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Article

Linear relations among pigeon pea traits

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Abstract

The objective of this research was to evaluate the linear relations among pigeon pea (*Cajanus cajan* (L.) Millsp.), cultivar BRS Mandarim, traits and identify the ones applied for indirect selection. Two uniformity experiments were carried out, in an experimental area located 29°42'S, 53°49'W and with 95m of altitude, selecting 360 plants per experiment, totaling 720 plants. For each plant, the number of nodes was counted and the height and stem diameter were measured, for ten evaluation times (62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 days after sowing - DAS) in the first experiment and 18 times (44, 51, 58, 65, 72, 79, 86, 93, 100, 107, 114, 120, 128, 135, 141, 148, 156 and 162 DAS) in the second experiment. During plant flowering, i.e. the 125 DAS in the first experiment and 162 DAS in the second experiment, the fresh and dry mass for each plant was obtained. The sigmoidal model was adjusted and it was studied the relations among the traits through correlation and path analysis. In the pigeon pea crop, the stem diameter has a positive and linear relation with the fresh and dry mass and it can be used for indirect selection.

Keywords: path analysis, *Cajanus cajan*, correlation.

Introduction

The pigeon pea (*Cajanus cajan* (L.) Millsp.) is tolerant to water deficit, can be helpful in recovering degraded areas and in soil fertility maintenance (Azevedo et al., 2007; Singh et al., 2013), being also used as a cover crop (Suzuki & Alves, 2006). In addition, it is a source of protein (Castilho et al., 2010; Chaithanya et al., 2014) and can be used on human and animal feeding (Azevedo et al., 2007).

In cover crops, such as pigeon pea, it is important to obtain plants with high production of fresh and dry masses. For the direct selection of plants with higher fresh and dry masses, in flowering, it is necessary to destroy the plants for the masses quantification.

However, characters such as the number of nodes per plant, plant height and stem diameter, besides being non-destructively measures, can be evaluated at different evaluation times, before flowering. Existing linear relationships between these characters and the fresh and dry masses, it is possible the indirect selection and at an early stage.

Linear relations between characters can be investigated using Pearson's linear correlation coefficient (r), and then the correlation of direct and indirect effects of explanatory characters on the main character via path analysis (Cruz, 2013). Thus, it is important to apply these statistical

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procedures to identify the cause and effect relation characters that can be used in the plants indirect selection.

Grain yield has been used as the main variable in path analysis with pigeon pea (Vange & Moses, 2009; Devi et al., 2012; Birhan et al., 2013; Singh et al., 2013; Chaithanya et al., 2014), crambe (Cargnelutti Filho et al., 2010) and sunflower (Amorim et al., 2008; Martin et al., 2012) traits.

In other studies of linear relations between characteristics, the fresh and/or dry masses have been used as main variable in the forage turnip and white lupine (Cargnelutti Filho et al., 2014), black oat (Cargnelutti Filho et al., 2006), elephant grass (Silva et al., 2008; Menezes et al., 2014) and *Brachiaria ruziziensis* (Borges et al., 2011). In general, the studies evidenced the possibility of the use of traits for indirect selection fresh mass, dry mass and grain yield.

It was not found in literature studies of linear relations between morphological characters and the fresh and dry masses in pigeon pea. It is assumed that these linear relations exist and can be used for the indirect selection of plants with higher fresh and dry masses. Thus, the objective of this study was to evaluate the linear relations between pigeon pea traits and to identify characters for indirect selection.

Material and Methods

Two experiments of uniformity were conducted with *Cajanus cajan* (L.) Millsp., Cultivar BRS Mandarim, in an experimental area of 28 m × 66 m (1,848 m^2) of the Plant Sciences Department of the Federal University of Santa Maria, Santa Maria, Rio Grande do Sul State, Brazil, at 29°42'S, 53°49'W and at 95m of altitude.

According to Köppen´s classification, the climate of the region is Cfa type, subtropical humid, with hot summers and no defined dry season (Heldwein et al., 2009) and the soil is classified as an arsenic red dystrophic argisol (Santos et al., 2006).

For the first uniformity trial, the pigeon pea seeds (2011/2012 crop year), were seeded on January 26th, 2012 and emerged on January 31st, 2012. For the second uniformity trial (2012/2013 crop year), in the same experimental area of the previous year, the seeds were sowed on November 20th, 2012 in rows spaced 0.50 m, with plants emergence on December 1st, 2012. In the two uniformity tials, the base fertilization was 40 kg ha^{-1} of N, 160 kg ha^{-1} of P_2O_5 and 160 kg ha^{-1} of K_2O and the seeding density was 20 seeds m^{-2}.

The obtained density during crop flowering was 116,889 and 120,118 plants ha^{-1}, respectively for the 2011/2012 and 2012/2013 crop year. All crop establishment and management (soil preparation, sowing, fertilization, treatments, evaluations and harvests) were carried out in a similar way throughout the experimental area, in the two growing seasons. The same procedures in the experimental area are recommended for the uniformity trials, according to Storck et al. (2011).

In the central area of each trial a grid of 2 m × 2 m (4 m^2) was marked with stakes, forming a matrix of 30 rows and 12 columns (1,440 m^2). For evaluations, the plant closest to each stake was selected, totaling 360 marked plants.

During the 2011/2012 crop year were evaluated the number of nodes per plant (NN) in the main stem, the plant height (PH) in cm and the stem diameter (SD) 5 cm above the soil level in mm, in ten evaluation periods (62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 days after sowing-DAS).

During the 2012/2013 crop year the same variables were evaluated (NN, PH and SD) in 360 plants in 18 evaluation times (44, 51, 58, 65, 72, 79, 86, 93, 100, 107, 114, 120, 128, 135, 141, 148, 156 and 162 DAS).

During the pigeon pea flowering, that is, 125 DAS in 2011/2012 and 162 DAS in 2012/2013, plants were harvested and the shoot and root were separated. The roots were not used in the present study and the shoot was weighted to obtain the fresh mass (FM) in g $plant^{-1}$, and after drying the dry mass was obtained in g $plant^{-1}$.

With data from the 360 plants, for each evaluation times, the mean and standard error were estimated for each variable (NN, PH, SD, FM and DM). For each crop year, the sigmoid model was adjusted for the variables NN, PH, SD (dependent variables) according to the evaluation period (independent variable – ten evaluations for 2011/2012 and 18 evaluations for 2012/2013).

For the study of linear relations during the 2011/2012 crop year, the Pearson´s linear correlation coefficient matrix (r) was estimated between the variables NN, PH and SD, evaluated at 62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 DAS, FM and DM evaluated at 125 DAS and, through Student's t test at 5% probability, the r significance was evaluated.

After the multicollinearity diagnosis (Cruz, 2013), the correlation matrix between the NN, PH and SD variables was performed in each evaluation period. For example, the first multicollinearity diagnosis was performed between NN at 62 DAS, PH at 62 DAS and SD at 62 DAS, the second between NN at 69 DAS, PH at 69 DAS and SD at 69 DAS, and thus successively, up to NN, PH and SD at 125 DAS.

For the interpretation of the multicollinearity diagnosis, the condition number (CN) was used and multicollinearity was considered weak when CN <100, moderate to severe multicollinearity when 100≤CN≤1,000 and severe multicollinearity when CN> 1,000, according to the Montgomery & Peck (1982) criterion.

Thus, path analysis of the main variables (FM and DM) at 125 DAS were performed, in a function of the explanatory variables (NN, PH and SD), measured in ten evaluation periods (62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 DAS), totaling 20 path analyzes. For example, the first path analysis was FM at 125 DAS on the basis of NN at 62 DAS, PH at 62 DAS and SD at 62 DAS, the second path analysis was FM at 125 DAS as a function of NN at 69 DAS , PH at 69 DAS and SD at 69 DAS, and so on, up to the twentieth path which was DM at 125 DAS according to NN at 125 DAS, PH at 125 DAS and SD at 125 DAS.

For the study of linear relations during the 2012/2013 crop year, the same procedures of the 2011/2012 crop year were performed, totaling 36 path analyzes. For example, the first path analysis was FM at 162 DAS on the basis of NN at 44 DAS, PH at 44 DAS and SD at 44 DAS, the second path analysis was FM at 162 DAS as a function of NN at 51 DAS, PH at 51 DAS and SD at 51 DAS, and so on, up to the 36th path that was DM at 162 DAS according to NN at 162 DAS, PH at 162 DAS and SD at 162 DAS.

Statistical analyzes were performed with the GENES software (Cruz, 2013) and Microsoft Office Excel®.

Results and Discussion

With the aid of Student's t-test for independent samples, applied at 5% probability, with 718 degrees of freedom, it was evidenced that in the flowering of pigeon pea plants (at 125 DAS in 2011/2012 and at 162 DAS in 2012/2013), the plants presented, in average, higher number of nodes (NN) per plant and higher plant height (PH) for the 2012/2013 crop year (NN = 61.78; PH = 253.48 cm), when compared to the 2011/2012 crop year (NN = 48.87; PH= 192.02 cm). The stem diameter measured at 5 cm from the soil (SD) was higher in 2011/2012 (17.84 cm) compared to 2012/2013 (17.13 cm) (Figure 1). The observed plant height was similar to Singh et al. (2013), who reported an average height of 21 genotypes of pigeon pea of 218.25 cm.

The average fresh mass (FM) evaluated at 125 DAS in 2011/2012 (365.98 g plant^{-1}) did not differ (p> 0.05) from the FM at 162 DAS in 2012/2013 (360.53 g plant $^{-1}$). The same was observed for the dry mass (DM), in which mean values for plants during flowering were 104.80 g plant^{-1} in 2011/2012 and 106.79 g plant^{-1} in 2012/2013. Based on the density of 116,889 and 120,118 plants ha^{-1}, respectively, for the 2011/2012 and 2012/2013 crop years, the estimated FM were 42,779 and 43,306 kg ha^{-1}, respectively and DM were 12,250 and 12,827 kg ha^{-1}, respectively.

These averages are superior to the fresh and dry masses of 32,708 and 6,465 kg ha^{-1}, respectively, obtained in a study by Suzuki & Alves (2006), and also higher than the dry masses of *Cajanus cajan* cv. Kaki, which ranged between 950 and 9,798 kg ha^{-1}, in the four evaluated sowing seasons (Lima et al., 2010). Comparisons of the results of this study with the results of other authors should be viewed with caution, since the environmental and management conditions of the experiments are different. However, in general, it can be inferred that the means of NN, PH, SD, FM and DM, reveal adequate development and confirm the potentialities of the crop (Azevedo et al., 2007), for the local in which the study was carried out.

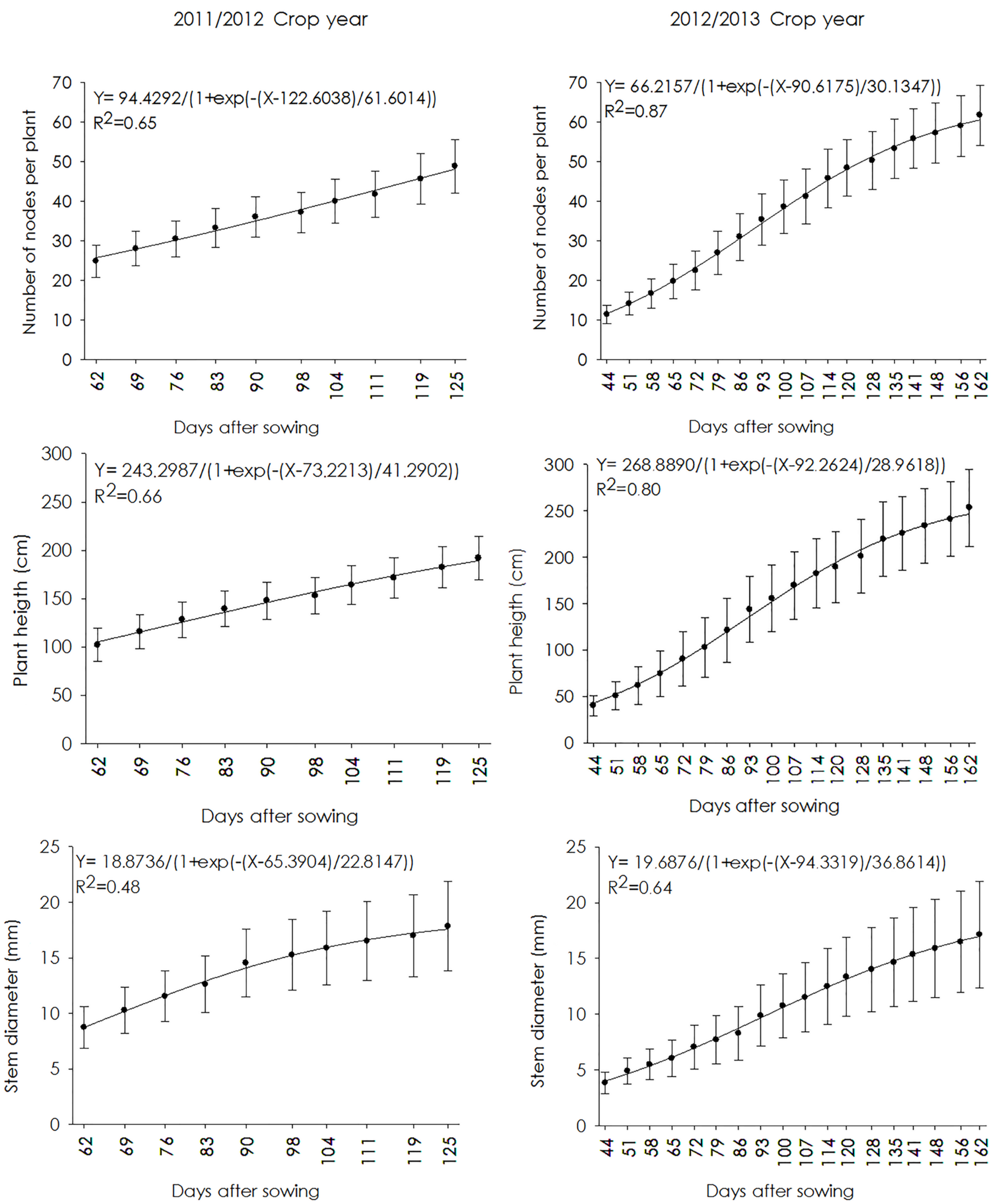

Figure 1. Sigmoidal model of the characters number of nodes per plant, plant height and stem diameter as a function of ten evaluation periods (62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 days after sowing - DAS) during the 2011/2012 crop year and of 18 evaluation periods (44, 51, 58, 65, 72, 79, 93, 100, 107, 114, 120, 128, 135, 141, 148, 156 and 162 DAS) during the 2012/2013 crop year. The vertical bars represent the mean ± standard deviation estimated based on 360 pigeon pea plants (*Cajanus cajan* L.), in each evaluation period.

The largest number of days for flowering during the 2012/2013 crop year may be associated with the different sowing periods between the crop years (January 26th, 2012 for the 2011/2012 crop year and November 20th, 2012 for the 2012/2013 crop year). The anticipation of the sowing season in 2012/2013 may have contributed to obtaining plants with higher NN and PH in this year. In addition, the sowing system (broadcast in 2011/2012 and rows in 2012/2013) may have contributed to these differences.

In relation to the sowing season, these results are in agreement with Lima et al. (2010). These authors verified, in a general way, that in from the first sowing season (11/15/2005) to the 2nd season (01/02/2006), 3rd season (02/14/2006) and 4th season (03/18/2006), there was a reduction in the number of days for flowering and dry mass for the species *Crotalaria juncea* cv. IAC KR1 (Crotalaria), *Mucuna deeringiana* cv. Common and *Cajanus cajan* cv. Kaki (pigeon pea), which shows influence of the sowing season in crop development.

For the three variables (NN, PH and SD) there was a better adjustment of the sigmoidal model in the year 2012/2013 ($0.64 \leq R^2 \leq 0.87$) when compared to the year 2011/2012 ($0.48 \leq R^2 \leq 0.66$) (Figure 1). In black oat, Cargnelutti Filho et al. (2015) obtained a reasonable adjustment ($0.45 \leq R^2 \leq 0.96$) of this model to data on plant height, number of leaves per plant, number of tillers per plant, fresh mass and dry mass. In the two years the plants were evaluated until the flowering, however, the best fit of the models in this year 2012/2013, can, among other not measured factors, be explained by the higher number of evaluations and the period of evaluation.

In both years, the inclusion of evaluations at the beginning of the cycle and after flowering, would contribute to the best fit of this growth model, because this sigmoidal model represents well the growth of plants with slight increases in the initial phase, high additions during the intermediate phase and stabilization at the end of the cycle.

For the NN, PH and SD traits of pigeon pea plants, the standard deviations in the initial seasons were lower than those obtained in the final evaluation periods (Figure 1). The variability between the plants is important and makes it possible to study the linear relationships between the characters, through correlation and path analysis. Thus, it is possible that the linear relationships between the characters are better established at periods with greater variability (higher standard deviation).

Thus, it is expected greater reliability in the results in which data from the final evaluations were used, when compared to the use of initial evaluation data. Therefore, considering the plants adequate development and data variability, together with the high number of plants (360 plants per year) and evaluations (10 seasons in 2011/2012 and 18 seasons in 2012/2013) it is inferred that this database offers credibility to the study of linear relations between these characters.

During the 2011/2012 crop year, Pearson's linear correlation coefficient (r) between NN at 62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 DAS and FM at 125 DAS ranged from 0.589 (NN at 62 DAS x FM at 125 DAS) and 0.637 (NN at 98 DAS x FM at 125 DAS) (Table 1). Thus, it can be inferred that pigeon bean plants with higher numbers of nodes, in these evaluation periods, are associated to plants with greater fresh mass in flowering. Similar results were observed in relation to PH and FM ($0.616 \leq r \leq 0.637$), indicating that higher plants are associated with plants with higher fresh mass.

Similar results were verified in a correlation and path analysis study with 100 pigeon pea genotypes performed by Birhan et al. (2013). The authors verified a phenotypic (rp= 0.62) and genotypic (rg = 0.61) correlation between plant height and biomass. In 122 genotypes of *Brachiaria ruziziensis*, Borges et al. (2011) verified a phenotypic correlation of 0.493 between plant height and fresh mass and of 0.4588 between plant height and dry mass.

The association between SD and FM presented rising r values and stabilizing tendency with evaluation periods, ranging from 0.766 to 0.919 (Table 1). Therefore, there was a greater linear association between SD × FM ($0.766 \leq r \leq 0.919$), when compared to linear associations between NN x FM ($0.589 \leq r \leq 0.637$) and PH x FM ($0.616 \leq r \leq 0.637$), suggesting that SD is strongly associated with FM.

Similar results were obtained for the correlations between the NN, PH and SD variables at 62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 DAS and the DM at 125 DAS. This can be explained, as expected, by the strong linear association between FM at 125 DAS and DM at 125 DAS (r = 0.994), that is, plants with higher FM have higher DM and vice versa.

A positive and high association between the fresh and dry masses was also observed in *Brachiaria ruziziensis* (r phenotype = 0.9257) (Borges et al., 2011), forage turnip (r = 0.9671), white lupine (R = 0.9828) (Cargnelutti Filho et al., 2014) and black oat (r = 0.94) (Cargnelutti Filho et al., 2015).

Table 1. Estimations of direct and indirect effects (path analysis) of the number of nodes per plant (NN), plant height (PH) and stem diameter (SD), measured in ten evaluation periods (62, 69, 76, 83 90, 98, 104, 111, 119 and 125 days after sowing – DAS) on the fresh mass (FM) and dry mass (DM) measured at 125 days after sowing, in 360 pigeon pea (*Cajanus cajan* L.)plants during the 2011/2012 crop year.

Effect	Evaluation times - DAS									
	62	69	76	83	90	98	104	111	119	125
				FM = function (NN, PH, SD)						
Direct NN on FM	0.056	0.211	0.109	0.075	0.114	0.077	0.070	0.046	0.041	0.021
Indirect NN via PH	0.022	-0.067	-0.044	0.003	-0.036	-0.019	0.011	0.050	0.057	0.121
Indirect NN via SD	0.511	0.476	0.532	0.525	0.542	0.579	0.550	0.524	0.505	0.469
Pearson´s correlation (r)	0.589*	0.621*	0.596*	0.603*	0.620*	0.637*	0.631*	0.620*	0.603*	0.612*
Direct PH on FM	0.027	-0.081	-0.058	0.004	-0.045	-0.024	0.013	0.060	0.069	0.145
Indirect PH via NN	0.046	0.172	0.083	0.060	0.091	0.061	0.058	0.038	0.034	0.017
Indirect PH via SD	0.550	0.525	0.597	0.556	0.576	0.599	0.550	0.521	0.518	0.470
Pearson´s correlation (r)	0.622*	0.616*	0.622*	0.620*	0.623*	0.637*	0.622*	0.619*	0.620*	0.632*
Direct SD on FM	0.704	0.705	0.790	0.805	0.851	0.880	0.866	0.849	0.846	0.798
Indirect SD via NN	0.041	0.143	0.073	0.049	0.073	0.050	0.045	0.028	0.024	0.012
Indirect SD via PH	0.021	-0.061	-0.044	0.003	-0.030	-0.016	0.009	0.037	0.042	0.085
Pearson´s correlation (r)	0.766*	0.787*	0.819*	0.856*	0.893*	0.915*	0.919*	0.914*	0.913*	0.895*
Coefficient of determination	0.589	0.635	0.676	0.737	0.803	0.839	0.849	0.841	0.840	0.818
Residual variable	0.641	0.604	0.569	0.513	0.444	0.401	0.389	0.399	0.400	0.426
Condition number	14.42	14.52	11.83	12.29	12.32	12.43	13.86	14.29	13.54	14.53
				DM = function (NN, PH, SD)						
Direct NN on DM	0.086	0.209	0.127	0.096	0.129	0.102	0.083	0.063	0.029	0.032
Indirect NN via PH	0.044	-0.025	-0.013	0.018	-0.010	0.006	0.039	0.072	0.094	0.137
Indirect NN via SD	0.487	0.456	0.505	0.513	0.525	0.556	0.532	0.509	0.494	0.462
Pearson´s correlation (r)	0.618*	0.640*	0.619*	0.627*	0.644*	0.664*	0.654*	0.644*	0.617*	0.631*
Direct PH on DM	0.055	-0.031	-0.018	0.023	-0.012	0.007	0.047	0.087	0.114	0.164
Indirect PH via NN	0.070	0.171	0.098	0.077	0.103	0.082	0.069	0.052	0.024	0.027
Indirect PH via SD	0.524	0.502	0.566	0.543	0.558	0.576	0.533	0.505	0.506	0.462
Pearson´s correlation (r)	0.648*	0.642*	0.646*	0.643*	0.649*	0.665*	0.648*	0.644*	0.644*	0.653*
Direct SD on DM	0.670	0.675	0.749	0.786	0.824	0.846	0.838	0.824	0.828	0.784
Indirect SD via NN	0.063	0.141	0.086	0.063	0.082	0.067	0.053	0.039	0.017	0.019
Indirect SD via PH	0.043	-0.023	-0.013	0.016	-0.008	0.005	0.030	0.053	0.070	0.097
Pearson´s correlation (r)	0.776*	0.793*	0.822*	0.864*	0.898*	0.918*	0.921*	0.916*	0.915*	0.900*
Coefficient of determination	0.609	0.649	0.683	0.754	0.815	0.849	0.856	0.851	0.849	0.833
Residual variable	0.625	0.593	0.563	0.496	0.431	0.389	0.379	0.386	0.389	0.408
Condition number	14.42	14.52	11.83	12.29	12.32	12.43	13.86	14.29	13.54	14.53

* Significant at 5% of error probability according to the Student´s t test with 358 degrees of freedom.

In general, the fresh (FM) and dry (DM) masses of pigeon pea, evaluated at flowering, showed a higher degree of positive linear association (higher r values) with SD and lower degree of association with NN and PH, which were similar (Table 1).

Therefore, these results suggest that pigeon pea plants with larger stem diameter during the crop development will present higher fresh and dry masses on flowering. However, only through the correlation coefficients, it is not possible to infer which of the variables (NN, PH and SD) has a direct effect on the fresh and dry masses. Thus, path analysis is an adequate procedure to infer the true cause and effect relations between variables (Cruz, 2013).

The diagnoses of multicollinearity in the Pearson linear correlation coefficient matrix, between the explanatory variables NN, PH and SD revealed a condition number (CN) between 11.83 (evaluation at 76 DAS) and 14.53 (evaluation at 125 DAS) (Table 1). Therefore, the matrices presented low co-linearity, according to Montgomery & Peck (1982) criteria. Thus, the analysis of the fresh (FM) and dry mass (DM) of pigeon pea, measured at 125 DAS, as a function of the explanatory variables NN, PH and SD in ten evaluation periods (62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 DAS) were performed under suitable conditions.

Regarding the stem diameter, a positive linear correlation (0.766 ≤ r ≤ 0.919) and direct effect (0.704 ≤ direct effect ≤ 0.880) and same signal was observed for the ten evaluated periods (62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 DAS), similar to the observed for FM at 125 DAS, confirming the cause and effect relation between SD and FM (Table 1).

For NN and the ten evaluation periods (62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 DAS) it was observed a linear positive correlation (0.589 ≤ r ≤ 0.637) with FM at 125 DAS. However, the direct effect of NN (0.021 ≤ direct effect ≤ 0.211) on FM at 125 DAS were negligible and, therefore, the existing association is explained by the greater indirect effects via SD (0.469 ≤ indirect effect ≤ 0.579).

Moreover, the PH in the ten evaluated periods (62, 69, 76, 83, 90, 98, 104, 111, 119 and 125 DAS) also had positive linear correlation (0.616 ≤ r ≤ 0.637) with FM at 125 DAS . However, the direct effects of PH (-0.081 ≤ direct effect ≤ 0.145) on FM at 125 DAS were with opposite signs and/or negligible and, therefore, the existing association is explained again by the greater indirect effects via SD (0.470 ≤ indirect effect ≤ 0.599).

Similar results were obtained for dry mass (DM) path analyzes, measured at 125 DAS, as a function of the explanatory variables NN, PH and SD, measured in the ten evaluation periods (62, 69, 76, 83, 90, 98 , 104, 111, 119 and 125 DAS). Thus, the results for the 2011/2012 crop year indicate that plants with larger stem diameter are associated with plants with larger fresh and dry mass on flowering.

These results are in accordance with Cargnelutti Filho et al. (2014), who concluded that in the forage turnip the stem diameter has a positive linear relation with the fresh and dry masses and can be used for indirect selection.

Also, they are similar to the study by Martin et al. (2012), in which the authors showed that in the sunflower crop the stem diameter has a direct effect on grain yield. Still, they are similar to the results obtained by Menezes et al. (2014), which showed that stem diameter and number of tillers showed a positive genotypic correlation with dry matter production of elephant grass.

During the 2011/2012 crop year, in general, from the first evaluation period (62 DAS), there was a gradual increase of the direct effect of the SD on the FM and DM and the coefficient of determination and decrease of the residual variable (Table 1). This reveals that, although the indirect selection of plants for higher DM and DM yields can be performed from the 62 DAS, there is an improve of the selection as the evaluations are close to the flowering period (125 DAS).

For the 2012/2013 crop year, the three characters (NN, PH and SD) evaluated in the 18 evaluation times (44, 51, 58, 72, 79, 86, 93, 100, 107, 114, 120, 128, 135, 141, 148, 156 and 162 DAS) presented positive linear correlation with the FM at 162 DAS. In general, the linear correlation coefficient increased from the first (44 DAS) until the last evaluation period (162 DAS), ranging from 0.391 to 0.608 for NN x FM, from 0.367 to 0.639 for PH x FM and from 0.422 to 0.927 for SD x FM (Table 2).

Thus, it can be inferred that the linear associations between these characters were better established from the first to the last evaluations. The increase of the standard deviation according to the evaluation times can probably explain this scenario of association between the traits.

Consequently, in the results of the path analyzes, it was verified that, from the first ones for the last evaluations, the negligible effects of NN and PH on the FM were more evident, being explained by the high indirect effects via SD and the high direct positive effects of SD and FM. Therefore, a cause and effect relation between SD and FM was confirmed. It was also confirmed that selection can be performed earlier and that it becomes more efficient as it approaches the last evaluation (162 DAS).

The strong linear association between FM at 162 DAS and DM at 162 DAS (r = 0.996), explains the similar results that were obtained

Table 2. Estimations of direct and indirect effects (path analysis) of the number of nodes per plant (NN), plant height (PH) and stem diameter (SD), measured in eighteen evaluation periods (44, 51, 58, 65, 72, 79, 86, 93, 100, 107, 114, 120, 128, 135, 141, 148, 156 and 162 days after sowing – DAS) on the fresh mass (FM) measured at 162 days after sowing, in 360 pigeon pea (*Cajanus cajan* L.) plants during the 2012/2013 crop year.

Effect	Evaluation periods - DAS								
	44	51	58	65	72	79	86	93	100
	FM = function (NN, PH, SD)								
Direct NN on FM	0.191	0.169	0.454	0.541	0.432	0.230	0.274	0.309	0.182
Indirect NN via PH	-0.019	0.025	-0.234	-0.463	-0.683	-0.432	-0.504	-0.583	-0.497
Indirect NN via SD	0.219	0.211	0.232	0.384	0.741	0.682	0.715	0.794	0.843
Pearson´s correlation (r)	0.391*	0.405*	0.452*	0.462*	0.490*	0.479*	0.486*	0.520*	0.529*
Direct PH on FM	-0.022	0.028	-0.256	-0.503	-0.757	-0.480	-0.566	-0.640	-0.555
Indirect PH via NN	0.167	0.149	0.415	0.497	0.390	0.207	0.244	0.281	0.163
Indirect PH via SD	0.222	0.219	0.248	0.402	0.789	0.680	0.743	0.802	0.840
Pearson´s correlation (r)	0.367*	0.396*	0.407*	0.396*	0.422*	0.407*	0.422*	0.444*	0.449*
Direct SD on FM	0.299	0.271	0.283	0.454	0.896	0.834	0.925	0.979	1.067
Indirect SD via NN	0.140	0.132	0.372	0.457	0.357	0.188	0.212	0.250	0.144
Indirect SD via PH	-0.016	0.023	-0.225	-0.445	-0.667	-0.391	-0.455	-0.524	-0.437
Pearson´s correlation (r)	0.422*	0.426*	0.430*	0.466*	0.586*	0.631*	0.682*	0.705*	0.774*
Coefficient of determination	0.193	0.195	0.223	0.262	0.418	0.441	0.526	0.567	0.674
Residual variable	0.898	0.897	0.882	0.859	0.763	0.748	0.689	0.658	0.571
Condition number	20.72	22.57	36.82	37.55	32.09	27.30	24.55	30.18	25.40
	107	114	120	128	135	141	148	156	162
	FM = function (NN, PH, SD)								
Direct NN on FM	0.131	0.116	0.093	0.034	-0.023	-0.050	-0.019	-0.025	-0.003
Indirect NN via PH	-0.374	-0.295	-0.273	-0.171	-0.081	-0.004	0.020	0.058	0.089
Indirect NN via SD	0.797	0.677	0.702	0.661	0.637	0.632	0.598	0.576	0.520
Pearson´s correlation (r)	0.554*	0.498*	0.522*	0.524*	0.533*	0.579*	0.600*	0.608*	0.606*
Direct PH on FM	-0.423	-0.349	-0.322	-0.201	-0.096	-0.004	0.025	0.072	0.109
Indirect PH via NN	0.116	0.098	0.079	0.029	-0.020	-0.041	-0.015	-0.021	-0.002
Indirect PH via SD	0.761	0.722	0.727	0.664	0.688	0.626	0.575	0.540	0.532
Pearson´s correlation (r)	0.453*	0.470*	0.484*	0.492*	0.572*	0.581*	0.585*	0.591*	0.639*
Direct SD on FM	1.040	1.021	1.030	0.993	0.994	0.955	0.915	0.900	0.846
Indirect SD via NN	0.100	0.077	0.063	0.023	-0.015	-0.033	-0.012	-0.016	-0.002
Indirect SD via PH	-0.309	-0.247	-0.227	-0.134	-0.066	-0.003	0.016	0.043	0.069
Pearson´s correlation (r)	0.831*	0.851*	0.866*	0.881*	0.913*	0.919*	0.918*	0.927*	0.913*
Coefficient of determination	0.745	0.762	0.784	0.794	0.841	0.847	0.844	0.861	0.841
Residual variable	0.505	0.488	0.464	0.454	0.399	0.392	0.395	0.373	0.399
Condition number	22.71	16.12	16.59	16.58	16.42	14.04	13.34	12.55	13.12

* Significant at 5% of error probability according to the Student´s t test with 298 degrees of freedom.

for the correlations between the NN, PH and SD characters evaluated at 44, 51, 58, 65, 72, 79, 86, 93, 100, 107, 114, 120, 128, 135, 141, 148, 156 and 162 DAS and the DM at 162 DAS, and the path analyzes (Table 3). Therefore, in general, the gradual increase of the direct effect of the SD on the FM and DM, together with the increase of the coefficient of determination and decrease of the residual variable from the first evaluation period (44 DAS) reveals that, although indirect selection of plants for higher FM and DM, can be performed from the 44 DAS, this selection improves as the evaluations approach the flowering (162 DAS).

In practice, the correlation coefficients and direct and indirect effects of path analysis were similar for the evaluated crop years, and showed that the stem diameter can be used for the indirect selection of plants with larger fresh and dry mass during flowering. This selection can be performed earlier, which means, before flowering.

The fact that it is not necessary a destructive analysis to obtain the stem diameter measures is advantageous, since it allows, if it is of interest, to maintain the plants until the seed production. The direct selection would have to be during flowering and destructive, to weigh the fresh and dry mass.

Table 3. Estimations of direct and indirect effects (path analysis) of the number of nodes per plant (NN), plant height (PH) and stem diameter (SD), measured in eighteen evaluation periods (44, 51, 58, 65, 72, 79, 86, 93, 100, 107, 114, 120, 128, 135, 141, 148, 156 and 162 days after sowing – DAS) on the dry mass (DM) measured at 162 days after sowing, in 360 pigeon pea (*Cajanus cajan* L.) plants during the 2012/2013 crop year.

Effect	Evaluation periods – DAS								
	44	51	58	65	72	79	86	93	100
	DM = function (NN, PH, SD)								
Direct NN on DM	0.201	0.164	0.434	0.530	0.441	0.249	0.286	0.327	0.198
Indirect NN via PH	-0.037	0.010	-0.227	-0.461	-0.713	-0.468	-0.534	-0.617	-0.521
Indirect NN via SD	0.220	0.227	0.234	0.383	0.756	0.694	0.729	0.805	0.848
Pearson´s correlation (r)	0.384*	0.400*	0.441*	0.452*	0.484*	0.475*	0.480*	0.515*	0.524*
Direct PH on DM	-0.042	0.011	-0.248	-0.501	-0.790	-0.519	-0.600	-0.678	-0.582
Indirect PH via NN	0.176	0.144	0.397	0.487	0.398	0.225	0.254	0.298	0.177
Indirect PH via SD	0.222	0.235	0.250	0.401	0.805	0.692	0.758	0.814	0.845
Pearson´s correlation (r)	0.357*	0.391*	0.399*	0.388*	0.412*	0.397*	0.412*	0.434*	0.440*
Direct SD on DM	0.300	0.291	0.285	0.454	0.914	0.849	0.943	0.993	1.073
Indirect SD via NN	0.148	0.128	0.356	0.447	0.365	0.204	0.221	0.265	0.156
Indirect SD via PH	-0.031	0.009	-0.218	-0.443	-0.696	-0.423	-0.482	-0.555	-0.458
Pearson´s correlation (r)	0.416*	0.428*	0.423*	0.458*	0.582*	0.629*	0.681*	0.703*	0.771*
Coefficient of determination	0.187	0.194	0.213	0.254	0.420	0.446	0.532	0.573	0.675
Residual variable	0.902	0.898	0.887	0.864	0.762	0.744	0.684	0.654	0.570
Condition number	20.72	22.57	36.82	37.55	32.09	27.30	24.55	30.18	25.40
	107	114	120	128	135	141	148	156	162
	DM = function (NN, PH, SD)								
Direct NN on DM	0.163	0.117	0.097	0.046	-0.017	-0.037	-0.001	-0.016	-0.002
Indirect NN via PH	-0.406	-0.310	-0.288	-0.187	-0.098	-0.021	-0.001	0.038	0.072
Indirect NN via SD	0.795	0.684	0.707	0.661	0.640	0.634	0.600	0.582	0.530
Pearson´s correlation (r)	0.552*	0.492*	0.515*	0.519*	0.526*	0.576*	0.598*	0.605*	0.600*
Direct PH on DM	-0.460	-0.367	-0.340	-0.220	-0.115	-0.026	-0.002	0.047	0.088
Indirect PH via NN	0.144	0.099	0.082	0.039	-0.014	-0.030	-0.001	-0.013	-0.001
Indirect PH via SD	0.759	0.729	0.732	0.663	0.691	0.628	0.577	0.546	0.543
Pearson´s correlation (r)	0.444*	0.461*	0.474*	0.482*	0.562*	0.571*	0.575*	0.581*	0.629*
Direct SD on DM	1.038	1.032	1.037	0.992	0.999	0.958	0.918	0.910	0.863
Indirect SD via NN	0.125	0.078	0.066	0.030	-0.011	-0.024	-0.001	-0.010	-0.001
Indirect SD via PH	-0.336	-0.260	-0.240	-0.147	-0.080	-0.017	-0.001	0.028	0.055
Pearson´s correlation (r)	0.827*	0.850*	0.863*	0.876*	0.909*	0.916*	0.917*	0.928*	0.917*
Coefficient of determination	0.745	0.765	0.784	0.787	0.835	0.841	0.840	0.863	0.846
Residual variable	0.505	0.485	0.465	0.462	0.407	0.398	0.400	0.370	0.392
Condition number	22.71	16.12	16.59	16.58	16.42	14.04	13.34	12.55	13.12

* Significant at 5% of error probability according to the Student´s t test with 298 degrees of freedom.

Conclusions

In the pigeon pea crop, the stem diameter has positive and linear relation with fresh and dry masses and can be used for indirect selection.

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