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Strategies for recommendation of common bean lines tested for value of cultivation and use in different environments

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ABSTRACT - *The purpose of this study was to develop strategies for the recommendation of common bean cultivars tested in VCU trials with regard to the performance of lines with different growth habits, at different fertilizer rates and sowing densities. It was found that the grain yield of lines is more affected by variations in fertilizer rates than of the sowing density; the response of the lines to higher planting density and fertilizer rate varies with the environment of evaluation and does not depend on the growth habit, the interactions between fertilizer rates and sowing densities were significant, demonstrating the importance of VCU trials with different fertilizer rates and sowing densities.*

Key words: *Phaseolus vulgaris* L., genotype - environment interaction, stability, fertilizer rates, sowing densities.

INTRODUCTION

Before a new common bean (*Phaseolus vulgaris* L.) line is recommended to farmers, it must be evaluated in trials testing the Value of Cultivation and Use (VCU). The Ministry of Agriculture, Livestock and Food Supply of Brazil (MAPA) requires that such experiments are conducted at least three locations per soil-climatic region that is relevant for the crop in each growing season (spring-summer, summer-autumn and autumn-winter) for a minimum period of two years (Brazil 1998).

A standard management system is used in such experiments, i.e., the row spacing, sowing density and fertilizer rates are invariable, based on the results of soil analysis. However, in the case of common bean, which can be cultivated all year long in the most diverse climate conditions, and above all, in view of the great diversity of management systems used by farmers, other environments could be included in the VCU trials. It was investigated whether changes in the management systems would alter the performance, particularly when lines with different growth habits are evaluated in the experiments (Stone and Pereira 1994, Shimada et al. 2000).

Aside from the different growth habits, the crop cycle is also highly variable. For plants with type-II growth habit higher sowing densities might be more

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suitable, and the nutrient requirements for earlier cultivars may differ.

It is therefore important that the recommendation of a line is coupled with information on the most recommended density and fertilizer. For this purpose, information could be obtained in the VCU trials using different management systems. This would not only produce the desired information, but the interactions involving these different management variables could be estimated as well.

The purpose of this study was to develop strategies for the recommendation of common bean cultivars tested in VCU trials with regard to the performance of lines with different growth habits, at different fertilizer rates and sowing densities.

MATERIAL AND METHODS

The experiments were conducted in six environments (growing seasons and locations) from November 2006 to February 2008. Nine experiments were conducted in each environment, resulting from combinations of three fertilizer rates and three sowing densities. Fertilizer rates of 0, 300 and 600 Kg ha^{-1} of N, P_2O_5 and K_2O compound fertilizer (8-28-16) were applied at sowing and 0, 100 and 200 Kg ha^{-1} ammonium sulfate as top dressing, 20 days after emergence. The sowing densities were 10, 15 and 20 seeds per meter. The main characteristics of the locations and growing seasons of the experiments are listed in Table 1 and the soil chemical properties in Table 2.

Eleven common bean lines were evaluated in these experiments (main traits in Table 3) in a randomized block design with three replications. Each plot consisted of three 3.0-m long rows, spaced 0.5 m apart in all experiments. Along the entire length of each row, 60 seeds were sown for a density of 10 plants m^{-1} and 90 seeds for densities of 15 and 20 seeds m^{-1}. Seven to ten days after emergence the seedlings were thinned to 30, 45 and 60 plants (densities of 10, 15 and 20 seeds m^{-1}, respectively) in each row.

The fertilizer rates at sowing as well as for top dressing (20 days after emergence) were applied by hand in all experiments. In the dry and winter growing seasons, sprinkler irrigation was used. The other cultural treatments in the three growing seasons were applied as recommended for the crop. The center row of each plot was harvested, the plants per row were counted and the grain yields calculated in kg ha^{-1}.

Prior to the analysis of variance of grain yield, analysis of variance was performed for the stand of each experiment. Since the effect of lines was not significant in most tests, it was decided to correct the stand to an ideal value for each sowing density, in all experiments, by analysis of covariance. Subsequently, the Hartley test was applied to verify the homogeneity of variance of errors prior to the joint analysis of variance of grain yield (kg ha^{-1}) involving the effects of environments (growing seasons and locations), fertilizer rates and sowing densities, using PROC GLM of SAS (SAS 2000). Using the sum of squares (SS) in the joint analysis, the contribution of each source of variation to total sum of square (R^2_f) was estimated be the expression:

$$R_f^2 = {SS_{source\ variation}}\Big/{SS_{total}}$$

The means of the lines were compared by the Scott-Knott test (1974). Based on the grain yield means (Kg ha^{-1}) of the lines evaluated in the different experiments, the stability and adaptability were analyzed by the graphical method (Nunes et al. 2005), using software SAS (SAS 2000).

Table 1. Main characteristics of the environments (growing seasons and locations) of the experiments

Locations	Growing season	Sowing	Latitude	Longitude	Altitude (m asl)
Lavras-MG DBI[1/]	Wet 2006/2007 Dry 2007 Winter 2007 Wet 2007/2008	November/2006 March/2007 July/2007 November/2007	21º14’ S	44º59’ W	919
Lavras-MG FAEPE[2/]	Wet 2006/2007	November/2006	21º12’ S	44º59’ W	951
Ijaci-MG	Dry 2007	March/2007	21º10’ S	44º75’ W	832

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[2/] Farm of FAEPE (Fundação de Amparo ao Ensino, Pesquisa e Extensão)

Table 2. Chemical analyses of soil samples from the 0-20 cm layer of experimental areas in Lavras-MG and Ijaci-MG, prior to the installation of the experiments[1/]

Chemical properties	Wet 2006/2007		Dry 2007		Winter2007	Wet 2007/2008
	LAVRAS MG DBI	LAVRAS MG FAEPE	LAVRAS MG DBI	IJACI MG	LAVRAS MG DBI	LAVRAS MG DBI
pH H_2O	5.0	6.2	5.5	5.2	6.0	5.4
P (mg dm^{-3})	38.9	2.5	20.0	24.9	11.5	30.9
K (mg dm^{-3})	67.0	184.0	86.0	108.0	56.0	78.0
Ca^{2+} ($cmol_c$ dm^{-3})	1.0	1.6	1.8	1.3	3.0	1.9
Mg^{2+} ($cmol_c$ dm^{-3})	0.3	0.6	0.7	0.4	0.9	0.7
Al^{3+} ($cmol_c$ dm^{-3})	0.7	0.1	0.0	0.3	0.0	0.1
H + Al ($cmol_c$ dm^{-3})	7.0	3.2	3.6	4.5	2.3	4.0
SB ($cmol_c$ dm^{-3})	1.5	2.7	2.7	2.0	4.0	2.8
t ($cmol_c$ dm^{-3})	2.2	2.8	2.7	2.3	4.0	2.9
T ($cmol_c$ dm^{-3})	8.5	5.9	6.3	6.5	6.3	6.8
V (%)	17.4	45.5	43.0	30.6	63.7	41.2
m (%)	32.0	4.0	0.0	13.0	0.0	3.0
OM (dag kg^{-1})	3.1	2.6	2.4	1.9	2.2	2.5
P-rem (mg L^{-1})	12.2	15.1	16.4	20.5	13.2	9.9
Zn (mg dm^{-3})	-[2/]	-	7.6	5.0	8.8	7.9
B (mg dm^{-3})	-	-	0.2	0.3	0.2	0.3
S (mg dm^{-3})	-	-	32.6	39.2	26.2	43.7

[1/] Analyses at the soil analysis laboratory of the Soil Science Department, UFLA
[2/] Element not stated in the soil analysis
SB : sum of bases; t : Effective cation exchange capacity ; T : Total cation exchange capacity V : base saturation
m : aluminum saturation; OM : organic matter

Table 3. Main characteristics of the common bean lines used in the experiments

Lines	Origin	Growth habit/	Grain color
BRS Radiante	EMBRAPA	I	beige with red stripes
CNFRJ 10564	EMBRAPA	I	beige with red stripes
IAPAR 81	IAPAR	II	beige with brown stripes
BRS Horizonte	EMBRAPA	II	beige with brown stripes
BRS Valente	EMBRAPA	II	black
BRS Supremo	EMBRAPA	II	black
Carioca MG	UFLA	II	beige with brown stripes
BRSMG Talismã	UFLA/UFV/EPAMIG/EMBRAPA	III	beige with brown stripes
Pérola	EMBRAPA	III	beige with brown stripes
Ouro Negro	Honduras	III	black
BRSMG Majestoso	UFLA/UFV/EPAMIG/EMBRAPA	III	beige with brown stripes

[1/] I- determinate growth , II- indeterminate growth with short vines, III- indeterminate growth with long vines

To apply the graphical method in each experiment the line means were standardized by the expression:

$$Z_{iq} = \frac{\overline{X}_{iq} - \overline{X}_{.q}}{s_{.q}}$$ where:

Z_{iq}: standardized value of the variable in line i in experiment q; $\overline{X}_{iq}$: mean of line i in experiment q; $\overline{X}_{.q}$: mean of the experiment q; $s_{.q}$: phenotypic standard deviation among the lines in experiment q.

Since the standardized variable can have positive or negative values, a constant was added to ensure that the Z_{iq} values are always positive to facilitate the graphical interpretation. The mean Z_{iq} values for line *i* in the experiments considered ($\bar{Z}_{i.}$) produce the measure of adaptation of line *i*. Estimates for Z_{iq} were subjected to analysis of variance and the mean values were grouped by the Scott-Knott cluster analysis (1974). Based on the standardized values (Z_{iq}) graphs were constructed for each line *i*. The dimensions of the axes (experiments) were equivalent to the Z_{iq} values of line *i* in experiment *q*. The coefficients of variation of Z_{iq} were computed for line *i* in the different experiments (CV_{iq}) and the confidence intervals of CV_{iq} estimated using the modified McKay expression suggested by Vangel (1996).

The confidence index in the adoption of the lines was estimated, i.e., the risk of planting a particular line was assessed. For this purpose the method proposed by Annichiarico (1992) was used, based on the mean line yield in the different experiments.

RESULTS AND DISCUSSION

Heterogeneity was observed in the variance of errors by the Hartley test. Six experiments were therefore excluded from the joint analysis. According to the combined analysis of variance, considering the 48 experiments, the experimental precision evaluated by the coefficient of variation (CV =17.7%) was satisfactory and the effect for all sources of variation was highly significant (P<0. 01) (Table 4).

The source of variation that contributed most to the total variation was the environment (growing season and location) with an estimated R^2_f of 18.14%. This marked contribution of the environment to total variation was expected, since it comprised, as mentioned before, the effects of locations and growing seasons. In regional studies of the last 30 years with common bean, a marked variation in grain yield was observed in different growing seasons and at different locations (Ramalho et al. 1998, Bruzi et al. 2007, Matos et al. 2007, Sena et al. 2008).

In the different growing seasons and locations where the experiments were conducted there was great variation in the conditions of temperature and rainfall, in the “wet”, “dry” and winter / spring growing seasons. Of the environmental effect, one of the most important factors is temperature, which influences the duration of the phenological phases, as well as determining grain yield since it influences the abortion of flowers, pods and grains (Didonet and Silva 2004). Water is also a limiting factor for the crop. Therefore, all experiments in the dry and winter/ spring growing seasons were irrigated. Another noteworthy factor is soil fertility. The fertility of the soils of the different experiments differed (Table 2).

Table 4. Combined analysis of variance of grain yield (Kg ha^{-1}) of 11 common bean lines with different growth habits, in six environments (locations and growing seasons), three fertilizer rates and three sowing densities and the estimated relative contribution to the total sum of squares (R^2_f) in (%)

Source of variation	df	MS	R^2_f (%)	Pr >F
Rep./exper.	96	422433.664	4.07	0.0001
Lines (L)	10	2010630.740	2.02	0.0001
Density (D)	2	7719037.198	1.55	0.0001
Fertilizer (F)	2	31469375.038	6.32	0.0001
Env. (season and location) (E)	5	36145275.419	18.14	0.0001
L x D	20	337837.443	0.68	0.0166
L x F	20	588892.152	1.18	0.0001
L x E	50	1301044.429	6.53	0.0001
D x F	4	8444857.470	3.39	0.0001
D x E	10	5408438.549	5.43	0.0001
F x E	10	4417675.745	4.43	0.0001
L x D x F	40	436133.202	1.75	0.0001
L x D x E	100	455579.334	4.57	0.0001
L x F x E	100	574348.371	5.76	0.0001
D x F x E	14	7237862.900	10.17	0.0001
L x D x F x E	140	423299.391	5.95	0.0001
Error	960	187475.524	18.06	-
CV (%)		17.67		
Mean (kg ha^{-1})		2449		

The contribution of the source plant densities (D) to the total sum of squares was only 1.55% and the interaction density x lines was 0.68% (Table 4). However, the contribution to the total sum of squares of the source of variation of fertilizer rates (F) was four times higher than of plant densities, indicating that in the mean, variations in fertilizer rates affect the grain yield of lines more than variations in sowing densities.

The interactions involving both the fertilizer rates as well as sowing densities were significant, indicating that the performances of lines in different densities or under different fertilizer rates were not coincident (Table 4). This information is essential for research of this nature. It shows that prior to the recommendation of a cultivar, it would be important to test different management systems (sowing densities and fertilizer rates) in the VCU trials, aside from the locations and growing seasons already required by the MAPA (Brazil 1998).

When choosing the lines to be used here, the most relevant trait was the growth habit. The objective was to compare cultivars with type I, II and III growth habit in different management systems and environments. The reason is that improvement programs have focused on the breeding of cultivars with erect, type I or type II growth habit, in view of to the numerous benefits, particularly compared to type III, such as: greater ease in cultural treatments; lower losses in case of rain during the harvest, lower disease incidence due to an improved aeration of the crop, and others (Collicchio et al. 1997, Cunha et al. 2005, Menezes Junior et al. 2008). However, it has been found that the yield potential cultivars of plants with this architecture may be lower (Didonet and Silva 2004). An alternative to improve this performance could be to increase the plant population and/or quantity of fertilizers, as verified by some authors in other conditions (Souza et al. 2003, Souza et al. 2008). However, the results showed that it is not possible to generalize recommendations, in other words, the response of the lines to higher planting densities and fertilizer rates varies according to the environment and is independent of the growth habit. This is most likely due to the marked interaction of lines with all other sources of variation, as pointed out above.

In the combined analysis (Table 4), considering all interactions, R^2_f was 49.84%, evidencing a high contribution to the total sum of squares. In view of the foregoing, it is clear that the line response is influenced by the environment (growing season and location), apart from the fertilizer rates and sowing densities. As mentioned above, this makes the interpretation of results and, consequently, the identification of the lines most adapted to the different conditions rather difficult. One way to mitigate the genotype-environment interaction to increase the reliability in cultivar recommendations, is the identification of most adapted and stable lines. Several methods have been proposed (Cruz and Carneiro 2003) for this purpose and have been widely used in the cultivation of common bean (Nunes et al. 2005, Bruzi et al. 2007, Matos et al. 2007, Sena et al. 2008). In principle, the methodology to be used should be the most easily analyzable and, particularly, most easily interpretable. For these reasons, the graphical method was chosen (Nunes et al. 2005). This method uses the coefficient of variation to identify the most stable line, although in the original study the CV_{zi} values had not been compared. The confidence interval of CV_{zi} was therefore estimated to compare these estimates in this study.

The line Ouro Negro, with the highest estimate, was the most adapted (Table 5). In terms of stability, due to the overlapping estimates of confidence intervals of CV_{zi} it was not possible to detect differences between lines. However, in 32 of the 48 experiments the yield of 'Ouro Negro ' was equal to or above the mean, and even in the 16 experiments in which the performance was lower, the cultivar was more productive than others with worse performance (Figure 1). The CV_{zi} should therefore be interpreted with caution and along with the graphical analysis, since the reason for a high CV_{zi} or instability of a line could be the fact that the yield is far above the mean in some environments.

Another criterion that has also been widely used by breeders to identify the most promising lines is the estimated risk of use, based on the methodology proposed by Annicchiarico (1992). To study the adaptability and stability of the lines in 48 experiments, in addition to the methodology proposed by Nunes et al. (2005), the risk of use of lines was therefore also estimated. This methodology showed that the risk use was lowest for Ouro Negro, since in the worst case, with 75% probability, the yield would be 3.97% below the mean of the environment. The low risk of use of line CNFRJ 10564, I_i = 92.92%, is also emphasized. A comparison with the diagram representing the lines Ouro

Negro and CNFRJ 10564 shows that in 32 and 29 of the 48 experiments, respectively, these lines had yields above the environmental mean (Figure 1), in agreement with the confidence index.

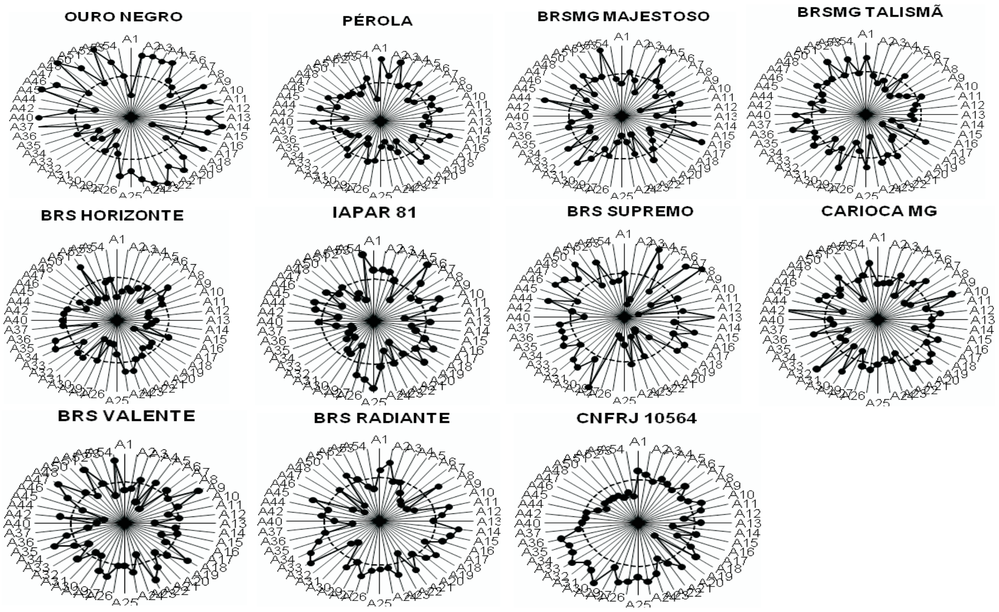
All lines, except CNFRJ 10564 with striped grains, are already recommended for planting (Ramalho and Abreu 2006). The good performance of cultivar Ouro Negro observed by other authors was confirmed (Borges et al. 2000, Nunes et al. 2005), although it has the disadvantage of a very prostrate growth habit. The analysis in 48 trials (Table 5) indicated the lines BRSMG Talismã and Carioca MG with carioca grain as high-performing. The growth of Carioca MG is upright, but the grain size below consumer standards and the beige color is darker (Ramalho and Abreu 2006). On the other hand, the market acceptance of color and grain size of BRSMG Talismã is satisfactory, despite the prostrate growth habit. Besides, it also stood out with good grain yields in the VCU trials in the state of Minas Gerais (Abreu et al. 2004).

Table 5. Mean grain yield (Kg ha^{-1}) of 11 common bean lines evaluated in 48 experiments, estimates of the standardized means ($\bar{Z}_{i.}$) and of the coefficients of variation (CV_{zi}) by the graphical method (Nunes et al. 2005) and the confidence index (I_i) as proposed by Annichiarico (1992)

Lines	Mean	I_i	$\bar{Z}_{i.}$	CV_{zi}(%)
Ouro Negro	2740a*	96.03	3.67a*	33.2 (27.2;42.8)$^{1/}$
Pérola	2407c	88.36	2.91c	27.8 (22.9;35.5)
BRSMG Majestoso	2333c	82.19	2.76c	33.0 (27.0;42.5)
BRSMG Talismã	2373c	88.19	2.86c	25.4 (20.9;32.3)
BRS Horizonte	2247d	82.47	2.56d	29.5 (24.2;37.8)
IAPAR 81	2407c	86.12	2.89c	33.1 (27.1;42.7)
BRS Supremo	2507b	86.31	3.10b	40.1 (32.6;52.5)
Carioca MG	2473b	89.23	3.06b	26.7 (22.0;34.1)
BRS Valente	2473b	88.11	3.04b	28.9 (23.8;37.0)
BRS Radiante	2467b	88.50	3.00b	29.5 (24.2;37.8)
CNFRJ 10564	2520b	92.92	3.15b	26.0(21.4;33.1)

*Means followed by the same letter in a column belong to the same group in the test of Scott-Knott at 5% error probability

$^{1/}$In brackets, the confidence interval of CV_{zi}



OURO NEGRO

PÉROLA

BRSMG MAJESTOSO

BRSMG TALISMÃ

BRS HORIZONTE

IAPAR 81

BRS SUPREMO

CARIOCA MG

BRS VALENTE

BRS RADIANTE

CNFRJ 10564

Figure 1. Diagram of the performance of 11 common bean lines with different growth habits, in 48 experiments in six environments (locations and growing seasons), three fertilizer rates and three sowing densities

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Estratégias para recomendação de linhagens de feijoeiro provenientes de VCU em diferentes ambientes

RESUMO - *O presente trabalho foi conduzido visando desenvolver estratégias para a recomendação de cultivares de feijoeiro provenientes do VCU a partir da avaliação do desempenho de linhagens de diferentes hábitos de crescimento, em diferentes doses de fertilizantes e densidades de semeadura. Verificou-se que: a variação nas doses de fertilizantes afeta mais a produtividade de grãos das linhagens que a variação nas densidades de semeadura; a resposta das linhagens ao aumento da densidade de semeadura e doses de fertilizantes varia com o ambiente em que são avaliadas e independem do hábito de crescimento das mesmas; as interações envolvendo as doses de fertilizantes e densidades de semeadura foram expressivas, mostrando que é importante realizar os VCU em diferentes doses de fertilizantes e densidades de semeadura.*

Palavras-chave: *Phaseolus vulgaris* L., interação genótipos x ambientes, estabilidade, doses de fertilizante, densidades de semeadura.

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