REVISTA DE CIÊNCIASAGRÁRIAS
Amazonian Journal
of Agricultural and Environmental Sciences
www.ajaes.ufra.edu.br

http://dx.doi.org/10.4322/rca.ao1412

ORIGINAL ARTICLE

Phenotypic correlations and path analysis of soybean production components in the brazilian cerrado of Piauí state

Correlações fenotípicas e análise de trilha entre os componentes de produção de soja no cerrado piauiense

Fabiano André Petter[1]*
Francisco de Alcântara Neto[2]
Willian Silva Barros[3]
Fernandes Antônio de Almeida[2]
Leandro Pereira Pacheco[4]
Larissa Borges de Lima[5]
Geraldo de Amaral Gravina[6]

[1]Universidade Federal de Mato Grosso – UFMT, Instituto de Ciências Agrárias e Ambientais, Sinop, MT, Brasil
[2]Universidade Federal do Piauí – UFPI, Departamento de Agronomia, Bom Jesus, PI, Brasil
[3]Universidade Federal de Pelotas – UFPel, Departamento de Estatística, Pelotas, RS, Brasil
[4]Universidade Federal de Mato Grosso – UFMT, Instituto de Ciências Agrárias e Tecnológicas, Rondonópolis, MT, Brasil
[5]Universidade Federal de Goiás – UFG, Programa de Pós-Graduação em Agronomia, Goiânia, GO, Brasil
[6]Universidade Estadual do Norte Fluminense Darcy Ribeiro – UENF, Departamento de Produção Vegetal, Campos dos Goytacazes, RJ, Brasil

Autor Correspondente:
*E-mail: petter@ufmt.br

KEYWORDS
Potassium fertilization
Cerrado
Productivity
Breeding

PALAVRAS-CHAVE
Adubação potássica
Cerrado
Produtividade
Melhoramento

ABSTRACT: The objective of this work was to examine the phenotypic correlations and their consequences in direct and indirect effects through path analysis among agronomic traits and soybean grain yields subjected to varying doses and times of application of potassium (K) in the Piauí Cerrado. The experiment was conducted in the field, in the County of Bom Jesus, Piauí State in the 2011/2012 crop season. A randomized block, factorial [(5×4)+1] design was used. Five K rates (30, 60, 90, 120. and 150 kg ha^{-1} K_2O) and control (without K fertilizer) were applied at 4 times: 100% at planting, 50% at planting and 50% at 30 days after sowing (DAS), 100% at 30 DAS, 50% at 20 DAS and 50% to 40DAS. We evaluated the height (PHF) and dry weight of plants at flowering (DWAPF) and harvesting (DWAPH), number of grains pod^{-1} (NGPP), number of pods plant^{-1} (NPPP), weight of a thousand seeds (WOTS), grain yield and grain harvest index (GHI). The treatments that received potassium fertilization differed significantly ($p<0.05$) from the control in yield and height at flowering. The variables WOTS and GHI had higher correlations (0.88** and 0.71**), these being positive and significant with soybean yield. NGPP showed greater direct effect and high correlation (-0.89**) however negative with grain yield. The largest positive direct effects and superior to the residual effect on productivity were obtained with the variables WOTS, DWAPH and GHI, indicating that indirect selection for these primary characters would be effective.

RESUMO: *Objetivou-se, com este trabalho, verificar as correlações fenotípicas e seus desdobramentos em efeitos diretos e indiretos pela análise de trilha, entre caracteres agronômicos e de rendimentos de grãos na cultura da soja submetida a doses e épocas de aplicação de potássio no Cerrado do Piauí. O experimento foi conduzido a campo, na cidade de Bom Jesus, na safra 2011/2012. Foi utilizado o delineamento experimental em blocos casualizados, em esquema fatorial (5×4)+1, com quatro repetições. Cinco doses de potássio (30, 60, 90, 120 e 150 kg ha*$^{-1}$ *de* K_2O*) e controle (sem adubação potássica) foram aplicadas em quatro épocas: 100% no plantio; 50% no plantio e 50% aos 30 dias após a semeadura (DAS); 100% aos 30 DAS; 50% aos 20 DAS e 50% aos 40 DAS. Foram avaliados os seguintes caracteres: a altura e a fitomassa seca das plantas na floração (FSPAF) e na colheita (FSPAC); o número de grãos vagem*$^{-1}$ *(NGPV); o número de vagens planta*$^{-1}$*; o peso de mil sementes (PMS); a produtividade de grãos, e o índice de colheita de grãos (ICG). Os tratamentos que receberam adubação potássica diferiram significativamente (p<0,05) do tratamento-controle (sem adubação potássica) quanto à produtividade e à altura na floração. As variáveis PMS e ICG apresentaram maior correlação (0,88** e 0,71**), sendo estas positivas e significativas com a produtividade da soja. O NGPV apresentou maior efeito direto e alta correlação (-0,89**), porém negativa, com a produtividade de grãos. Os maiores efeitos diretos positivos e superiores ao efeito residual com a produtividade foram obtidos com as variáveis PMS, FSPAC e IGC, indicando que a seleção indireta sobre estes caracteres primários seria eficiente.*

Received: 10/22/2013
Accepted: 02/26/2014

1 Introduction

The Piauí Cerrado (Piauí savannah) stands out in the national agricultural scenario as a region of great potential for grain production. Considered the last agricultural frontier of the Cerrado biome, this region has soy as the main grain producing crop of the state. With the increasing expansion of cultivated areas in the state demand increases for chemical fertilizers, among which can be highlighted the potash fertilizers (Petter et al., 2012).

The Cerrado soils are characterized by high acidity and aluminum saturation, as well as low base saturation (Alcântara Neto et al., 2011). In the specific case of the Piauí Cerrado, in addition to the features mentioned, most of the soils of this biome, located on plateaus, have low clay content and low cation exchange capacity (CEC). This is due mainly due to low levels of organic matter (MO) that for these soils may represent up to 80% of CEC (Pacheco; Petter, 2011).

Associated with these characteristics that increase the potential for loss of K by leaching under high rainfall conditions is, on the other hand, the occurrence of wet season dry spells commonly encountered in the Cerrado region. These comprise the most important environmental conditions for the management of K fertilization mainly because K availability to plants depends on its mobility in the soil and this is due almost exclusively to diffusion, a process that is highly dependent on humidity in the soil (Oliveira et al., 2004).

Given this, the importance of fertilizer management becomes evident, since new trends of this crop aim both to detect the influence of the environment on the productivity of cultivars, as well as the factors limiting the deployment in new areas. Thus, it is desirable to use analyses that correlate the effects of the environment modified by fertilizer management on the components of yield and productivity.

Correlation refers to measuring the intensity of the association between two variables, which can be positive or negative, when there is an increase in the two variables or an increase in one and a decrease in the other, respectively (Steel; Torrie, 1980). Understanding these relationships between the characters is of great importance for breeding programs, considering that it lets you work with a set of characters simultaneously and not only improve the genetic material for individual characters. Moreover, the improvement of one characteristic may cause changes in others. Correlations can also be used when a target breeding feature shows low heritability, complex inheritance or presents measurement difficulties (Goldenberg, 1968; Vencovsky; Barriga, 1992).

Several studies have addressed the importance of correlations among the primary components for the character of yield (Ferreira et al., 2007; Amorim et al., 2008; Alcântara Neto et al., 2011; Rigon et al., 2012). However, correlation is only a measure of association, and does not allow conclusions about cause and effect, nor does it allow inferences about the type of association that governs a pair of characters. To overcome this limitation, Wright (1921) developed a method that allows the correlation coefficients to be broken down into direct and indirect effects on the main variable, whose estimates are obtained by means of regression equations in which the variables are previously standardized.

For the estimates of these coefficients to lead to a biologically appropriate and safe interpretation, it is of fundamental importance to test the degree of collinearity among the independent variables. In this case, the analysis of eigenvalues of matrix (X'X) is used to identify the existing linear dependence among the characters, identifying those that contribute to the emergence of the problem of multicollinearity (Carvalho et al., 2002). It is quite prudent when obtaining the direct effects, that the matrix X'X is well conditioned, multicollinearity can make it non-unique and, as a consequence, generate unreliable least squares estimates (Cruz; Carneiro, 2003). That said, studies using path analysis will allow a better understanding of the association between the different components that contribute to the productive yield of soybean (Ferreira et al., 2007).

The objective of this study was to see whether management of potassium fertilization interferes with phenotypic correlations and their consequences in direct and indirect effects through path analysis, among agronomic traits and grain yield in the soybean crop.

2 Materials and Methods

The test was conducted in the 2011/2012 crop season, in the County of Bom Jesus-PI. The soil was classified as dystrophic Yellow Latosol, of sandy clay texture, with the following composition: clay: 280 g kg^{-1}; silt: 80 g kg^{-1}; sand: 640 g kg^{-1}. The chemical properties of the soil is shown in Table 1. The experiment was conducted in an area planted with soybean monoculture for eight years and had been receiving annual applications of 500 kg ha^{-1} of 00-20-18 N-P_2O_5-K_2O fertilizer applied at planting.

The regional climate is Aw according to the Köppen global climate classification, with two distinct seasons, consisting of a dry season that lasts from May to September and a rainy season from October to April. The precipitation and temperatures that occurred during the experiment are shown in Figure 1.

Table 1. Chemical composition of soil (0-0.2m) in experimental area before installation of experiment.

pH (H_2O)	P (Mehlich)	K	Ca	Mg	Al	H+Al	O.M[1]
	mg dm^{-3}		cmol$_c$ dm^{-3}				g dm^{-3}
5.0	36.4	77.0	2.1	0.4	0.2	4,6	14
V[2]	**CEC[3]**	**Fe**	**B**	**Mn**	**Zn**	**Cu**	**S**
%	cmol$_c$ dm^{-3}		mg dm^{-3}				
37	7.3	129	0.3	8.5	3.7	1.4	8.0

[1]O.M.: organic matter; [2]V: based saturation; [3]CEC: cation exchange capacity. Methodology according Embrapa (1997).

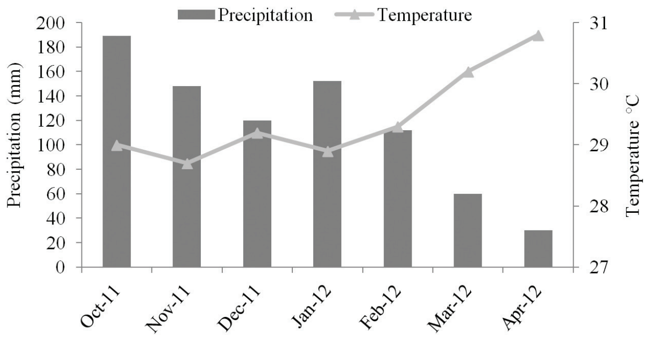

Figure 1. Average temperature and precipitation occurring in Bom Jesus, PI during conduct of the experiment, in the Piauí Cerrado region (2011/2012 crop season).

Planting took place on December 5, 2011 (cultivar Monsoy 9350), distributing 13 seeds per meter at 0.5 m spacing between rows and seeding depth of 2-3 cm. Seeds were treated with *Bradyrhizobium*. Basic fertilizer was applied at the time of planting, consisting of 400 kg ha^{-1} of superphosphate.

The experimental design was randomized block with four replicates in a factorial (5×4)+1 design. The treatments consisted of combinations of five K rates - 30, 60, 90, 120 and 150 kg ha^{-1} (K_2O) + control (zero kg ha^{-1}) – applied at four time periods: 100% at planting, 50% at planting and 50% at 30 days after sowing (DAS), 100% at 30 DAS, and 50% at 20 DAS and 50% at 40 DAS, using as a source of potassium chloride. Each plot consisted of ten rows spaced at 0.5 m and 5 m long, totaling 25 m^2; the usable area for the evaluations was 12 m^2. The treatments were applied manually.

Crop treatments (weed control, pests and diseases) before and after planting were those recommended for the region and for the variety, and according to the needs of the crop.

At full bloom, the following was evaluated: height and dry weight of plants, taking five plants per plot. To determine the dry weight, the plants were placed in a forced circulation oven at 65 °C for 72 h. At harvest, we evaluated the dry weight, number of pods plant^{-1}, number of grains pod^{-1} by taking five plants per plot, thousand seed weight and grain yield, standardized at 13% moisture.

The grain harvest index (GHI) was obtained as follows (Equation 1):

$$GHI = \frac{grain\,yeld}{grain\,yeld + straw} \quad (1)$$

Estimates of simple and phenotypic correlation coefficients were obtained by means of the original data with repetitions, among the characters as described by Steel and Torrie (1980). Correlations were split into direct and indirect effects of traits of agronomic importance for soybean (independent variables from the regression model) on the variable of productivity by means of path analysis (Wright, 1921).

To minimize the effect of multicollinearity that may occur in path analysis, which is when there is an overestimation of the direct effects of the explanatory variables on the response variable, leading to misinterpretation, particularly when multicollinearity is strong (>100) proceeding to the establishment of the degree of multicollinearity of singular matrix X'X based on its number of conditions and introduction of the constant K in the model (Montgomery; Peck, 1981). The analysis of the eigenvalues of the matrix of phenotypic correlation was performed to identify the nature of the existing linear dependence among the characters, detecting those that contributed to the emergence of multicollinearity (Belsley et al., 1980). The characters with the largest elements in the eigenvectors associated with smallest eigenvalues were the main contributors to this emergence.

Phenotypic correlations were estimated by the method proposed by Steel and Torrie (1980) and subsequently partitioned into direct and indirect effects by path analysis (Cruz; Carneiro, 2003). The analyses were performed by using of the GENES computer software (Cruz, 2001) and SAEG. Although testing the effect of crop season as a factor was not an objective, a pre-analysis was done, in order to verify a possible effect on the evaluated traits. All variables showed normal distribution according to the Shapiro Wilk at 1 or 5% probability.

3 Results and Discussion

With the exception of the variable plant height at flowering ($p \leq 0.01$), the other variables were not significantly affected by treatments (Table 2), thus demonstrating that the application time of K does not affect the variables analyzed. The control treatment (zero K application) differed from factorial combinations of treatments (contrast control versus factor) for the variables PROD, DWAPF and DWAPH at the significance level of 5% and at 1% significance level for the variable PHF. This implied that with no potassium fertilization, productivity will be lower. Predominantly, it was found that the variation coefficients were low to medium in magnitude.

Even with the lack of significance for the factorial combinations, all data obtained in the factorial were used for the calculation of Pearson correlations and later in the path analyses.

The estimates of the simple or phenotypic correlation coefficients evaluated for the eight traits of agronomic importance for soybean are presented in Table 3. In interpreting correlations between characters the magnitude, direction and significance should be considered. Positive correlation coefficient estimates indicate a trend of one variable increasing while the other increases; negative correlations indicate a tendency of one variable to increase as the other decreases. According to Falconer e MacKay (1996), one of the reasons for high correlations is pleiotropism, in which the same gene affects the expression of more than one character. This information is useful in plant breeding because it facilitates simultaneous selection of two or more characters by selection of only one of them.

The highest phenotypic correlations (of the same sign and significance) with PROD were obtained for WOTS (0.88) and GHI (0.71). These positive values were higher than those estimated for the other characters evaluated in this study, suggesting that these characters contributed to the linear increase of PROD of soybean. In contrast, the highest correlation (significant and negative) with PROD was NGPP

Table 2. Analysis of variance of variables submitted to doses of potassium applied at four different times.

F.V	G.L.	Mean Squares							
		PROD	PHF	DWAPF	DWAPH	NPPP	NGPP	WOTS	GHI
Blocks	3	1119958.81	25.00	266.96	3.75	404.14	0.11	98.21	0.00244
Treatments	20	293136.66	27.41**	195.92	17.18	187.51	0.05	200.07	0.00093
Factorial	19	244579.72	18.35	174.28	15.46	179.80	0.04	197.41	0.00098
Contrast	1	1215718.60*	199.55**	607.20*	49.97*	333.93	0.07	250.71	0.00004
Residual	60	208002.72	12.41	135.09	11.37	132.03	0.06	257.93	0.00087
Mean Experiment		3843.51	63.89	95.77	22.70	86.42	2.05	148.98	0.79179
Mean Factorial		3870.41	64.24	96.38	22.87	86.86	2.06	149.36	0.79163
Mean Control		3305.50	57.00	83.75	19.25	77.50	1.93	141.25	0.79500
CV (%)		11.78	5.48	12.06	14.74	13.23	12.19	10.75	3.75

(PROD: Productivity (kg.ha^{-1}); PHF: Height at flowering; DWAPF – dry weight of aerial part of plant at flowering; DWAPH- dry weight of aerial part at harvest; NPPP: number of pods per plant; NGPP: number of grains per pod; WOTS: weight of one thousand seeds; GHI: grain harvest index. * and ** represent that the correlation was significant at the 5% and 1% levels, respectively, by F test.

Table 3. Estimate of phenotypic correlation coefficients of eight agronomic characters submitted to doses of potassium combined with timing of application for the soybean cultivar Monsoy 9350, in Bom Jesus-PI.

Variables (+)	PHF	DWAPF	DWAPH	NPPP	NGPP	WOTS	GHI
PROD	-0.32	-0.41	0.23	0.37	-0.89**	0.88**	0.71**
PHF		-0.64**	-0.52*	-0.84**	0.10	-0.09	-0.21
DWAPF			0.64**	0.25	0.36	-0.71**	-0.60**
DWAPH				0.00	-0.45*	-0.27	-0.44*
NPPP					0.04	0.40	0.62**
NGPP						-0.64**	-0.35
WOTS							0.94**

(+)PROD: Productivity (kg.ha^{-1}); PHF: Height at flowering; DWAPF – dry weight of aerial part of plant at flowering; DWAPH- dry weight of aerial part at harvest; NPPP: number of pods per plant; NGPP: number of grains per pod; WOTS: weight of one thousand seeds; GHI: grain harvest index.* and ** represent that the correlation was significant at the 5% and 1% levels, respectively, by Student's t-test.

(-0.89), indicating that these characters are inversely linearly related; that is, as the average value of PROD increases the average value of NGPP decreases.

These correlation results disagree with those derived by Nogueira et al. (2012), who did not find significant correlations between the number of seeds per pod and yield of soybean at two sowing dates (February and December). These same authors found high correlations, positive and significant, among the number of pods per plant and yield at the two sowing dates, also disagreeing with the results of the present work. However, there was agreement for correlations between harvest index and productivity that were high, positive and significant.

A likely explanation for change in correlations among soybean traits could be fertilization management. In this study, possibly because of the soybean plants had received potassium fertilization in installments and at various dosages, the grains were well supplied with photoassimilates (attested to by the high GHI) and some yield components were certainly affected, altering their correlations with production. The GHI expresses the efficiency of the crop in converting biomass into grain productivity. According to Fageria and Santos (2008) there is a positive correlation between GHI and productivity. It appears that in this study there was a direct effect of DWAPF and GHI, confirming the assertion previously reported. These results highlight the importance of GHI in path analysis for use in breeding programs, since many studies have disregarded GHI as a composition parameter in path analysis.

Accordingly, the mass of grains is generally much more positively affected by fertilization than by increase of NGPP, since the latter is influenced more heavily by the genetic characteristics of the cultivars and thus a variable that could not be as important in final yield because there are others that contribute with greater weight, such as WOTS. Additionally, on this basis is also possible to explain the fact of having obtained low values of correlation between number of pods per plant (NPPP) and production, as well as low direct effect of this trait on production.

In several studies, these two variables were strongly correlated and the NPPP with high direct effect on production (Alcântara Neto et al., 2011; Nogueira et al., 2012). One of the practical uses of correlations among characters is in plant breeding, where it is important to identify among the characters of high correlation with the main character and of greater direct effect in the direction favorable to selection, so that the correlated response through indirect selection is efficient (Cruz et al., 2004). However, grain productivity is a complex character and its expression depends on other characters, which influence it directly or indirectly.

The correlation coefficient measures only linear relationships, but there may be high determination among the variables not of the linear type. A high correlation does not imply a cause and effect relationship between the variables analyzed. The correlations are generally explained by the additive effect, affecting two characters simultaneously (Santos; Vencovsky, 1986). The study of correlations among characters does not allow the drawing of conclusions about cause and effect relationships, because correlation is a measure of association (Vencovsky; Barriga, 1993). Therefore we proceeded to path analysis which investigates cause and effect relationships and provides quantities, called path coefficients. Estimates of the direct and indirect effects of the primary yield components on the variable PROD are outlined in Figure 2. The sum of the direct and indirect effects results in the correlation coefficient. The characters DWAPH, WOTS and GHI showed the largest direct effects, the highest correlation coefficients and low indirect effects with PROD.

Estimates of the direct and indirect effects of the primary components on the main variable (PROD) are well explained by the proposed path model, by the high value of its coefficient of determination ($R^2 = 0.98$) and low residual effect (Table 4). Certainly, the inclusion of the constant K in the model eliminated the potential problems of multicollinearity. Thus, the explanatory model expressed the cause and effect relationship among the primary variables and soybean productivity.

Analyzing the highest positive values of total correlation of the secondary variables with productivity (PROD), observed in Table 3, which were WOTS and GHI, it is observed in Table 3 that the direct effect of WOTS on PROD was 0.31, only 35% of the total correlation. The largest indirect effect of WOTS on PROD was via NGPP (0.28), representing 32% of the total correlation. GHI, despite having presented a high positive correlation with PROD (0.71), had a much smaller cause and effect relationship, because its direct effect on PROD was only 0.20 (28% of the total correlation). Among its indirect effects, the largest of was via PMS (0.29), higher even than its direct effect on PROD (Table 4).

Another variable that also deserves mention is NGPP which showed high correlation value with PROD although negative (-0.89); however, on breaking out the direct effect the value obtained was -0.44 for the direct effect of NGPP on PROD. This represents less than 50% of the total correlation. The largest indirect effect of NGPP on PROD was via WOTS (-0.19) (Table 4).

The variable DWAPH, despite having presented low total correlation with PROD (0.23), nearly all of this amount resulted in a direct effect on PROD (0.21) (Table 3). The variables DWAPF and PHF showed low direct effects on PROD, lower even than the residual effect (Table 4), and also low indirect effect on PROD via secondary variables.

Based on the effects of secondary characters on the primary, it is possible to identify characters that can maximize the correlated response in a genetic breeding program. The largest positive direct effects and greater than the residual effect on productivity were obtained with the variables WOTS, DWAPH and GHI, indicating that indirect selection on these primary characters would be effective. The variable NGPP showed the

Table 4. Estimates of the direct and indirect effects of the primary yield components (PHF, DWAPF, DWAPH, NPPP, NGPP, WOTS e GHI) on the principle variable (PROD) of soybean.

Character	Estimator	Correlation Estimate	Total
PHF			
Direct effect on PROD	$\hat{P}01$	-0.12	
Indirect effect on DWAPF	$\hat{P}02.r12$	0.09	
Indirect effect on DWAPH	$\hat{P}03.r13$	-0.11	
Indirect effect on NPPP	$\hat{P}04.r14$	-0.06	
Indirect effect on NGPP	$\hat{P}05.r15$	-0.04	
Indirect effect on WOTS	$\hat{P}06.r16$	-0.03	
Indirect effect on GHI	$\hat{P}07.r17$	-0.04	
Phenotypic correlation (Total)	r01		-0.32
DWAPF			
Direct effect on PROD	$\hat{P}02$	-0.14	
Indirect effect on DWAPF	$\hat{P}01.r12$	0.08	
Indirect effect on DWAPH	$\hat{P}03.r23$	0.14	
Indirect effect on NPPP	$\hat{P}04.r24$	0.18	
Indirect effect on NGPP	$\hat{P}05.r25$	-0.16	
Indirect effect on WOTS	$\hat{P}06.r26$	-0.22	
Indirect effect on GHI	$\hat{P}07.r27$	-0.12	
Phenotypic correlation (Total)	r02		-0.41
DWAPH			
Direct effect on PROD	$\hat{P}03$	0.21	
Indirect effect on DWAPF	$\hat{P}01.r13$	0.06	
Indirect effect on DWAPH	$\hat{P}02.r23$	-0.09	
Indirect effect on NPPP	$\hat{P}04.r34$	0.00	
Indirect effect on NGPP	$\hat{P}05.r35$	0.20	
Indirect effect on WOTS	$\hat{P}06.r36$	-0.08	
Indirect effect on GHI	$\hat{P}07.r37$	-0.09	
Phenotypic correlation (Total)	r03		0.23
NPPP			
Direct effect on PROD	$\hat{P}04$	0.07	
Indirect effect on DWAPF	$\hat{P}01.r14$	0.10	
Indirect effect on DWAPH	$\hat{P}02.r24$	-0.03	
Indirect effect on NPPP	$\hat{P}03.r34$	0.00	
Indirect effect on NGPP	$\hat{P}05.r45$	-0.01	
Indirect effect on WOTS	$\hat{P}06.r46$	0.12	
Indirect effect on GHI	$\hat{P}07.r47$	0.13	
Phenotypic correlation (Total)	r04		0.37
NGPP			
Direct effect on PROD	$\hat{P}05$	-0.44	
Indirect effect on DWAPF	$\hat{P}01.r15$	-0.01	
Indirect effect on DWAPH	$\hat{P}02.r25$	-0.04	
Indirect effect on NPPP	$\hat{P}03.r35$	-0.09	
Indirect effect on NGPP	$\hat{P}04.r45$	0.00	
Indirect effect on WOTS	$\hat{P}06.r56$	-0.19	
Indirect effect on GHI	$\hat{P}07.r57$	-0.07	
Phenotypic correlation (Total)	r05		-0.89
WOTS			
Direct effect on PROD	$\hat{P}06$	0.31	
Indirect effect on DWAPF	$\hat{P}01.r16$	0.01	
Indirect effect on DWAPH	$\hat{P}02.r26$	0.10	
Indirect effect on NPPP	$\hat{P}03.r36$	-0.05	
Indirect effect on NGPP	$\hat{P}04.r46$	0.03	
Indirect effect on WOTS	$\hat{P}05.r56$	0.28	
Indirect effect on GHI	$\hat{P}07.r67$	0.19	
Phenotypic correlation (Total)	r06		0.88
GHI			
Direct effect on PROD	$\hat{P}07$	0.20	
Indirect effect on DWAPF	$\hat{P}01.r17$	0.02	
Indirect effect on DWAPH	$\hat{P}02.r27$	0.09	
Indirect effect on NPPP	$\hat{P}03.r37$	-0.09	
Indirect effect on NGPP	$\hat{P}04.r47$	0.04	
Indirect effect on WOTS	$\hat{P}05.r57$	0.16	
Indirect effect on GHI	$\hat{P}06.r67$	0.29	
Phenotypic correlation (Total)	r07		0.71
Variable residual effect	$\hat{P}\varepsilon$		0.15
Coefficient of Determination			0.98
Value of K			0.0052

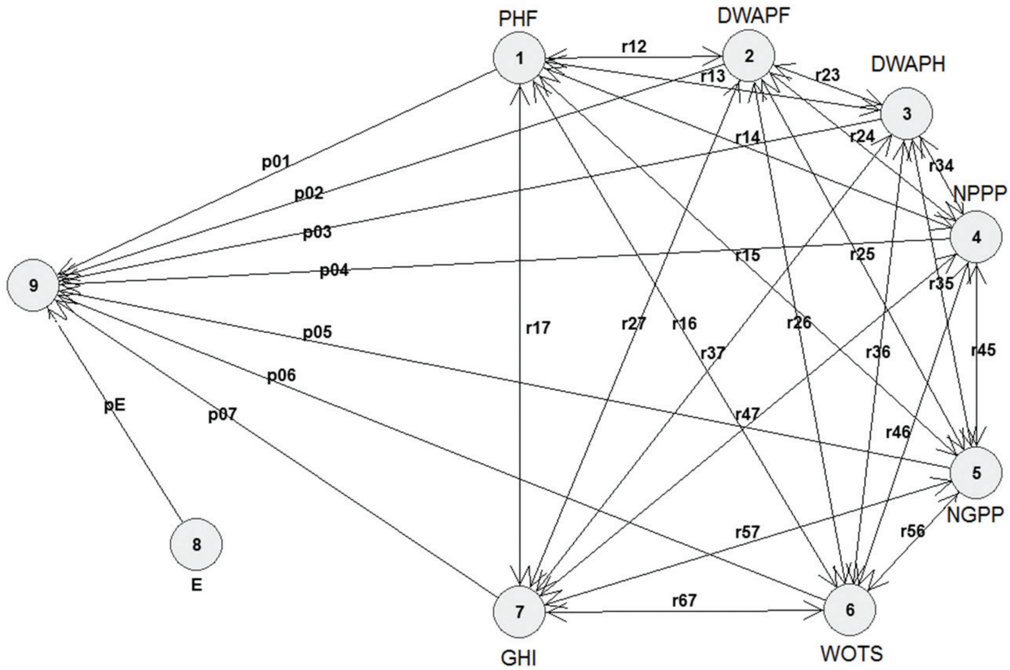

Figure 2. Schematic demonstration of the phenotypic correlation coefficients among the primary components production height at flowering (PHF); dry weight of aerial part at flowering (DWAPF); dry weight of aerial part at harvest (DWAPH); number of pods per plant (NPPP); number of grains per pod (NGPP); weight of one thousand seeds (WOTS); grain harvest index (GHI) on the principle productivity variable (PROD) of soybean submitted to different doses and application timing of potassium.

highest direct effect on productivity, but with a negative sign. The variables PHF, DWAPF and NPPP had direct effects on productivity lower than the residual effect; therefore, they can be considered insignificant and are not indicated for indirect selection.

4 Conclusions

The timing of K application in Piauí Cerrado did not influence the magnitude of phenotypic correlations. Treatments that received potassium differed significantly from control (without fertilizer) in terms of productivity. WOTS and GHI were the variables that showed higher and positive correlations with soybean productivity. The largest positive direct effects and greater than the residual effect on productivity were obtained with the variables WOTS, DWAPH and GHI, indicating that indirect selection of these primary characters would be effective under the conditions of conduct of the study. GHI was found to present high viability as a parameter to be evaluated in path analysis.

References

ALCÂNTARA NETO, F.; GRAVINA, G. A.; MONTEIRO, M. M. S.; MORAIS, F. B., PETTER, F. A.; ALBUQUERQUE, J. A. A. Análise de trilha do rendimento de grãos de soja na microrregião do Alto Médio Gurguéia. *Comunicata Scientiae*, v. 2, p. 107-112, 2011.

AMORIM, E. P.; RAMOS, N. P.; UNGARO, M. R. G.; KIIHL, T. A. M. Correlações e análise de trilha em girassol. *Bragantia*, v. 67, p. 307-316, 2008. http://dx.doi.org/10.1590/S0006-87052008000200006

BELSLEY, D. A.; KUH, E.; WELCH, R. E. Regression diagnostics: identifying data and sources of colinearity. New York: J. Wiley, 1980. 292 p. http://dx.doi.org/10.1002/0471725153

CARVALHO, C. G. P.; ARIAS, C. A. A.; TOLEDO, J. F. F.; OLIVEIRA, M. F.; VELLO, N. A. Correlações e análise de trilha em linhagens de soja semeadas em diferentes épocas. *Pesquisa Agropecuária Brasileira*, v. 37, p. 311-320, 2002. http://dx.doi.org/10.1590/S0100-204X2002000300012

CRUZ, C. D. Programa GENES – Versão Windows, aplicativo computacional em genética e estatística. Viçosa: UFV, 2001. 648 p.

CRUZ, C. D.; CARNEIRO, P. C. S. *Modelos biométricos aplicados ao melhoramento genético.* Viçosa: UFV, 2003. 579 p.

CRUZ, C. D.; REGAZZI, A. J.; CARNEIRO, P. C. S. *Modelos biométricos aplicados ao melhoramento genético.* v. I. 3. ed. Viçosa: UFV, 2004. 480 p.

EMBRAPA. Centro Nacional de Pesquisa de Solos. *Manual de métodos de análise de Solo*. 2. ed. rev. atual. Rio de Janeiro: Embrapa, 1997. 212 p.

FAGERIA, N. K.; SANTOS, A. B. Yield physiology of dry bean. *Journal of Plant Nutrition*, v. 31, p. 983-1004, 2008. http://dx.doi.org/10.1080/01904160802096815

FALCONER, D. S.; MacKAY, T. F. C. *Introduction to quantitative genetics.* 4th ed. Essex: Longmans Green, 1996. 464 p.

FERREIRA, F. M.; BARROS, W. S.; DA SILVA, F. L.; BARBOSA, M. H. P.; CRUZ, C. D.; BASTOS, I. T. Relações fenotípicas e genotípicas entre componentes de produção em cana-de-açúcar.

Bragantia, v. 66, p. 605-610, 2007. http://dx.doi.org/10.1590/S0006-87052007000400010

GOLDENBERG, J. B. El empleo de la correlacion en el mejoramento genetico de las plantas. *Fitotecnia Latinoamericana*, v. 5, p. 1-8, 1968.

MONTGOMERY, D. C.; PECK, E. A. *Introduction to linear regression analysis*. New York: Editora John Wiley & Sons,1981. 504 p.

NOGUEIRA, A. P. O.; SEDIYAMA, T.; SOUZA, L. B.; HAMAWAKI, O. T.; CRUZ, C. D.; PEREIRA, D. G.; MATSUO. E. Análise de trilha e correlações entre caracteres em soja cultivada em duas épocas de semeadura. *Bioscience Journal*, v. 28, p. 877-888, 2012.

OLIVEIRA, R. H.; ROSOLEM, C. A.; TRIGUEIRO, R. M. Importância do fluxo de massa e difusão no suprimento de potássio ao algodoeiro como variável de água e potássio no solo. *Revista Brasileira de Ciência do Solo*, v. 28, n. 03, p. 439-445, 2004. http://dx.doi.org/10.1590/S0100-06832004000300005

PACHECO, L. P.; PETTER, F. A. Benefits of Cover Crops in Soybean Plantation In Brazilian Cerrados. In: NG, T. B. (Ed.). *Soybean – Applications and Technology*. 2011. p. 67-94. http://dx.doi.org/10.5772/15675

PETTER, F. A.; SILVA, J. A.; PACHECO, L. P.; ALMEIDA, F. A.; ALCÂNTARA NETO, F.; ZUFFO, A. M.; LIMA, L. B. Desempenho agronômico da soja a doses e épocas de aplicação de potássio no cerrado piauiense. *Revista de Ciências Agrárias*, v. 55, n. 3, p. 190-196, 2012. http://dx.doi.org/10.4322/rca.2012.057

RIGON, J. P. G.; CAPUANI, S.; BRITO NETO, J. F.; DA ROSA, G. M.; WASTOWSKI, A. D.; RIGON, C. A. G. Dissimilaridade genética e análise de trilha de cultivares de soja avaliada por meio de descritores quantitativos. *Revista Ceres*, v. 59, p. 233-240, 2012. http://dx.doi.org/10.1590/S0034-737X2012000200012

SANTOS, J.; VENCOVSKY, R. Correlação fenotípica e genética entre alguns caracteres agronômicos do feijoeiro (*Phaseolus vulgaris* L.). *Ciência e Prática*, v. 10, n. 3, p. 265-272, 1986.

STEEL, R. G. D.; TORRIE, J. H. *Principles and producers of statistics: a biometrical approach*. 2nd ed. New York: McGraw-Hill, 1980. 631 p.

VENCOVSKY, R.; BARRIGA, P. Genética biométrica no fitomelhoramento. Ribeirão Preto: Sociedade Brasileira de Genética, 1992. 486 p.

WRIGHT, S. Correlation and causation. *Journal Agricultural Research*, v. 20, p. 557-585, 1921.

Authors' contributions: Fabiano André Petter – Conducted the experiment, statistical analysis and scientific writing; Francisco de Alcântara Neto - Conducted the experiment and scientific writing; Willian Silva Barros - Statistical analysis and scientific writing; Leandro Pereira Pacheco - Conducted the experiment and scientific writing; Larissa Borges de Lima - Conducted the experiment and helped in the English revision of scientific writing; Geraldo de Amaral Gravina – Statistical analysis and scientific writing.

Funding source: There was no financial support.

Conflict of interest: The authors declare no conflicts of interest.