to low soil P and showed that the tolerant genotypes had higher root length, root biomass, greater number of nodules and higher yields than the sensitive genotypes. There has been less work on the development of beans that are efficient in acquisition and utilization of N, partly from the perception that as a legume it is an efficient N fixer (Caixeta-Franco et al., 2001). Common bean lines vary in N fixation potential and N use efficiency (Ramírez, 2009). Bean lines with higher N use efficiency that were inoculated with *Rhizobium leguminosarum* biovar *phaseoli* produced more root and shoot biomass than inefficient genotypes (Henson, 1993; Vadez et al., 1999). The objective of this study was to identify bean lines capable of producing higher yields as the result of greater N and P use efficiency under conditions of intermediate soil N and P availability.

2. Materials and methods

The experiment was conducted at the University of Puerto Rico, Agricultural Experiment Station near Isabela (67°3′ N lat., 18°3′ W long) at 128 m above sea level and mean annual temperature of 28 °C. The soil was an Oxisol (very-fine, kaolinitic isohyperthermic Typic Eutrustox). The soil was sampled from each main-plot to a depth of 0–15 cm prior to planting the field trials (Table 1). Soil NO_3-N was extracted with 1 M KCl and determined by automated colorimetry (Keeney and Nelson, 1982) and available P was extracted with Bray 1 (Bray and Kurtz, 1945). Cations (Ca, Mg and K) were extracted with ammonium acetate, and the micronutrients were extracted with DTPA-TEA and quantified by inductively coupled plasma (Ag-Source Harris Laboratories, 2009).

Thirty-three bean lines were selected from an initial screening of 228 genotypes from the bean research programs at the Escuela Agricola Panamericana in Honduras and the University of Puerto Rico. The varieties ‘Morales’ and ‘Verano’ from Puerto Rico and ‘Salagnac 90’ from Haiti were used as checks (Dorcinvil, 2009). Morales and Verano are white bean varieties developed and released by the Puerto Rico Agricultural Experiment Station and the USDA-ARS (Beaver and Miklas, 1999; Beaver et al., 2008). Salagnac 90 is a variety developed and released in 1990 by the Salagnac Experimental Station of Haiti and has an indeterminate type III growth habit (Clermont-Dauphin et al., 2003). Several of the Mesoamerican small red and black lines in this study were developed in Honduras for adaptation to low soil P (Singh et al., 2001a,b; Rosas et al., 2004).

The experiment was conducted in two growing seasons: June 2007 and January 2008 in the same field. The agronomic performance of the bean lines were evaluated under three fertilization regimes: (i) 50 kg N/ha (+N), 57 kg P_2O_5/ha (+P), 54 kg K_2O/ha (+K); (ii) −N, +P and +K; and (iii) +N, −P and +K. The source of N, P and K were urea, triple superphosphate, and KCl, respectively. The experimental design was a split-plot arrangement of a randomized complete block (RCB) with five replications. The fertilization regimes were the whole plots and the bean breeding lines were the subplots. The experimental units were single rows, 4-m length that were spaced 0.6 m apart. All plots were inoculated with N-DURE® (INTX Microbials, LLC, Kentland, IN) containing 200×10^6 viable cells of *Rhizobium leguminosarum* biovar phaseoli per gram, at the rate of 5 kg/ha. In June 2007 planting, the total rainfall received for the season was 197 mm with a median air temperature of 26.3 °C, while in January 2008 planting, the total rainfall was 207 mm with a median air temperature of 21.8 °C. Supplemental irrigation was applied when needed to avoid drought stress and weeds were manually controlled.

At maturity, plants were harvested for seed yield. Seed yields were corrected to 12% moisture. The agronomic efficiency (AE) value is the additional yield obtained per unit of nutrient (nut) applied and was calculated using the yield in the plot with (Y_{nut}) and without ($Y_{-\text{nut}}$) the nutrient (N or P):

$$(\text{AE})_{\text{nut}} = \frac{Y_{\text{nut}} - Y_{-\text{nut}}}{\text{Nutrient applied}} \quad (1)$$

Higher AE values indicate that there was a greater response to the application of the nutrient (N or P). According to Dos Santos and Fageria (2007), a bean line with an AE greater than 12 is responsive, whereas a line with an AE lower than 12 can be considered non-responsive to the application of the nutrient. The utilization efficiency UE describes the ability of a bean line to extract nutrients from the soil and convert them into seed yield (Dos Santos and Fageria, 2007). Values of UE were calculated as the ratio of the line yield (kg/ha) without nutrient application ($Y_{-\text{nut}}$) and the extractable nutrient in soil (nut_{soil}, kg/ha). Soil NO_3-N and P were extracted as described previously and the values calculated are dependent on the methodology used to extract the nutrients.

$$(\text{UE})_{\text{nut}} = \frac{Y_{-\text{nut}}}{n_{\text{soil}}} \quad (2)$$

Lines with higher UE are considered more efficient in nutrient acquisition. A line with UE greater than 35 was considered efficient and one with UE lower than 35 was considered inefficient (Muurinen, 2007).

The relative yield (*RY*) is defined as the relationship between the seed yield obtained without fertilizer nutrient addition ($Y_{-\text{nut}}$) and the seed yield potential as (Loboski et al., 2008).

$$\text{RY} = \frac{Y_{-\text{nut}}}{Y_{\text{potential}}} \times 100 \quad (3)$$

The percentage of adaptability (Ad) measures the capacity of a line to adapt to several conditions (St-Pierre et al., 1967) and was