Vol. 15(1), pp. 1-7, January 2021
DOI: 10.5897/AJPS2020.2009
Article Number: 5E060BD65835
ISSN 1996-0824

http://www.academicjournals.org/AJPS

ACADEMIC JOURNALS
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African Journal of Plant Science

Full Length Research Paper

Association between agro-morphological traits in common bean under organic fertilization management in Brazil

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Received 2 May, 2020; Accepted 27 November, 2020

The objective of this work was to analyze the association between agro-morphological traits of the common bean cultivar "BRS Esplendor" under organic fertilization management. The experiment was implemented in the field, in a randomized block design, with three replications, in a split plot scheme, with two types of organic compounds (grass enriched with cattle manure and bean straw enriched with cattle manure) applied in six doses (0.0, 33.32, 66.65, 100.00, 133.32 and 166.65%). The control treatment comprised the recommended mineral fertilization. The characteristics include total number of pods, plant height and pod lengths are determinant to directly increase grain yield. The indirect determinant includes total weight of pods, total number of grains, plant height, root length and length of pods that had a positive effect with high magnitude on the characteristic total number of pods.

Key words: *Phaseolus vulgaris*, correlations, track analysis.

INTRODUCTION

Brazil is the world's leading producer of common beans (*Phaseolus vulgaris* L.), with production of 2.7 million tons and average productivity around 1,964 kg ha^{-1} in the 2019/2020 crop, and its cultivation was carried out in almost all regions of the country (CONAB, 2020). One of the options to leverage the stability of its commercialization is the aggregation of value to the grain, which can be desired with the use of the organic production system. Thus, the demand for this organically produced food has increased, even with values that are 30-40% higher than conventionally grown beans (Pereira et al., 2015).

The predominant bean cultivation system is conventional planting associated with the abusive use of nitrogen fertilizers in addition to pesticides; these factors influence the loss of soil quality, in addition to degradation by erosive processes (Ferreira et al., 2010). Darolt (2000) cited by Pereira et al. (2015) found that the barriers to organic cultivation is directly related to the lack of credit programs to finance such activity, in addition to the difficulties in marketing the products and the lack of technical information. Consequently, there is a need for examination that shows increased productivity and the expression of phenotypic characteristics. The variability in the expression of the results is essential for the success of the selection of phytotechnical characteristics and the breeder, with a focus on the main characteristic of economic importance (Cabral et al., 2010; Silva et al., 2008; Vieira et al., 2008 cited by Cabral et al., 2011).

With the use of appropriate statistical analysis, important information can be extracted for productivity gain; using trail analysis for yield and related components directly and indirectly. Hoogerheide et al. (2007) report that knowledge of the degree of this association, through correlation studies and trail analysis and possibilities identify characters that can be used as selection criteria for productivity. In addition, these analyses can be used for the selection of characters using different organic fertilizers via soil as treatments, favouring phytotechnists when performing similar work, avoiding waste of time and manpower.

In view of this context, Kurek et al. (2001) commented that path analysis is a tool that phytotechnist and improver has to understand the causes and effects involved in the combinations of characters and dissociate the correlation into direct and indirect effects, through a main variable. The trail analysis is used by several researchers in several crops of economic importance such as cotton (Hoogerheide et al., 2007), wheat (Vieira et al., 2007), beans (Kurek et al., 2001), and exotic forest species (Lorentz et al., 2006). This can be obtained from phenotypic, genotypic, environmental correlations, among others (Cruz and Carneiro, 2003); and phenotypic correlations are the most promising by phytotechnists and improver. Thus, the objective of this work was to analyze the associations between agro-morphological traits of the common bean cultivar "BRS Esplendor" under organic fertilization management.

MATERIALS AND METHODS

Study area

The experiment was conducted in the municipality of Campos dos Goytacazes, Rio de Janeiro State, Brazil (21°44'47'' S and 41°18'24'' W, and an average altitude of 10 m in relation to sea level). According to the Köppen climate classification, the climate of the Norte Fluminense region is classified as Aw, humid tropical climate, with rainy summer, dry winter and colder month temperature above 18°C.

Compost types

Two types of composts were formulated: the first based on elephant grass (*Pennisetum purpureum* Schum.) plus bovine manure and the second was based on bean straw with the addition of bovine manure. The materials used were dried for about 30 days in shade before being used in the composters. The windrow was installed in PESAGRO-RIO from June to September 2018, in a flat area protected from rain, sun and strong winds, with dimensions of 1.5 m^2. Each windrow was made by alternating layers of 20 (cm) in height of the bovine section (about 10 l) with grass or bean straw. During the production process of the compounds, the windrows were turned over and the temperature and humidity monitored, determining factors for the production of quality compost (Nunes, 2009). At the end of the composting process, a sample was taken for chemical analysis. The samples were ground and submitted to nitric-perchloric digestion in a digestor block. For the resulting extract, chemical characterization was performed to determine the nutrients content (Table 1), according to the methodologies described by Malavolta et al. (1997).

Soil

The soil of the experimental area is an Argissol, according to the Brazilian soil classification system (Santos et al., 2014). Ten simple soil samples were collected at PESAGRO - RIO, using a stainless probe and a depth of 0-20 cm. Composite samples, originated from the homogenization of simple samples were sent to the laboratory of the Federal Rural University of Rio de Janeiro (UFRRJ), in the municipality of Campos dos Goytacazes - RJ. The chemical characteristics of the soil were determined according to the methodology described by Teixeira et al. (2017). The results of the soil analysis of the experimental plot are shown in Table 2.

Experimental design

The experiment was implemented in the field, in a randomized

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Table 1. Chemical characterization of organic composts

Parameters	Elephant Grass and Dung	Bean Straw and Manure
pH (water)	6.9	7.5
N g / kg^{-1}	11.67	12.32
P_2O_5 g / kg^{-1}	8.87	9.57
K_2O g / kg^{-1}	7.01	9.53
Ca g / kg^{-1}	9.31	15.77
Mg g / kg^{-1}	4.37	4.7
C g / kg^{-1}	127.2	148.8
S g / kg^{-1}	2.02	1.19
Fe mg / kg^{-1}	14436	14496
Cu mg / kg^{-1}	26	40
Zn mg / kg^{-1}	276	276
Mn mg / kg^{-1}	480	456
B mg / kg^{-1}	37.95	80.42

pH = acidity; N = nitrogen; P_2O_5=phosphorus oxide; K_2O= potassium oxide; Ca = calcium; Mg = magnesium; C =organic carbon; S = sulfur; Fe = iron; Cu = copper; Zn = zinc; Mn = manganese; B = boron.

Table 2. Chemical attributes of the soil used in the study

Parameters	Soil
pH (water)	5.6
P mg dm^{-3}	7
K mg dm^{-3}	29
Ca cmol$_c$ dm^{-3}	2.2
Mg cmol$_c$ dm^{-3}	1.4
Al cmol$_c$ dm^{-3}	0.00
H+Al cmol$_c$ dm^{-3}	2.71
Na cmol$_c$ dm^{-3}	0.06
C %	1.24
N %	0.17
MO g dm^{-3}	2.1
SB cmol$_c$ dm^{-3}	3.7
T cmol$_c$ dm^{-3}	6.4
t cmol$_c$ dm^{-3}	3.7
m %	0.0
V %	57.9
Fe mg dm^{-3}	78
Cu mg dm^{-3}	1.0
Zn mg dm^{-3}	4.9
Mn mg dm^{-3}	12.6
S mg dm^{-3}	9.83
B mg dm^{-3}	0.80

pH= measurement of acidity and alkalinity (water); P= phosphorus (Extractor Mehlich 1); K= potassium; Ca= calcium; Mg= magnesium; Al= aluminum; H+Al=Hydrogen aluminum; Na = sodium; C = carbon; N = nitrogen; OM = organic matter; SB = sum of bases; T = CEC = cation exchange capacity; t = effective CEC; m = aluminum saturation; V = base saturation; Fe = iron; Cu = copper; Zn = zinc; Mn = manganese; S = sulfur; B = boron.

Table 3. Phenotypic (r_f) correlations related to agro - morphological characteristics of common beans in response to organic fertilization.

Variable	TNP	TWP	TNG	W100	PH	RL	SD	PW	PL	LAI
TNP	-	0.96	0.99	0.56	0.92	0.85	0.72	0.64	0.79	0.02
TWP			0.97	0.69	0.95	0.87	0.79	0.69	0.79	0.02
TNG				0.58	0.91	0.80	0.67	0.59	0.76	0.02
W100					0.64	0.61	0.55	0.67	0.43	0.07
PH						0.93	0.84	0.85	0.90	0.29
RL							0.96	0.88	0.90	0.18
SD								0.84	0.86	0.11
PW									0.85	0.54
PL										0.43
LAI										-

TNP - total number of pods; TWP - total weight of pods; TNG - total number of grains; W100 - weight of one hundred grains; PH - plant height; RL - root length; SD - stem diameter; PW - pod width; PL - pod length; LAI - leaf area index.

block design, with three replications, in a split plot scheme, with two types of organic compounds (grass enriched with cattle manure and bean straw enriched with cattle manure) applied in six doses (0.0, 33.32, 66.65, 100.00, 133.32 and 166.65%). The control treatment consisted of the mineral fertilizer recommended for the bean-producing region (Freire, 2013). The experimental plots contained 3 planting lines with 2 m linear each, being considered for evaluation; 1 m linear axis contains 10 plants.

The evaluated variables

The variables evaluated were: total number of pods (TNP), total number of grains (TNG), and total weight of pods (TWP) expressed in kg, obtained by means of precision electronic scale, performed in the useful area of the plot (10 plants). The other variables such as plant height (PH), root length (RL) and pod length (PL) were obtained using a ruler graduated in cm. For stem diameter (SD) and pod width (PW) (in mm) a digital pachymeter was been used. Leaf area index (LAI) was determined using AccuPAR (model 80) meter equipment configured in $m^2\ m^{-2}$ (Tewolde et al., 2005).

Pods were removed manually during harvest, then, their weight was determined on the same day, when they were collected as samples. Due to the difficulty in opening the pods on the same day of harvest, without damaging the seeds, it was preferred to wait four days at room temperature (25 to 30°C) and, after natural loss of moisture as pods began to open, the removal of seeds from the pods became easy.

Statistical analyses

Phenotypic correlation analyses were performed (r_f) through the following expressions: $r_F = \frac{PMG_{XY}}{\sqrt{QMG_X\, QMG_Y}}$. Where, PMG_{xy} = average product among genotypes for the characters of X and Y; QMG_x = square between genotypes for character X; QMG_y = square between genotypes for character Y. The trail analysis consisted of studying the direct and indirect effects of the explanatory variables mentioned above (X) on grain yield, the main dependent variable (Y). As Y is considered a complex feature, resulting from the combined action of other characteristics, the following model can be established: $Y = \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n + \varepsilon$, in that: $X_1, X_2, \ldots, X_n$ are the explanatory variables, and Y is the dependent variable. The direct and indirect effects of explanatory variables are estimated on the dependent variable. Like this, $r_{iy} = p_i + \sum_{j\neq 1}^{n} p_{ij}\, r_{ij}$ where: correlation between the dependent variable (Y) and the i-th explanatory variable; p_i: direct effect of the variable *i* on the dependent variable; and $p_j r_{ij}$: indirect effect of the variable *i* variable route *j*, about the dependent variable (Almeida et al., 2014; Cabral et al., 2011; Coimbra et al., 2000; Cruz and Carneiro, 2003; Dalla Corte et al., 2010).

RESULTS

Phenotypic correlation (r_f)

The estimates of phenotypic correlation coefficients (r_f) evaluated for agro-morphological traits are presented in Table 3. The magnitudes of phenotypic correlation (r_f) between the characters ranged from 0.02 for LAI characteristics correlated with TNP, TWP and TNG and 0.99 for the TNG characteristic correlated with TNP. With the exception for W100, all correlations of TWP, TNG, PH, RL, SD and PL characteristics had positive values with high magnitude. The correlation of these characteristics on TNP varied with magnitudes of 0.96, 0.99, 0.92, 0.85, 0.72 and 0.79, respectively. The LAI characteristic had correlation of mean magnitude only with the PW characteristic with 0.54. The PW characteristic showed a correlation of medium magnitude with the characteristics TNP, TWP, TNG and W100 with 0.64, 0.69, 0.59 and 0.67, respectively, and of high magnitude with the characteristics PH, RL and SD with 0.85, 0.88 and 0.84 in this order.

Phenotypic (r_f) track coefficients

In the trail analysis, phenotypic (r_f) correlation coefficients ranged from negative high values to high magnitude positive levels, including direct and indirect effects for all evaluated characteristics, respectively (Table 4). Investigating the positive direct effects of the primary components on productivity, the main variable, the

Table 4. Direct and indirect effects of agro - morphological variables of common bean in response to organic fertilization.

Variable	Effect	Via	Coefficients(r_f)	Variable	Effect	Via	Coefficients(r_f)
	Direct	GY	0.6687		Direct	GY	-0.0590
		TWP	0.1061			TNP	0.5702
		TNG	-0.8412			TWP	0.0964
		W100	0.2228			TNG	-0.6810
		ALT	1.0000			W100	0.2424
TNP	Indirect	RL	-0.0503	RL	Indirect	PH	1.0000
		SD	-0.4329			SD	-0.5743
		PW	-0.2178			PW	-0.3003
		PL	0.4071			PL	0.4615
		LAI	-0.0087			LAI	-0.0536
	Total		0.9666		**Total**		0.8258
	Direct	GY	0.1097		Direct	GY	-0.5944
		TNP	0.6466			TNP	0.4870
		TNG	-0.8245			TWP	0.0868
		W100	0.2725			TNG	-0.5728
		ALP	1.0000			W100	0.2180
TWP	Indirect	RL	-0.0518	SD	Indirect	PH	1.0000
		SD	-0.4703			RL	-0.0570
		PW	-0.2357			PW	-0.2855
		PL	0.4042			PL	0.4406
		LAI	-0.0060			LAI	-0.0329
	Total		0.9843		**Total**		0.7066
	Direct	GY	-0.8486		Direct	GY	-0.3379
		TNP	0.6629			TNP	0.4311
		TWP	0.1066			TWP	0.0766
		W100	0.2290			TNG	-0.5089
		PH	1.0000			W100	0.2664
TNG	Indirect	RL	-0.0473	PW	Indirect	PH	1.0000
		SD	-0.4012			RL	-0.0524
		PW	-0.2026			SD	-0.5022
		PL	0.3908			PL	0.4365
		LAI	-0.0073			LAI	-0.1620
	Total		0.9782		**Total**		0.6729
	Direct	GY	0.3943		Direct	GY	0.5114
		TNP	0.3778			TNP	0.5323
		TWP	0.0758			TWP	0.0867
		TNG	-0.4927			TNG	-0.6485
		PH	0.7749			W100	0.1704
W100	Indirect	RL	-0.0363	PL	Indirect	PH	1.0000
		SD	-0.3286			RL	-0.0532
		PW	-0.2283			SD	-0.5122
		PL	0.2209			PW	-0.2884
		LAI	-0.0211			LAI	-0.1278
	Total		0.7368		**Total**		0.75
	Direct	GY	1.0000		Direct	GY	-0.2971
		TNP	0.6213			TNP	0.0195
		TWP	0.1044			TWP	0.0022
PH	Indirect	TNG	-0.7767	LAI	Indirect	TNG	-0.0210
		W100	0.2551			W100	0.0281
		RL	-0.0553			PH	0.3498
		SD	-0.5046			RL	-0.0106

Table 4. Cont'd

	PW	-0.2894		SD	-0.0658
	PL	0.4608		PW	-0.1843
	LAI	-0.0867		PL	0.2200
Total		0.9267	**Total**		0.0408
	Coefficient of determination		1.0000		
	Effect of residual variable		0.00		

TNP - total number of pods; TWP - total weight of pods; TNG - total number of grains; GY - grain yield; W100 - weight of one hundred grains; PH - plant height; RL - root length; SD - stem diameter; PW - pod width; PL - pod length; LAI - leaf area index.

primary variables (TNP, PH and PL) presented the greatest effects, especially PH, which obtained maximum direct effect with (0.6687, 1.0000 and 0.5114 (r_f)) respectively. Indirect effects were relatively high, for some characteristics such as TWP, TNG, PH, RL and PL on the TNP variable of 0.6466, 0.6629, 0.6213, 0.5702 and 0.5323 (rf), respectively. This result is indicative of the feasibility of indirect selection to obtain gains in the character of greater primary importance. In general, all primary variables presented high values of indirect effect on the PH variable, ranging from 0.7749 to 1.00 (rf), except for the characteristic LAI.

DISCUSSION

Correlations between agro-morphological characters

According to Dalla Corte et al. (2010), higher grain yield was obtained with smaller seeds, through high and negative correlations between seed width and thickness. The maximum correlation between PL and TNG shows the strong relationship between them, and their importance for productivity, since larger pods tend to provide a greater number of grains (Table 3). According to Carvalho et al. (2003), there is a positive correlation between chlorophyll concentration with N content in leaves and grain yield in beans. In this sense, the strong correlation between SD and PW with RL suggests that larger roots tend to increase the crude sap content in xylem in transport to shoots, showing that the plant nutrition factor is determinant for the performance of these characteristics that have a strong association with grain yield.

Path analysis between agro-morphological characters

The selection for any secondary character has no value if its performance does not correlate with the primary character (Coimbra et al., 2000). Also, according to Coimbra et al. (2000), the characters number of vegetables per plant and mass of one thousand grains showed a high degree of association with grain yield. The greater direct effect (rf) of PH on productivity is a complement that the increase in production has cause and effect relationship with the variable pod weight (Santos et al., 2014). The TNP and the PL are determinants for the increase in grain yield, since they presented positive direct effect values and high magnitude with GY (Table 4). According to Coelho et al. (2002), the number of pods per plant showed a high correlation with grain yield in the summer-autumn season. According to Ribeiro et al. (2016), the direct effects of phenotypic correlations indicate the true association between architecture and precocity of grain production.

The coefficient of determination was similar to that found by Almeida et al. (2014), when concluding that the number of pods per plant, and the number of grains per pod had a greater direct effect on yield. Higher PL indicates that the number of grains will be higher, possibly with lower thickness within the pods, which contributes to the increase in productivity. On the other hand, with lower PL, the number of grains for the plant will invest photoassimilates, making it possible to obtain larger grains (Table 4). According to Moura et al. (2012) the number of grains per pod correlates positively with grain yield, but the negative correlation between number of grains per pod, protein content and iron content suggests that the increase in the number of grains per pod decreases the protein and iron content in the grains. It is observed that the TNG characteristic negatively influences GY directly. According to Correa et al. (2015), the mass of five pods and the number of grains per pod are the components that contribute most to the production of grains in cowpea, surpassing the mass of one hundred grains. Both the number of grains and pod per plant and the number of grains per pod should be prioritized in indirect selection, since they have a higher genetic correlation with grain yield (Ribeiro et al., 2001). The negative direct effects of SD, PW, RL with GY characteristics suggest that the increase in productivity can be obtained by indirect selection with the characteristics TNP and PH, respectively.

Although the total coefficient (r_f) showed high magnitude, it was observed that there was no direct effect of the W100 variable with GY. The indirect effect via positive PH and high magnitude should be considered for the increase in productivity. A direct negative effect with yield was expected with this characteristic as an important aspect for the increase in grain yield, since smaller grains would be obtained. The selection of plants with larger grains causes a decrease in yield, considering that the average weight of the grains presents a negative correlation with the production (Coelho et al., 2002). The increase in productivity can also be obtained by indirect correlation of TWP and TNG characteristics both with TNP and PH, respectively. The selection based on grains of higher weight consequently leads to reduction in grain yield; and the number of pod/plants is the greatest contribution to higher yield (Kurek et al., 2001).

Conclusion

The associations between agro-morphological characters show that TNP, PH and PL are determinant to directly increase grain yield. Indirectly, there was gain in the characteristics, TWP, TNG, RL and PL, that had positive effect and with high magnitude on the characteristics, TNP and PH.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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