Correlations of agronomic characteristics of soybean cultivated with the use of organomineral fertilizers

Correlações de características agronômicas da soja cultivada com o uso de fertilizantes organominerais

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ABSTRACT
The use of correlations can identify the traits correlated with soybean grain yield. Therefore, the objective of this study is to use path analysis to examine how agronomic traits influence grain yield in soybeans, taking into account different doses and sources of organominerals used in cultivation. The experimental design used was randomized blocks arranged in a sub-subdivided plot with three replications. In the plots, the treatments consisted of two soybean cultivars (BMX Bônus IPRO and BMX Olimpo IPRO), and in the subplot, the treatments consisted of three phosphate fertilizers [two organomineral fertilizers manufactured and a phosphate fertilizer (simple superphosphate)]. The subplot used doses of 0 (control), 50, and 100 kg ha⁻¹ of P₂O₅. At full flowering, the relative chlorophyll index was evaluated. At physiological maturity, plant height, first pod insertion height, number of stems, pod number, number of grains per pod, thousand-grain mass, and grain yield were evaluated. The plant height variable presented the greatest positive direct effect on the soybean yield cultivated using organomineral fertilizers.

Keywords: Glycine max, direct selection, indirect selection.

RESUMO
O uso da das correlações pode identificar as características correlacionadas com a produtividade dos grãos da soja. Portanto, o objetivo deste estudo é utilizar a análise de trilha para examinar como os caracteres agronômicos influenciam a produtividade de grãos na cultura da soja, levando em consideração distintas doses e fontes de organominerais utilizadas no cultivo. O delineamento experimental utilizado foi o de blocos ao acaso, dispostos em esquema de parcela subsubdividida,
com três repetições. Nas parcelas, os tratamentos consistiram em duas cultivares de soja (BMX Bônus IPRO e BMX Olimpo IPRO), e na subparcela os três fertilizantes fosfatados [sendo dois fertilizantes organominerais fabricados, e um fertilizante fosfatado (superfosfato simples)]. E, na subparcela as doses de 0 (controle), 50 e 100 kg de P₂O₅ por ha⁻¹. No florescimento pleno foi avaliado o índice relativo de clorofila e na maturidade fisiológica foi avaliado a altura de plantas, altura de inserção do primeiro legume, número de hastes, número de legumes, número de grãos por legume, massa de mil grãos e produtividade de grãos. A variável altura de plantas foi a que apresentou maior efeito direto positivo na produtividade dos grãos de soja cultivada com o uso de fertilizantes organominerais.

**Palavras-chave:** *Glycine max*, seleção direta, seleção indireta.

**1 INTRODUCTION**

Soybean [*Glycine max* (L.) Merrill] is a relevant commodity for the Brazilian economy, with Brazil being the main producer and exporter of this legume to the world. In the 2021/2022 harvest, the country cultivated approximately 41.5 million hectares, with an average grain yield of 3.026 kg ha⁻¹ (CONAB, 2022). The Cerrado is Brazil's second-largest biome and an important grain-producing region. According to Mapbiomas (2020), the Cerrado Biome is responsible for slightly more than half of all national production, producing approximately 16.8 million hectares in the last 36 years.

Soils in tropical regions such as Brazil generally have low availability of phosphorus (P), which means there is a greater need for the use of fertilizers, especially those that are a source of phosphorus (LWIN *et al*., 2017). Thus, P deficiency in Brazilian soils, especially Cerrado, requires P fertilization to increase grain yield (CARNEIRO *et al*., 2017). Thus, to recommend the nutrients of this soil, it is necessary to use fertilizers available on the market. According to Vimal *et al*., (2017), due to the high costs of industrial fertilizers in addition to the damage caused to the environment, it is necessary to seek new alternatives, such as organic fertilization, as it provides greater fertility, improves physical characteristics, and stimulates soil microbial activity.

The soybean crop has variables that can influence grain productivity, and the study and understanding of these variables, as well as understanding the cause-and-effect relationship they cause in the agronomic performance of the crop, is one of the main ways to seek alternatives for genetic and cultural management of the plant. Thus, path analysis allows for understanding the direct and indirect effects of the difference between two variables, such as the main and
determinate ones. Therefore, it is possible to estimate the relationship between the characteristics after an analysis and using some correlation coefficient between the variables (OLIVEIRA et al., 2022).

The path analysis method developed by Wright (1921) lists the variables that cause direct or indirect effects of each character on a basic variable. It is possible to analyze whether the correlation between two variables is cause and effect or generated by the influence of other variables. Correlation is a statistical value that allows the evaluation of the degree of relationship between two variables and the intensity of this relationship, considering that for the correlated variables, the variation that occurs in one is followed by the variation in the other (RAMALHO et al., 2012). Identifying traits correlated with productivity is an important tool to select more responsive genotypes.

Using path analysis and correlations to study different soybean cultivars grown at different plant densities, Zuffo et al. (2018) concluded that indirect characteristics can explain more than 84% of the variation observed in grain yield. In addition, the number of pods was the most influential variable for soybean yield, with the number of grains per plant being the second variable. With a greater effect on soybean yield, it was also possible to see the effect of plant height on grain yield, which was negative and low, indicating that the trait has a small contribution to grain yield.

Path analysis can identify traits correlated with grain yield, which helps to select more responsive genotypes. Therefore, the objective of this study is to use path analysis to examine how agronomic traits influence grain yield in soybeans, taking into account different doses and sources of organominerals used in cultivation.

2 MATERIAL AND METHODS

The experiment was carried out in the field at the Experimental Station of 'Accert Pesquisa e Consultoria Agronômica' located in Balsas – MA, Brazil (07°31'57” S, 46°02'08” W and altitude of 283 m), in the 2022/23 growing season. According to the Köppen classification, the region's climate is tropical, hot, and humid (Aw), with rainy summers and dry winters (MARANHÃO, 2002). The total annual rainfall reaches an average values of 1175 mm (PASSOS et al., 2017). The data of the climatic conditions of the experiment are shown in Figure 1.
The soil in the experimental area was classified as sandy clay loam Yellow Latosol based on the Brazilian soil classification system (SANTOS et al., 2018). Before starting the experiment, the soils were sampled in the 0-20 and 20-40 cm layers, and the chemical and physical properties are shown in Table 1.

Table 1. Main chemical properties of the soils used in the experiment.

<table>
<thead>
<tr>
<th>Depth cm</th>
<th>pH H₂O</th>
<th>OM dag/kg</th>
<th>P_Mehlich-1 mg dm⁻³</th>
<th>H⁺Al cmol dm⁻³</th>
<th>Al³⁺</th>
<th>Ca²⁺</th>
<th>Mg²⁺</th>
<th>K⁺</th>
<th>CTC</th>
<th>BS %</th>
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<tbody>
<tr>
<td>0-20</td>
<td>6.00</td>
<td>1.29</td>
<td>54.95</td>
<td>1.20</td>
<td>0.01</td>
<td>2.15</td>
<td>0.71</td>
<td>136.00</td>
<td>4.41</td>
<td>72.78</td>
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<tr>
<td>20-40</td>
<td>4.65</td>
<td>0.23</td>
<td>20.72</td>
<td>1.80</td>
<td>0.54</td>
<td>0.95</td>
<td>0.30</td>
<td>70.00</td>
<td>3.23</td>
<td>44.26</td>
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<td>B</td>
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<tr>
<td>0-20</td>
<td>0.22</td>
<td>0.44</td>
<td>113.21</td>
<td>14.28</td>
<td>0.73</td>
<td>6.30</td>
<td>0.75</td>
<td>24.24</td>
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<td>66.49</td>
</tr>
<tr>
<td>20-40</td>
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<td>0.40</td>
<td>81.98</td>
<td>4.25</td>
<td>0.37</td>
<td>12.60</td>
<td>0.13</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Source: Research data.

The experimental design used was randomized blocks arranged in a sub-subdivided plot with three replications. In the plots, treatments consisted of two soybean cultivars (Cultivar 1: BMX Bônus IPRO - indeterminate growth habit, maturation cycle of 104 days, maturation group
7.9; Cultivar 2: BMX Olimpo IPRO - indeterminate growth habit, maturation cycle of 105 days, maturation group 8.0), and in the subplot was the three phosphate fertilizers [two organomineral fertilizers manufactured and a phosphate fertilizer (simple superphosphate)]. The subplot used the doses of 0 (control), 50, and 100 kg of P2O5 per ha-1. The manufacture of organomineral fertilizers consists of granulating bovine manure from feedlots in the region with natural phosphates (NP) and simple superphosphate (SS). Two organomineral fertilizers were produced, related to the proportions of the raw materials: 1- ORG1: Manure+NP and 2- ORG 2: Manure+Phosphate+SS. The chemical analysis of NP and SS was performed before fertilizer production. The production stages and proportion of raw materials are omitted from this text due to intellectual property. The organomineral fertilizers were granulated in the soil laboratory of the Federal University of Mato Grosso do Sul. The experimental unit consisted of four rows spaced 0.50 apart and 3.0 m long, totaling an area of 6.0 m². The two central rows were considered a useful area, with 1.0 m at each end discarded, making an area of 1.5 m².

Desiccation was performed using the products + Haloxyfop-R-methyl. After 15 days, the soybean was sown mechanically using a fertilizer seeder for a no-tillage system at a 3 cm depth, with a spacing of 0.50 m and 15 soybean seeds per meter, to reach a final stand of 300,000 plants per hectare. Sowing was carried out on December 28, 2022. The base fertilization only applied P sources (organominerals and super simple) in the sowing furrow. At 30 DAE of soybean plants, 90 kg ha⁻¹ of K₂O was applied, whose source was potassium chloride.

Soybean seeds treated with pyraclostrobin + methyl thiophanate + fipronil at a rate of 2 mL kg⁻¹ of seed were inoculated with Bradyrhizobium japonicum, Nod Soja® product at a dose of 3 mL kg⁻¹ of seed. During the development of the plants, the products recommended for the crop were used to manage weeds, pests, and diseases.

At stage R₂ (full flowering), five plants per plot were evaluated: relative chlorophyll index - with digital chlorophyll meter CFL 1030, readings were taken on the third trefoil developed from top to bottom (diagnostic leaf).

At the R₈ stage (maturation), the following variables were obtained from five plants per plot: plant height (cm) - determined from the soil surface to the insertion of the last leaf with the aid of a millimeter ruler; insertion height of the first pod (cm) - determined from the soil surface to the insertion of the first pod; number of stems, number of pods and number of grains per pod (unit) – through manual counting; mass of one thousand grains (g) - according to the
methodology described in Brasil (2009); grain yield (kg ha\(^{-1}\)) - determined by harvesting the useful area of the plot and standardized to a grain moisture content of 13%.

Analysis of statistical correlations based on Pearson's correlation networks (threshold set at 0.60, \(p < 0.05\)) between the different agronomic traits evaluated. A correlation network was used to graphically illustrate Pearson's correlation analyses, in which the proximity between nodes is proportional to the absolute correlation values between morphological characteristics. The relative thickness of the bands and the color density indicate the strength of the Pearson correlation coefficients, and the color of each band indicates a positive or negative correlation (red for negative and green for positive). These analyses were performed using Rbio software. Then, path analysis was performed as proposed by Wright (1921). Statistical analyses were performed using the Genes computational application (CRUZ, 2013). Before the path analysis, multicollinearity diagnosis was performed, as Cruz et al. (2012) detailed. The degree of multicollinearity of the correlation matrix was performed as described by Montgomery et al. (2006).

3 RESULTS AND DISCUSSION

Pearson's correlation analysis showed significant positive effects between the variable's number of pods per plant and the number of grains per plant (Figure 2). These results are similar to those observed by Ferreira et al. (2019), who studied the performance of soybean cultivars as a function of using organomineral fertilizers by foliar application to obtain high yields. The authors also found a positive correlation between the total number of pods per plant and the total number of grains per plant. Souza and Cabral (2023), when analyzing the use of biofertilizer doses in the soybean crop, concluded that the values found by the Pearson correlation indicated a weak or negligible relationship in the following variables: plant height, root dry mass, height of the root, dry mass of the plant, biomass of the plant, and biomass of the root, which was thus insufficient to say that the use of biofertilizers presents a proportional yield to that of conventional fertilizers.
Figure 2. Pearson correlation network between relative chlorophyll index (RCI), plant height (PH), the height of insertion of the first pod (HIFP), number of stems (NS), number of pods (NP), number of grains per plant (NGPL), number of grains per pod (NGP), thousand-grain mass (TGM) and grain yield (GY).

The variables number of pods per plant and number of grains per plant are directly related to the components of soybean seed yield, which is one of the main components of soybean yield because it is possible to estimate the mass of a thousand grains by yield (SCHEPKE et al., 2019). Thus, when using the analysis of statistical correlations based on Pearson's correlation networks (threshold set at 0.60, p<0.05) between the different agronomic traits evaluated, according to Zuffo et al. (2018), Pearson's correlation coefficient was used to express the degree of association between two numeric variables.

The coefficient of determination indicates that 0.574 of the effects on productivity are related to the indirect effects of the analyzed traits (Figure 3). In other words, 57.4% of the results obtained are explained by this model. According to Zuffo et al. (2020), the results of the path...
analyses allow the identification of the indirect relationship that exists between productivity and other factors, as well as the determination of which characteristics indirectly contribute most to these two main factors, thus assisting in future work on the crop of soy.

Figure 3. Direct and indirect effects of seven agronomic traits on soybean grain yield in the 2022/2023 season evaluated by means of relative chlorophyll index (a), plant height (b), insertion height of the first pod (c), number of stems per plant (d), number of pods per plant (e), number of grains per plant (f), number of grains per pod (g) and mass of one thousand grains (h). Balsas, MA, Brazil. Coefficient of determination of the causal model (R^2): 0.574. Effect of the residual variable (EVR): 0.390. Multicollinearity test of explanatory variables: moderate to strong (100<NC<1000). NC value: 952.48. K value: 0.05.

Source: Research data.
This coefficient of determination indicates that more than half of the indirect effects of the characteristics are found from the path analysis, which shows that this tool is very important when seeking greater productivity since it allows a better selection of these related characteristics to the main factor.

For the relative chlorophyll index (Figure 3a), the insertion of the first pod (Figure 3c), number of stems per plant (Figure 3d), number of pods per plant (Figure 3e), number of grains per plant (Figure 3f), number of grains per pod (Figure 3g) and mass of a thousand grains (Figure 3h), it was observed that the direct and indirect effects were not significant. These results do not corroborate those obtained by Zuffo et al. (2020), who found that the mass of a thousand grains and the total dry matter of the shoot were the characteristics that had the greatest positive direct effect on productivity. Alcântara Neto et al. (2011) found that the number of pods had a greater direct effect and that the number of nodes per plant had a strong indirect effect on soybean grain yield.

The chlorophyll content is a property of great importance for plants, as it is directly related to photosynthesis (chlorophyll molecules are responsible for capturing light energy to conduct reactions) where the better this content is, the greater the development of the plant and, therefore, the higher the yield (AHAMMED et al., 2018). The fact that there were no significant differences between the direct and indirect effects for the other variables can probably be explained by the fact that the organominerals used did not induce enough changes in the soil to promote changes in the behavior of the plant during its development period, consequently decreasing the influence of fertilization on these parameters.

Plant height significantly directly affected grain yield (Figure 3b). The data are similar to those obtained by Cabral et al. (2020), who investigated the effect of different doses of organominerals and triple superphosphate in response to plant height and other parameters in the soybean crop and found that the application of different sources of fertilizers resulted in significant differences in the plant height of soybean. Regardless of the doses, however, the highest plant height was found in plants fertilized with organomineral, 4% higher than the values found in plants fertilized with triple superphosphate. Machado et al. (2018), who sought to analyze the effect of organomineral fertilizer and mineral fertilizer with chicken manure on soybeans, did not find significant differences between average plant heights for organomineral doses.
Knowing that plant height may be closely related to root development, the direct effect of height on productivity may have been provided by the organomineral fertilizer, which, according to Gonçalves et al. (2022), promotes greater use of nutrients, minimizing their losses due to their slow release, in addition to improving soil attributes by incorporating organic matter, improving root development and consequently plant height. For Zanon et al. (2018), height influences the number of nodes and pods and affects grain yield.

4 CONCLUSION

The plant height variable presented the greatest positive direct effect on the productivity of soybeans cultivated using organomineral fertilizers.

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