Original Article

PATH ANALYSIS IN SOYBEAN GENOTYPES AS FUNCTION OF GROWTH HABIT

ANÁLISE DE TRILHA EM GENÓTIPOS DE SOJA EM FUNÇÃO DO HÁBITO DE CRESCIMENTO

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ABSTRACT: Aiming to identify quantitative descriptors directly or indirectly related to grain yield and to verify whether this relationship depends of the growth habit of soybean (*Glycine max* (L.) Merrill), an experiment was conducted at Universidade Estadual de Mato Grosso do Sul –Aquidauana Unit, in a soil classified as Ultisol sandy loam texture. The experimental design was randomized block with four replications. The treatments consisted of six soybean genotypes, being three determinate growth habit and three indeterminate. The following descriptors were evaluated: plant height (PH), first pod insertion height (PIH), number of ramifications per plant (NR), number of pods (NP), mass of hundred grains (MHG) and grains yield (YIE). The data of each parameter of genotypes with determinate and indeterminate growth habit for each genetic class were compared by t-test at 5% probability. The results obtained showed that genotypes with indeterminate growth habit are more productive compared to those who have determinate growth habit. It is recommended simultaneous selection of the descriptors NP and NR for genotypes with determinate growth habit and PH, NP and NR for genotypes with indeterminate growth.

KEYWORDS: Genetic breeding. *Glycine max*. Quantitative descriptors. Grain yield.

INTRODUCTION

Among the major oilseeds cultivated in the world, the soybean (*Glycine max* (L.) Merrill) stands out with production of 253 million tons of grains (2012), with Brazil accountable for 25% of the total, characterizing it as the second largest producer of this crop (FAO, 2013). The average increase of 36 kg ha^{-1} $year^{-1}$ on productivity between 1976/77 to 2012/13 was provided mainly by genetic breeding and expansion in the area under cultivation, that this crop totaled about 28 million hectares, with an average yield of 2.9 t ha^{-1} (CONAB, 2013).

Although increases have occurred each year, genotypes with higher grain yield will be increasingly difficult to obtain, requiring more efforts of the soybean breeding programs. Carvalho et al. (2002) reinforce that grain yield is a complex character and resultant of expression and association of different components.

According to Pandini et al. (2002) knowledge of direct and indirect correlations on a particular production component, especially grain yield, allow the breeder to use this additional information to rule out or to promote more accurately interest genotypes. Pípolo et al. (2005) reported that the correlation between characters allows indirect selection of a quantitative character, with hard to gain selection, by selecting from another character to it directly correlated of greater genetic gain or easy visual selection.

According to the theory of quantitative genetics, genetic and environmental causes of correlation are combined to produce phenotypic correlation (WAITT; LEVIN, 1998). In this context, pleiotropy is the principal genetic cause for occurrence of correlations, where two or more characteristics are influenced by the same genes. The effect of all genes that affect both characteristics results in correlation (RAMALHO et al. 2004).

However, Rodrigues et al. (2010) reinforces the fact that simple correlation coefficients do not represent the exact relation of cause and effect between characters, which according to Dewey and Lu (1959) can be misleading if the high correlation between two characters is a result of indirect effect of other characteristics.

The path analysis proposed by Wright (1921), allows better understanding between the association of different characters, through the

Received: 02/04/14
Accepted: 10/10/14

unfolding of correlation coefficients into direct and indirect effects on a main character. This analysis was initially used in plants by Dewey and Lu (1959), and was later used in other crops, such soybeans, and their use reported by Board et al. (2003) and Bizeti et al. (2004). Although the analysis has been widely used, there are no studies linking grain yield with different genotypes growth habits of this crop.

According to Bernard (1972), two gene locus [(Dt1/dt1) and (Dt2/dt2)] control the type of growth in soybean. Nogueira et al. (2009) classifies indeterminate genotypes (Dt1 Dt1 dt2 dt2) as plants that have only axillary inflorescence, and in these the yolk apical maintains vegetative growth after flowering initiation. The determinate (dt1 dt1 - -) have terminal and axillary racemose inflorescences, vegetative growth almost ceases after flowering and can grow up to 10% of final height.

Perini et al. (2012) reports that the determinate growth habit prevalent in Brazilian soybean cultivars is one of the restrictions for to increase the yield grain. However, in recent years the cultivation of soybean cultivars of indeterminate growth habit has significantly increased.

In this context, the aim of this study was to identify quantitative descriptors that are directly or indirectly related to the grains yield and if this relationship depends on the growth habit of soybean.

MATERIAL AND METHODS

The experiment was installed in the experimental area of the Universidade Estadual de Mato Grosso do Sul – Aquidauana Unit (UEMS/UUA), in Aquidauana (MS), located in the Brazilian Savanna, comprising the coordinates 20º27'S and 55º40'W and with an average elevation of 170 m.

The climate of the region according to classification described by Köppen-Geiger is Aw (Savanna Tropical) with cumulative rainfall during the experiment of 450 mm and maximum and minimum temperatures of 19 and 33ºC, respectively. The soil was identified as Ultisol sandy loam texture with the following characteristics in the layer 0 – 0.20 m: pH (H_2O) = 6.2; Al exchangeable ($cmol_c\ dm^{-3}$) = 0.0; Ca+Mg ($cmol_c\ dm^{-3}$) = 4.31; P ($mg\ dm^{-3}$) = 41.3; K ($cmol_c\ dm^{-3}$) = 0.2; Organic matter ($g\ dm^{-3}$) = 19.7; V (%) = 45.0; m (%) = 0.0; Sum of bases ($cmol_c\ dm^{-3}$) = 2.3; cation exchange capacity (or CEC) ($cmol_c\ dm^{-3}$) = 5.1.

The experiment was conducted in randomized blocks with four replications. The area was divided into four blocks with a total of twenty-four plots, with area of 15.75 m² (3.15 x 5.0 m), 2 m spacing between blocks and 0.45 m between the planting lines. The treatments consisted of six soybean genotypes of determinate (BRS 245, BRS 255 and MSOY 7908) and indeterminate (BMX Potência, SYN 3358 and ND 5909) growth habit.

Sowing was done manually in 08/12/2011 with 20 seeds per meter, in a germination rate of 80%, achieving an average density of 16 plants per linear meter, corresponding to a population of 355.555 plants ha^{-1}.

Seed treatment was performed with active ingredient Thiram at dose of 300 mL 100 kg^{-1} seeds of the commercial product, Imidacloprido (Imidacloprido) insecticide at dose of 150 mL 100 kg^{-1} seeds of the commercial product, and at the moment of sowing the seeds were inoculated with peaty-based inoculant *Bradyrhizobium japonicum* at a dose of 240 grams per 100 kg seeds of the commercial product.

At 80 days after emergence (DAE) was measured the descriptors plant height (PH) and first pod insertion height (PIH). The assessments were done on 10 plants per plot using a tape-measure.

Harvest was done manually at 115 DAE, and at this time was evaluated the descriptors: number of ramifications per plant (NR), number of pods (NP), mass of hundred grains (MHG) and grains yield (YIE). To evaluate the number of pods and number of ramifications per plant were used 10 plants per plot, and to evaluate the mass of hundred grains and grains yield were collected plants from the two central rows of each plot using an analytical balance to determine the last two variables The grain moisture was corrected to 13% and productivity was extrapolated for kg ha^{-1}.

Initially, the genotypes data of determinate and indeterminate growth habit were grouped to obtain the average of each parameter to each genetic class to be compared by t-test at 5% probability following the procedure carried out by Teodoro et al. (2014).

Subsequently, were estimated the Pearson's correlation coefficients among the parameters evaluated to each genetic class. Onto correlations matrix between the eight characteristics, proceeded to multicollinearity diagnosis. Then, the correlations among the other characteristics and YIE (dependent variable) were split into direct and indirect effects, establishing cause and effect relations among them, as described in the literature (CRUZ et al., 2004).

All procedures were performed using the statistical software Genes (CRUZ, 2006).

RESULTS AND DISCUSSION

There were significant differences among treatments to all descriptors evaluated (Table 1). Genotypes with indeterminate growth habit presented higher plant height, number of pods, number of ramifications, mass of hundred grains and grains yield. Similar results were obtained by Board et al. (2003), Bizeti et al. (2004), Arshad et al. (2006), Barbaro et al. (2006) and Torres et al. (2014).

Table 1. Average values of plant height (PH), pod insertion height (PIH), number of pods (NP), number of ramifications (NR), mass of hundred grains (MHG) and grain yield (YIE) of three soybean genotypes with determinate growth and three soybean genotypes with indeterminate growth (lower diagonal).

	Determinate growth[1]	Indeterminate growth	CV (%)
PH (cm)	52.17 b	58.93 a	5.78
PIH (cm)	8.47 a	7.80 b	8.00
NP	109.47 b	119.85 a	11.21
NR	8.52 b	10.34 a	14.76
MHG (g)	22.98 b	26.05 a	11.12
YIE (kg ha^{-1})	1,987.79 b	2,782.73 a	28.79

[1]Averages followed by the same letter in the column do not differ significantly by t-test at 5% significance; CV = coefficient of variation.

These genotypes also presented grains yield 40% higher compared to genotypes with determinate growth. This is because larger plants have larger number of underarm and ramifications, where the pods will develop, therefore resulting in higher productivity.

These results disagree with those obtained by Perini et al. (2012) that not observed superiority of genotypes with indeterminate growth habit compared to those who have determinate growth. Data from this research indicate that the yield components are associated with the type of growth. Therefore, obtaining soybean genotypes with high depends upon the type of growth.

The descriptor NP presented significant correlation (P<0.01) of high magnitude with YIE (Table 2), independent of the genotypes growth habit. This parameter according to Bárbaro et al. (2006) is one of the most important on the productivity of soybean.

Table 2. Estimates of the Pearson's correlations between plant height (PH), pod insertion height (PIH), number of pods (NP), number of ramification (NR), mass of hundred grains (MHG) and grains yield (YIE) of three soybean genotypes with determinate growth (upper diagonal) and three soybean genotypes with indeterminate growth (lower diagonal).

Descriptors	PH (m)	PIH (m)	NP	NR	MHG (g)	YIE (kg ha^{-1})
PH	-	-0.2904	-0.0224	.8649**	-0.8550**	0.0697
PIH	-0.3364	-	-0.5557*	-0.2704	0.0759	-0.2758
NP	-0.0635	-0.6327 **	-	-0.2917	-0.0622	0.8567**
NR	0.8940**	-0.3286	-0.3391	-	-0.5669*	-0.2917
MHG	-0.8834**	0.0867	-0.0478	-0.6159*	-	-0.2945
YIE	0.0784	-0.3275	0.8871**	-0.3262	-0.3486	-

* and ** Significant at 5% and 1% probability, respectively, by t-test.

Independent of growth habit, there were significant negative correlations between plant height x mass of hundred grains, pod insertion height x number of pods and number of ramifications x mass of hundred grains and significant positive between plant height x number of ramifications. These results demonstrated that genotypes with higher plant height will posses higher number of ramifications and, consequently, smaller mass of hundred grains, resulting in lower production per plant, however without significant variation in grains yield, showing a tampon behavior for this culture (SILVA JUNIOR et al., 2014).

To gather into a single larger genotype x number of pods, number of ramifications and mass of hundred grains, was employed path analysis proposed by Wright (1921), which is a strategic tool to overcome the difficulties encountered by plant breeders. When it prioritizes some features of importance (highest association degree), obtains higher grains yield in shorter time.

Thus, correlation between grains yield and quantitative descriptors was split into direct and indirect effects. This analysis showed weak collinearity (NC <100) for both the genotypes with determinate growth habit (Table 3), as for those with indeterminate growth (Table 4), probably because in both treatments, only the number of pods variable (explanatory) correlated positively with grains yield (principal).

Table 3. Estimates of the direct and indirect effects of plant height (PH), pod insertion height (PIH), number of pods (NP), number of ramification (NR), mass of hundred grains (MHG) on grains yield (YIE) of three soybean genotypes with determinate growth habit.

Effect	PH (m)	PIH (m)	NP	NR	MHG (g)
Direct over YIE	0.0424	0.2242	0.9045	-0.1960	-0.3301
Indirect through PH	--	-0.0123	-0.0009	0.0366	-0.0362
Indirect through PIH	-0.0651	--	-0.1246	-0.0457	0.0170
Indirect through NP	-0.0203	-0.0123	--	0.6871	0.2111
Indirect through NR	0.1696	0.0400	0.0572	--	-0.1563
Indirect through MHG	0.2822	-0.0250	0.0205	-0.7638	--
Total (Pearson)	0.0697	-.0250	0.8567**	-0.2818	-0.2945
	Coefficient of determination = 0.8685				

** Significant at the 1% probability by t-test.

Table 4. Estimates of the direct and indirect effects of plant height (PH), pod insertion height (PIH), number of pods (NP), number of ramification (NR), mass of hundred grains (MHG) on grains yield (YIE) of three soybean genotypes with indeterminate growth habit.

Effect	PH (m)	PIH (m)	NP	NR	MHG (g)
Direct over YIE	0.8178	0.3347	0.9909	-0.5702	-0.1892
Indirect through PH	--	-0.1405	-0.0265	0.3735	-0.3691
Indirect through PIH	-0.5126	--	-0.2118	-0.1010	0.0290
Indirect through NP	0.0629	0.1216	--	0.6165	0.2280
Indirect through NR	-0.3310	-0.6269	0.1255	--	-0.0474
Indirect through MHG	0.1671	-0.0164	0.0090	-0.5360	--
Total (Pearson)	0.0784	-0.3275	0.8871**	-0.3262	-0.3487
	Coefficient of determination = 0.9888				

** Significant at 1% probability by t-test.

From the results obtained, independently of growth habit, it was observed that the number of pods had high direct effect on grains yield. This reinforces the assertion of Arshad et al. (2006) that this descriptor receives greater emphasis in the selection of soybean lines with high yield.

It is worth mentioning that in both treatments, the pod insertion height exerted direct influence moderate on the grains yield. Although there are no significant correlation, plant height descriptor has a direct influence on the high grains yield, probably due to the greater height genotypes possess greater amounts of trefoil, which results in larger photosynthetic active area (TORRES et al., 2015).

Based on these results, is recommended to increase the grains yield variable the direct selection of genotypes which have higher number of pods, independent of growth habit. Particularly, the plant height descriptor can be used to selection of genotypes with indeterminate growth to increase the productivity.

The effect of number of ramifications on the grains yield occurs indirectly through the route of association with number of pods. Thus, in soybean breeding programs aimed at increasing the grains yield must consider the number of pods.

The coefficient of determination of grains yield by the independent variables demonstrates that in genotypes with determined growth habit 86.85% of the grains yield is explained by the same, while in genotypes with indeterminate growth this value is 98.88%.

CONCLUSION

Genotypes with indeterminate growth habit are more productive compared to those who have determinate growth. The recommended strategy to a soybean genetic breeding program is the simultaneous selection of the descriptors number of pods and number of ramifications to genotypes with determinate growth habit and plant height, number of pods and number of ramifications to genotypes with indeterminate growth habit.

RESUMO: Objetivando identificar descritores quantitativos relacionados direta ou indiretamente ao rendimento de grãos e verificar se esta relação depende do hábito de crescimento da soja (*Glycine max* (L.) Merrill), foi conduzido um experimento na Universidade Estadual de Mato Grosso do Sul – Unidade Aquidauana, em um Argissolo Vermelho-Amarelo de textura arenosa. O delineamento experimental utilizado foi o de blocos casualizados com quatro repetições. Os tratamentos consistiram de seis genótipos de soja, sendo 3 de hábito de crescimento determinado e 3 indeterminado. Foram avaliados os seguintes descritores: altura de plantas (PH), altura de inserção da primeira vagem (PIH), número de ramificações por planta (NR), número de vagens (NP), massa de cem grãos (MHG) e rendimento de grãos (YIE). Os dados de cada variável dos genótipos de hábito de crescimento determinado e indeterminado para cada classe genética foram comparados pelo teste t a 5% de probabilidade. Os resultados obtidos mostraram que os genótipos de hábito de crescimento indeterminado foram mais produtivos comparados aos de hábito determinado. Recomenda-se a seleção simultânea dos descritores NP e NR para genótipos de hábito de crescimento determinado e PH, NP e NR para genótipos de crescimento indeterminado.

PALAVRAS CHAVE: Melhoramento genético. *Glycine max.* Descritores quantitativos. Rendimento de grãos.

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