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TECHNICAL NOTE

LINEAR RELATIONS AMONG TRAITS IN JACK BEAN (*Canavalia ensiformis*)

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ABSTRACT

The study of the linear relations between plant characteristics is important to identify traits for indirect selection of plants with large fresh and dry matter production. The objectives of this research were to evaluatethe linear relations amongtraits of jack bean (*Canavalia ensiformis*) and identify traitsfor indirect selection. In experimental area of 160 m^2, 194 plants were collected randomly at 202 days after sowing. The traits plant height, stem diameter, number of nodes, number of leaves, number of pods, fresh matter of pods, fresh matter of aerial part without pods, fresh matter of aerial part, dry matter of pods, dry matter of aerial part without pods and dry matter of aerial part were measured in each plant. The mean and coefficient of variation were calculated for each trait. The linear relations among the traits were studied through correlation and path analyzes. The number of pods showed to have positive linear relation with fresh and dry matter of pods. The number of leaves has positive linear relation with fresh and dry matter of aerial part without pods and with fresh and dry matter of aerial part. It is concluded that the number of pods and leaves can be used for indirect selection of jack bean plants.
Additional key words: *Canavalia ensiformis*, correlation, path analysis, indirect selection

RESUMEN

Relaciones lineales entre caracteres de la planta de frijol de cerdo (*Canavalia ensiformis*)

El estudio de las relaciones lineales entre características de las plantas es importante para identificar rasgos que permitan la selección indirecta de aquellas con mayor producción de masa fresca y seca. Los objetivos de este trabajo fueron evaluar las relaciones lineales entre caracteres de frijol de cerdo (*Canavalia ensiformis*) e identificar caracteres para la selección indirecta. En un área experimental de 160 m^2, a los 202 días después de la siembra, se seleccionaron, al azar, 194 plantas. En cada planta se midieron los caracteres altura de planta, diámetro del tallo, número de nudos, número de hojas, número de vainas, masa fresca de vainas, masa fresca de parte aérea sin vainas, masa fresca de parte aérea, masa seca de vainas, masa seca de parte aérea sin vainas y masa seca de parte aérea. Para cada carácter se calculó la media y el coeficiente de variación. Se investigó la relación lineal entre los caracteres por medio de análisis de correlación y de trayectoria (path analysis). El número de vainas mostró relación lineal positiva con la masa fresca y seca de vainas. El número de hojas presentó relación lineal positiva con la masa fresca y seca de la parte aérea sin vainas y con la masa fresca y seca de la parte aérea. Se concluye que el número de vainas y de hojas se puede utilizar para la selección indirecta del frijol de cerdo.
Palabras clave adicionales: *Canavalia ensiformis*, correlación, análisis de trayectoria, selección indirecta

INTRODUCTION

Research with soil cover crops such as jack bean (*Canavalia ensiformis*) has demonstrated its importance in biomass production, soil covering rate, and nutrient accumulation (Cavalcante et al.,

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2012; Carvalho et al., 2013; Duarte et al., 2013).In plant breeding of soil cover crops, it is important to select plants with highest production of fresh and dry matter. In direct selection, the plant destruction is necessary to measure these traits. However, traits such as plant height, stem diameter, number of nodes, number of leaves, and number of pods can be measured non-destructively. These traits may or may not be linearly related with fresh and dry matter. If there are linear relations among these traits with fresh and dry matter it is possible to select indirectly without destroying the plants.

The Pearson's linear correlation coefficient (r) is appropriate for measuring the degree of relation among two traits, and Lenkala et al. (2015) utilized correlation coefficients to identify associations among jack bean traits. On the other hand, path analysis provides information about the interrelations among traits and is appropriate in the study of more than two traits, i.e., a dependent trait (main) in function of several independent traits (explanatories). In path analysis, the correlation coefficients are unfolded into direct and indirect effects, which makes possible to measure the influence of one variable on another independently of the others, i.e., enabling the study of the interrelationships between traits, unlike the Pearson's correlation that involves only two traits. Thus, it is important to apply these statistical procedures to identify cause and effect relations among traits. Traits with cause and effect relation can be used for indirect selection of plants.

Linear relations researches among traits of forage turnip (*Raphanus sativus* L.) and white lupine (*Lupinus albus* L.) indicated that the stem diameter and the number of pods per plant, respectively, have a positive linear relation with fresh and dry matter and it can be used for indirect selection of plants (Cargnelutti Filho et al., 2014). In black oat (*Avena strigosa*) Cargnelutti Filho et al. (2015) concluded that the number of leaves per plant and plant height are positively correlated with fresh and dry matter and can be used for indirect selection.

In 15 jack bean genotypes, Lenkala et al. (2015) found that it is possible to early select plants with largest number, length and mass of pods in order to have higher pods production. However, linear relations studies between the traits plant height, stem diameter, number of nodes, number of leaves, and number of pods with fresh and dry matter in jack bean were not found in the literature. It is supposed that these linear relations exist and that it is possible to use traits for indirect selection of plants with larger fresh and dry matter production. Thus, the objectives of this research were to evaluatethe linear relations amongtraits of jack bean and identifytraitsfor its indirect selection.

MATERIALS AND METHODS

An uniformity trial (experiment without treatments, in which the crop and all procedures performed during the experiment are homogeneous in the experimental area) was conducted with jack bean, cultivar Comum (Mapa, 2004), in experimental area 10m×16m located at 29º42'S, 53º49'W, with 95 m altitude. According to Köppen classification, the climate is subtropical humid, with warm summers and without dry season defined (Heldwein et al., 2009). The soil is classified as ‘Argissolo Vermelho distrófico arênico’ (Santos et al., 2013). A basic fertilization of 40, 150 and 100 $kg \cdot ha^{-1}$of N, $P_2O_5$and K_2O, respectively, was carried out on November 12, 2010. A row sowing was performed at the same day using 0.5m between rows and 0.125m between seeds in the row, totaling 16 $seeds \cdot m^{-2}$. Seeds with 99 % of purity and 70 % of germination were utilized.

There were 194 plants randomly selected in the experimental area on June 2nd, 2011 (202 days after sowing). The plants were in the grain maturation stage at this time. The plants were cut at the soil surface. Thereupon, the plant height (PH) and the stem diameter below the first node (SD) of each plant were measured. Also, the number of nodes on the main stem (NN), number of leaves (NL), and number of pods (NP) were counted. In each plant the pods were removed. The fresh matter of pods (FMP) and aerial part without pods (FMAPWP) were obtained by weighing, and the fresh matter of aerial part obtained by FMAP=FMP+FMAPWP. After drying in an oven, the dry matter of pods (DMP), aerial part without pods (DMAPWP), and the aerial part (DMAP=DMP+DMAPWP) were obtained. At harvest time, the number of plants was counted in three rows of 12.5 m randomly taken in the experimental area and obtained the density of 110,933 plants·ha^{-1}.

The mean and coefficient of variation of each trait were estimated with the data of 194 plants. The Pearson's linear correlation coefficient matrix was estimated between the traits for the study of linear relations, and the significance of r was verified through the Student's t-test. Following, a multicollinearity diagnosis (Cruz & Carneiro, 2003) was performed in the correlation matrix among PH, SD, NN, NL, and NP traits. The condition number (CN=λmax / λmin), which is obtained by the ratio between the maximum (λmax) and minimum (λmin) eigenvalue of the correlation matrix, was used to interpret the diagnostic of multicollinearity. It was considered low multicollinearity when the condition number was < 100, moderate to severe multicollinearity when 100 ≤ condition number ≤ 1,000, and severe multicollinearity when the condition number > 1,000, according to criteria of Montgomery & Peck (1982).

Thus, the path analyzes were conducted with each main traits (FMP, FMAPWP, FMAP, DMP, DMAPWP, and DMAP) in function of all explanatory traits (PH, SD, NN, NL, and NP), totaling six path analysis. The statistical analyzes were performed using Microsoft Office Excel and Genes software (Cruz, 2013).

The quantification of fresh and/or dry matter is usually done in research with soil cover crops such as jack bean (Cavalcante et al., 2012; Carvalho et al., 2013; Duarte et al., 2013).Those traits may show the cover crop potential as they influence the soil conditions and growth of following crops. Although a high association exists between the traits of fresh and dry matter (Cargnelutti Filho et al., 2014; Cargnelutti Filho et al., 2015), in this paper we used both of them as independent main traits under the assumption that they may add replications to the analysis and power the conclusions. The same consideration applies in the case of the summation of individual traits.

RESULTS AND DISCUSSION

The means of the traits (Table 1) showed adequate development of the crop. The coefficient of variation (CV) of 11 traits ranged from 19.04 % for the PH to 109.06 % for DMP, with average of 69.64 %. This variability may be explained by external conditions and possible genetic effects of the seeds from the S2 category (Mapa, 2004). Based on appropriate development of plants and in wide variability of the database allied to the large number of plants (194 plants), it can be inferred that this database provides credibility to the study of linear relations among these traits, through correlation and path analyzes.

Table 1. Mean, coefficient of variation (CV) and estimates of the Pearson's linear correlation coefficients among traits measured in 194 plants of jack bean (*Canavalia ensiformis*).

Trait[(1)]	Mean	CV (%)	Pearson's linear correlation coefficients[(2)]										
			PH	SD	NN	NL	NP	FMP	FMAPWP	FMAP	DMP	DMAPWP	DMAP
PH	132.51	19.04	1										
SD	13.49	25.17	0.559	1									
NN	23.18	20.89	0.836	0.560	1								
NL	28.51	95.65	0.448	0.662	0.439	1							
NP	1.72	91.31	0.114	0.204	0.173	-0.131	1						
FMP	55.39	106.32	0.174	0.249	0.236	-0.035	0.822	1					
FMAPWP	290.87	84.14	0.485	0.770	0.475	0.957	-0.067	0.032	1				
FMAP	346.26	73.23	0.508	0.801	0.513	0.915	0.127	0.263	0.973	1			
DMP	23.54	109.06	0.126	0.196	0.184	-0.211	0.835	0.789	-0.141	0.047	1		
DMAPWP	85.81	78.07	0.507	0.781	0.494	0.954	-0.032	0.051	0.993	0.971	-0.111	1	
DMAP	109.35	63.12	0.539	0.831	0.547	0.847	0.280	0.343	0.912	0.960	0.264	0.929	1

[(1)]PH - plant height, in cm; SD - stem diameter, in mm; NN - number of nodes on the main stem; NL - number of leaves; NP - number of pods; FMP - fresh matter of pods, in g·plant^{-1}; FMAPWP - fresh matter of aerial part without pods, in g·plant^{-1}; FMAP - fresh matter of aerial part, in g·plant^{-1}; DMP - dry matter of pods, in g·plant^{-1}; DMAPWP - dry matter of aerial part without pods, in g·plant^{-1}; DMAP - dry matter of aerial part, in g·plant^{-1}. [(2)]Correlation coefficients ≥ |0,18| are significant at 1 % of probability for the Student's t-test with 192 degrees of freedom.

The jack bean reached fresh and dry matter of 346.26 g·plant^{-1} (38.41 Mg·ha^{-1}) and 109.35 g·plant^{-1} (12.13 Mg·ha^{-1}), respectively (Table 1). These results are higher than those found by Cavalcanti (2011) and Cavalcante et al. (2012).

The FMP and DMP showed higher degree of linear association (greater r magnitude) with NP [average r = (0.822+0.835)/2 = 0.829], when compared to SD (average r = 0.222), NN (average r = 0.210), PH (average r = 0,150) and NL (average r = -0.123) (Table 1). This indicates that the NP would be most strongly associated with fresh and dry matter of jack bean pods. Therefore, it can be inferred that jack bean plants with larger number of pods also exhibit greater fresh and dry matter of pods. According to Lenkala et al. (2015), the production of pods per plant has a negative correlation with the number of days to 50 % flowering; the authors also observed high pod yield heritability and other production components of the jack bean.

The correlation coefficient of the NP with FMAPWP, FMAP, DMAPWP, and DMAP traits were not significant or significant with low magnitude (r = 0.280) (Table 1). Thereby, generally, it can be inferred the absence of linear relations between the number of pods with these traits.

The linear association of PH with FMAPWP, FMAP, DMAPWP, and DMAP traits presented low magnitude r values, i.e., between 0.485 and 0.539 (Table 1). In the study conducted by Lenkala et al. (2015), it was also found positive association of low magnitude between plant height with number and matter of pods per plant. Insomuch, it can be inferred that jack bean plants with greater height exhibit greater fresh and dry matter of aerial part without pods and greater fresh and dry matter of aerial part. Linear association with similar magnitude, i.e., between 0.475 and 0.547 was observed when comparing NN and FMAPWP, FMAP, DMAPWP, and DMAP traits. This signifies that jack bean plants with greater number of nodes presented greater fresh and dry matter of aerial part without pods and greater fresh and dry matter of aerial part.

Intermediate magnitude of linear association was observed regarding to SD and FMAPWP, FMAP, DMAPWP, and DMAP traits ($0.770 \leq r \leq 0.831$). This indicates that plants with greater stem diameter have greater fresh and dry matter of aerial part without pods and greater fresh and dry matter of aerial part. Moreover, linear association with greater magnitude was observed between NL and FMAPWP, FMAP, DMAPWP, and DMAP traits ($0.847 \leq r \leq 0.957$), indicating that plants with more leaves also have greater fresh and dry matter of aerial part without pods and greater fresh and dry matter of aerial part.

As mentioned, the FMP and DMP traits showed a greater linear positive association degree with NP and FMAPWP, FMAP, DMAPWP, and DMAP traits with NL (Table 1), which suggests that NP and NL could be used for indirect selection of plants. This linearity pattern is important for the traits identification towards indirect selection. However, it is not possible to infer which of the five explanatory traits studied has direct effect on the six main traits only through the correlation coefficients. Therefore, the path analysis is an appropriate procedure to indicate the true cause and effect relations among traits (Cruz & Carneiro, 2003; Cruz, 2013).

The multicollinearity diagnosis in the Pearson's linear correlation coefficient matrix between the explanatory traits revealed a condition number of 17.16 (Table 2). Therefore, the matrix showed low multicollinearity, according to criteria of Montgomery & Peck (1982). Thereby, it can be infer that path analyzes of the main traits of jack bean, in function of the studied explanatory traits were carried out in appropriate conditions.

The Pearson's linear correlation coefficients between the PH, SD, NN, and NL traits with fresh and dry matter of pods (FMP and DMP) showed low magnitude ($r \leq |0.249|$) and the direct effects were reduced (direct effect $\leq |-0.2578|$), which indicates absence of linear relation of cause and effect between traits. Conversely, high magnitude linear association was observed between the NP and FMP (r = 0.822) and NP and DMP (r= 0.835) with direct effects of 0.8052 and 0.7537, respectively (Table 2). Therefore, as r and direct effect had the same sign and similar magnitude, it can be inferred that the number of pods have positive relation with the fresh and dry matter of pods and it can be used for indirect selection. The high magnitude linear association (r = 0.789) between the FMP and DMP traits (Table 1) explains the similar results of these two path analyzes (Table 2).

The Pearson's linear correlation coefficients between the NP with the FMAPWP, FMAP, DMAPWP, and DMAP traits were with low magnitude (r ≤ |0.280|) and the direct effects were reduced (direct effect ≤ |0.2994|), which confirms the absence of linear relation of cause and effect.

The traits PH, SD, and NN showed a positive linear correlation (0.475 ≤ r ≤ 0.831) with the traits FMAPWP, FMAP, DMAPWP, and DMAP. However, direct effects of PH, SD, and NN (direct effect ≤ |0.3107|) on these four traits were reduced and/or inferior magnitude to r. Therefore, the association is explained by higher indirect effects via NL (0.2922 ≤ indirect effect ≤ 0.5237) (Table 2).

Table 2. Estimates of the direct and indirect effects (path analysis) of the traits plant height (PH), stem diameter (SD), number of nodes on the main stem (NN), number of leaves (NL), and number of pods (NP) on fresh matter of pods (FMP), fresh matter of aerial part without pods (FMAPWP), fresh matter of aerial part (FMAP), dry matter of pods (DMP), dry matter of aerial part without pods (DMAPWP), and dry matter of aerial part (DMAP), measured at 202 days after sowing in 194 plants of jack bean (*Canavalia ensiformis*).

Effect	Main traits					
	FMP	FMAPWP	FMAP	DMP	DMAPWP	DMAP
Direct of PH on	-0.0135	-0.0008	-0.0040	0.0007	0.0260	0.0255
Indirect of PH via SD	0.0190	0.1437	0.1431	0.0971	0.1416	0.1736
Indirect of PH via NN	0.0683	-0.0113	0.0050	0.0576	-0.0149	0.0070
Indirect of PH via NL	0.0080	0.3548	0.3443	-0.1156	0.3519	0.2985
Indirect of PH via NP	0.0919	-0.0015	0.0199	0.0861	0.0022	0.0342
Pearson correlation (r)	0.1738ns	0.4849*	0.5084*	0.1258ns	0.5068*	0.5387*
Direct of SD on	0.0341	0.2572	0.2562	0.1738	0.2535	0.3107
Indirect of SD via PH	-0.0075	-0.0005	-0.0022	0.0004	0.0145	0.0142
Indirect of SD via NN	0.0458	-0.0076	0.0033	0.0386	-0.0100	0.0047
Indirect of SD via NL	0.0119	0.5237	0.5082	-0.1707	0.5194	0.4406
Indirect of SD via NP	0.1645	-0.0027	0.0356	0.1540	0.0040	0.0612
Pearson's correlation (r)	0.2487*	0.7702*	0.8011*	0.1961*	0.7814*	0.8314*
Direct of NN on	0.0817	-0.0135	0.0059	0.0690	-0.0178	0.0083
Indirect of NN via PH	-0.0113	-0.0007	-0.0033	0.0005	0.0217	0.0213
Indirect of NN via SD	0.0191	0.1440	0.1435	0.0973	0.1419	0.1740
Indirect of NN via NL	0.0079	0.3472	0.3370	-0.1132	0.3444	0.2922
Indirect of NN via NP	0.1391	-0.0023	0.0301	0.1301	0.0034	0.0517
Pearson's correlation (r)	0.2365*	0.4748*	0.5132*	0.1838*	0.4936*	0.5474*
Direct of NL on	0.0179	0.7912	0.7679	-0.2578	0.7847	0.6657
Indirect of NL via PH	-0.0061	-0.0004	-0.0018	0.0003	0.0116	0.0114
Indirect of NL via SD	0.0225	0.1703	0.1696	0.1150	0.1678	0.2056
Indirect of NL via NN	0.0359	-0.0059	0.0026	0.0303	-0.0078	0.0037
Indirect of NL via NP	-0.1055	0.0017	-0.0228	-0.0987	-0.0026	-0.0392
Pearson's correlation (r)	-0.0352ns	0.9569*	0.9154*	-0.2110*	0.9538*	0.8472*
Direct of NP on	0.8052	-0.0131	0.1744	0.7537	0.0196	0.2994
Indirect of NP via PH	-0.0015	-0.0001	-0.0005	0.0001	0.0030	0.0029
Indirect of NP via SD	0.0070	0.0526	0.0523	0.0355	0.0518	0.0635
Indirect of NP via NN	0.0141	-0.0023	0.0010	0.0119	-0.0031	0.0014
Indirect of NP via NL	-0.0024	-0.1037	-0.1006	0.0338	-0.1028	-0.0872
Pearson's correlation (r)	0.8224*	-0.0666ns	0.1267ns	0.8349*	-0.0315ns	0.2800*
Coefficient of determination	0.6870	0.9492	0.9313	0.7305	0.9503	0.9244
Residual variable	0.5594	0.2253	0.2622	0.5191	0.2229	0.2749
Condition number	17.16	17.16	17.16	17.16	17.16	17.16

* Significant at 1 % of probability for the Student's t-test with 192 degrees of freedom. ns: non significant.

The NL showed a positive linear correlation (0.847 ≤ r ≤ 0.957) with the four traits (FMAPWP, FMAP, DMAPWP, and DMAP) and direct effect (0.6657 ≤ direct effect ≤ 0.7912) with the same sign and similar magnitude, confirming cause and effect relation between NL and FMAPWP, FMAP, DMAPWP, and DMAP traits. Thus, it can be inferred that the number of leaves has positive linear relation with fresh and dry matter of aerial part without pods and with fresh and dry matter of aerial part and it can be used for indirect selection.

The high linear association between the traits FMAPWP, FMAP, DMAPWP, and DMAP ($0.912 \leq r \leq 0.993$) (Table 1) explains the similar results of these four path analyzes (Table 2).

In practice, it can be inferred that the number of pods and leaves can be used for indirect selection of plants with greater production of fresh and dry matter. It is possible that plants with higher number of pods and leaves has developed better and, consequently, are plants with greater production of fresh and dry matter. The fact of not destroying the plants to count the number of pods and leaves is advantageous because it allows keeping the plants until seed production.

CONCLUSIONS

In jack bean, the number of pods has positive linear relation with fresh and dry matter of pods. The number of leaves has positive linear relation with fresh and dry matter of aerial part without pods and with fresh and dry matter of aerial part. The number of pods and leaves can be used for indirect selection.

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