AGRONOMY SCIENCE AND BIOTECHNOLOGY

RESEARCH ARTICLE

# Genetics, phosphorus and correlations in soybean yield

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## ABSTRACT

It is essential to select soybean genotypes with high yield and adaptability to the Cerrado Biome, mainly related to the supply of phosphorus. In soybeans, studies on correlations involving their characters with phosphate fertilization are insipient. The objective of this work was to evaluate the phenotypic correlations of soybean under different concentrations of phosphorus, aiming to improve the selection and identification of the most promising characters regarding the possibility of gains in grain yield. The study was conducted in Mineiros, Goiás, Brazil. The experimental design used was in randomized blocks in factorial corresponding to four soybean genotypes in five levels of phosphorus. The soil tillage system was carried out conventionally. The crop treatments relevant to the control of weeds and pests were carried out following the best practices of integrated pest management. At the end of the experiment, the data were submitted to multivariate analysis of variance. The treatments differed, mainly due to the number of grains per plant, where their similars were grouped in clusters. The correlations between the characters were significant and pointed to affinities, in addition to the potential explanation for the yield. It is concluded that genetic factor is largely responsible for the soybean yield indices, however, this was also influenced by the concentrations of triple super phosphate as a phosphate source. And that in order to increase the yield of the soybean crop it is necessary to reduce the stand and plant height, as well as to increase the average of pods with three grains, pods per plant and grains per plant.

**Keywords**: Agricultural genetics, *glycine max* (L), multivariate analysis, phosphating, fertilization, correlation.

## INTRODUCTION

In Brazil, soybeans (*Glycine max* L.) are grown in a wide variety of environments, including high and low latitudes. Due to this wide variation, it is essential to select genotypes with high yield and adaptability to various environments (Lopes et al., 2002). Among the environments, the Central region of Brazil is the largest producer of these commodities. Included in the Cerrado Biome, it naturally has its ecological peculiarities such as good rainfall and generally acidic soils, requiring management in order to perform agriculture.

Due to the acidity and clay minerals of these soils in relation to phosphorus, some difficulties have been observed in defining optimal levels of fertilization, when aiming at high yield, due to the complexation and unavailability of this nutrient. In basic fertilizations (sowing), phosphorus is generally supplied to plants in the form of soluble phosphates. The results of research and technical indications for the use of reactive natural phosphates, in the replacement of soluble sources, still raise doubts as to the best management. However, there is a consensus that the most soluble phosphates provide greater response in the year of application, while natural phosphates have less initial efficiency.

Soluble sources such as monoammonium (MAP) and diammonium (DAP) phosphates, and single, double and triple superphosphates are the main tools used by growers for supplementation via soil. For the latter, there are few studies that elucidate the behavior in soybeans, as for example in Ono et al. (2009) who found that the yield of this crop was positively influenced by the triple superphosphate doses, even so, its correlations with the analyzed characters were not addressed.

According to Lopes et al. (2002), the correlations reflect the degree of association between characters, their knowledge is important because it shows how the selection for one character influences the expression of other characters. In breeding programs, generally, in addition to aiming to improve a main character, we also seek to maintain or improve the expression of other characters simultaneously. In soybeans, studies on correlations involving their characters with different focuses are reported by Bárbaro et al. (2007), Sha et al. (2016), Zhang et al. (2016), Kong et al. (2019), Ferreira et al. (2019a), Ferreira et al. (2019b) and Kurt et al. (2020), however, there are no references to the correlations that describe their magnitudes with phosphate fertilization.

Thus, the present work aimed to evaluate the phenotypic correlations in eleven characters easily accessible to soybean growers under different concentrations of phosphorus, aiming at improving the selection and identification of the most promising characters regarding the possibility of gains in grain yield.

## MATERIAL AND METHODS

The study was conducted at the Luiz Eduardo de Oliveira Sales Experimental Farm at the University Center of Mineiros - UNIFIMES, in the county of Mineiros, Goiás, Brazil, located between the geographical coordinates of 17°34'10'' South latitude and 52° 33'04'' West longitude, with an average altitude of 760 m. The average temperature is 22.7 °C, the average annual rainfall is 1695 mm occurring mainly in spring and summer. The experimental area is classified as Aw type climate (hot to dry). The soil of the experimental area was classified as a Quartzarenic Neosol (Enitol) (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2013).

Before the installation of the experiment, soil collection and analysis was performed in the 0-20 cm surface layer, verifying the following characteristics:

hydrogen potential 4.1; phosphorus 3 in mg $dm^{-3}$; potassium 0.6, calcium 5, magnesium 3, aluminum 4, potential acidity 29, sum of bases 8.6, cation exchange capacity 37.6 and base saturation 22.94 in mmolc $dm^{-3}$; clay 80, silt 30 and sand 890 in g $dm^{-3}$. The analyzes were carried out according to the methodology of Embrapa (2009).

The experimental design used was in randomized blocks in a 4x5 factorial corresponding to four soybean genotypes (AS3680, NA5909, NA7337 and TMG1180), in five levels of phosphorus (0, 100, 200, 300 and 400 kg $ha^{-1}$ of $P_2O_5$) using as a nutritional source, Triple Superphosphate (41% $P_2O_5$ and 9% Ca), in 4 repetitions, totaling 20 treatments and 80 experimental units, dimensioned with six rows spaced 0.5 m and 5 m long. The main morpho-agronomic characteristics of soybean genotypes are shown in Table 1.

**Table 1**. Main morpho-agronomic characteristics of soybean genotypes. UNIFIMES, Mineiros, GO, Brazil, 2020.

| Genotype | | TGM (g) | Genetics | Maturity group | Growth habit | Cycle (days after emergence) Common |
|---|---|---|---|---|---|---|
| Common | Technical | | | | | |
| AS3680 | AS 3680 IPRO | 160 | Agroeste | 6.8 | Indeterminate | AS3680 |
| NA5909 | NA 5909 RR | 159 | Nidera | 6.2 | Indeterminate | NA5909 |
| NA7337 | NA 7337 RR | 171 | Nidera | 7.6 | Indeterminate | NA7337 |
| TMG1180 | TMG 1180 RR | 136 | TMG | 8.0 | Semideterminate | TMG1180 |

The soil tillage system was carried out with harrowing and plowing of the area on 10/07/2017. Sowing of the soybean genotypes was carried out on 10/8/2017, with 18 seeds distributed for NA7337 and TMG1180 (360,000 plants $ha^{-1}$), in addition to 15 seeds in the genotypes AS3680 and NA5909 (300,000 plants $ha^{-1}$) by meter in the furrow using a single-row planter and phosphate fertilizer in the sowing furrow according to the treatment description at a distance of 3 cm laterally from the seeds. Crop treatments related to weed and pest control were carried out whenever necessary, using the best practices of integrated pest management.

The variables were analyzed after the harvest on 03/08/2018. For this, it was determined: plant stand (STD, unit per linear meter); plant height (PH, meter), and first reproductive node height (FRH, centimeter); pods with one grain (POG, %), pods with two grains (PTWG, %), pods with three grains (PTHG, %), pods with four grains (PFG, %), pods per plant (PPP, unit), and grains per plant (GPP, unit), by counting the pods. The values were also determined; thousand grain mass (TGM, grams), and yield (YI, sc $ha^{-1}$ by means of an analytical balance, correcting the weight to 13% of grain moisture.

The data were submitted to the assumptions of the statistical model, verifying normality (Shapiro & Wilk, 1965) and homogeneity of variances (Steel et al., 1997). Afterwards, multivariate analysis of variance was performed in order to identify the differences resulting from the interaction between soybean genotypes and phosphate fertilization. Singh's (1981) criterion was used to quantify the relative contribution of the characters. The dendrogram was constructed using the UPGMA cluster and Tocher's optimization method (Rao, 1952). Subsequently, the canonical biplot method was used, where it was possible to visualize the general variability of the experiment and the multivariate trends. Canonical groups were established from variables related to those of production components (group 1) and the explanatory components of production (group 2). Group 1 consisted of the characters YI and

TGM; while group 2 was composed of STD, PH, FRH, POG, PTWG, PTHG, PFG, PPP and GPP. The Multi-trait stability Index was proposed according to Olivoto et al. (2019). The analyzes were performed using the statistical program R Core Team (2019).

## RESULTS AND DISCUSSION

The research briefly and objectively describes the interaction between the factors analyzed, which resulted in 20 treatments that differed from each other, as shown by the multivariate analysis of variance. The contributions of the characters were measured, describing their importance, where such divergences had their peers grouped into clusters. Thus, the correlations between the morpho-agronomic characters of fertilized soybean genotypes with the phosphate doses were described with their affinities, in addition to the potential for explaining the explanatory characters about those of production.

For that, the multivariate analysis of variance revealed significance among the treatments coming from the interaction (G x DP) ($p \leq 0.01$), by the test of the highest Hotelling-Lawley eigenvalue (Table 2). This information states that the element phosphorus in different doses influenced the behavior of soybean plants, and that these responses had different magnitudes among their genotypes. Some recent studies have reported positive effects on crop performance with phosphorus application, such as potatoes (Sausen et al., 2022; Sausen et al., 2021), beans (Mambrin et al., 2021) and amarantus (Rosa et al., 2021).

**Table 2.** Multivariate analysis of variance applied to the characters of soybean genotypes fertilized with phosphate doses, with significance based on the Hotelling-Lawley Test.

| SV | DF | approx | F num | Df den | Df | Pr(>F) |
|---|---|---|---|---|---|---|
| G x DP | 19 | 470.47 | 101.707 | 209 | 497 | 2.00E-16** |
| Blocks | 3 | 1.07 | 1.483 | 33 | 137 | 0.06113 |
| Residue | 57 | | | | | |

*** significant at 0.1% probability by the Hotelling-Lawley test. Soybean genotypes x doses of phosphorus G x DP.

As there were differences (G x DP), it was possible to observe that the character grains per plant (GPP) was responsible for the greatest divergence between treatments with a magnitude of 69.11% as can be seen in Figure 1. Less important characters were verified in pods per plant (PPP), pods with two grains (PTWG), pods with three grains (PTHG), plant height (PH) and yield (YI) in the contributions of 7.05, 6.51, 6.36, 5.43 and 4.59%, respectively (Figure 1).

The dendrogram obtained by combining the 5 phosphate concentrations and the 4 soybean genotypes generated 20 data entries, through the 11 characters described initially, there was the formation of 3 distinct clusters (Figure 2). Other studies, such as Sha et al. (2016), Zhang et al. (2016), Kong et al. (2019), Kurt et al. (2020) and Moura et al. (2021) also used the dendrogram to explain soybean performance.

In this analysis, it was observed that the genetic factor triggered the formation of clusters, where the AS3680 genotype formed cluster I, while cluster II was integrated by the TMG1180 genotype and the III cluster formed by the NA7337 and NA5909 genotypes with their respective phosphate concentrations (Figure 2). The information confirms the high influence of genetics on the effect of phosphate doses to distinguish differences. In the same, it was observed that the GPP was the character with the greatest contribution due to the divergence in the data entry of the gene interaction x doses of phosphate (Figure 2), as confirmed in Figure 1.

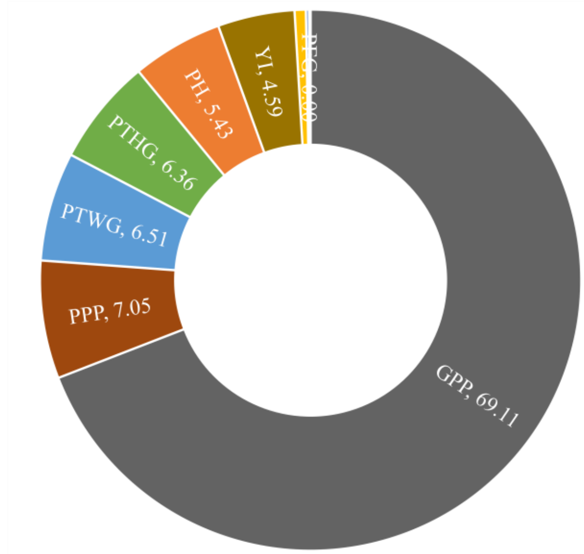


**Figure 1.** Relative contribution of agronomic characters (% percentage) to divergence of soybean genotypes fertilized with phosphate doses, by the method proposed by Singh (1981).

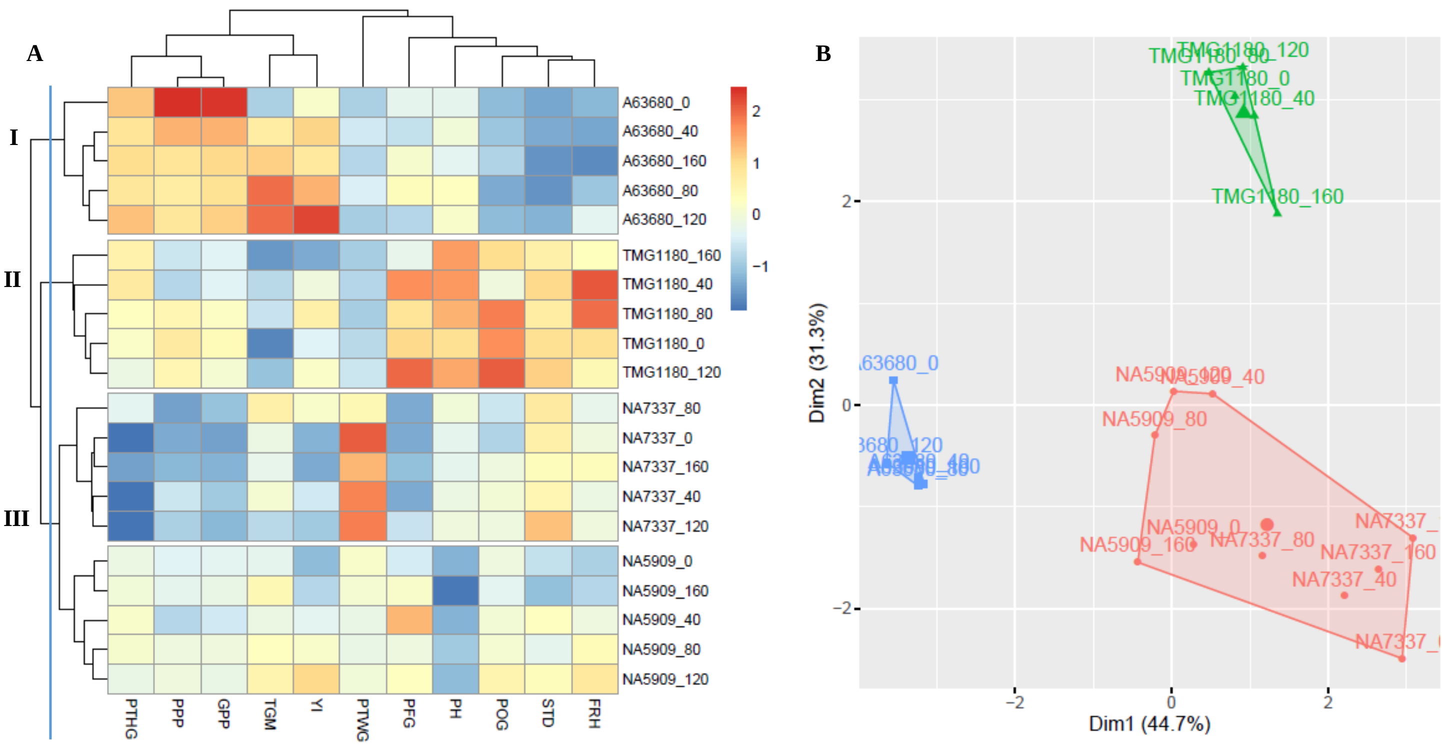


**Figure 2.** Heatmap dendrogram (A) and Cluster plot (B) constructed based on the average Euclidean distance, with UPGMA grouping and Tocher-optimized groups of soybean genotypes fertilized with phosphate doses.

In the analysis of principal components, the sum of the pairs was of the order of 76% of explanation of the total variation of the data (Figure 3). The analysis of canonical variables is still scarce in the literature, and works with good responses in the Cerrado are reported, such as Ferreira et al. (2019a) and Ferreira et al. (2019b). The TMG1180 genotype at all concentrations showed similarities for the characters

PFG, PH, POG and FRH. Similarity was also observed in the treatment AS3680 in the characters PTHG, PPP, GPP and YI confirming the influence of phosphorus dose on the genetic behavior of soybean genotypes. The PTWG character showed similarity in the NA7337 genotype in all phosphorus concentrations (Figure 3).

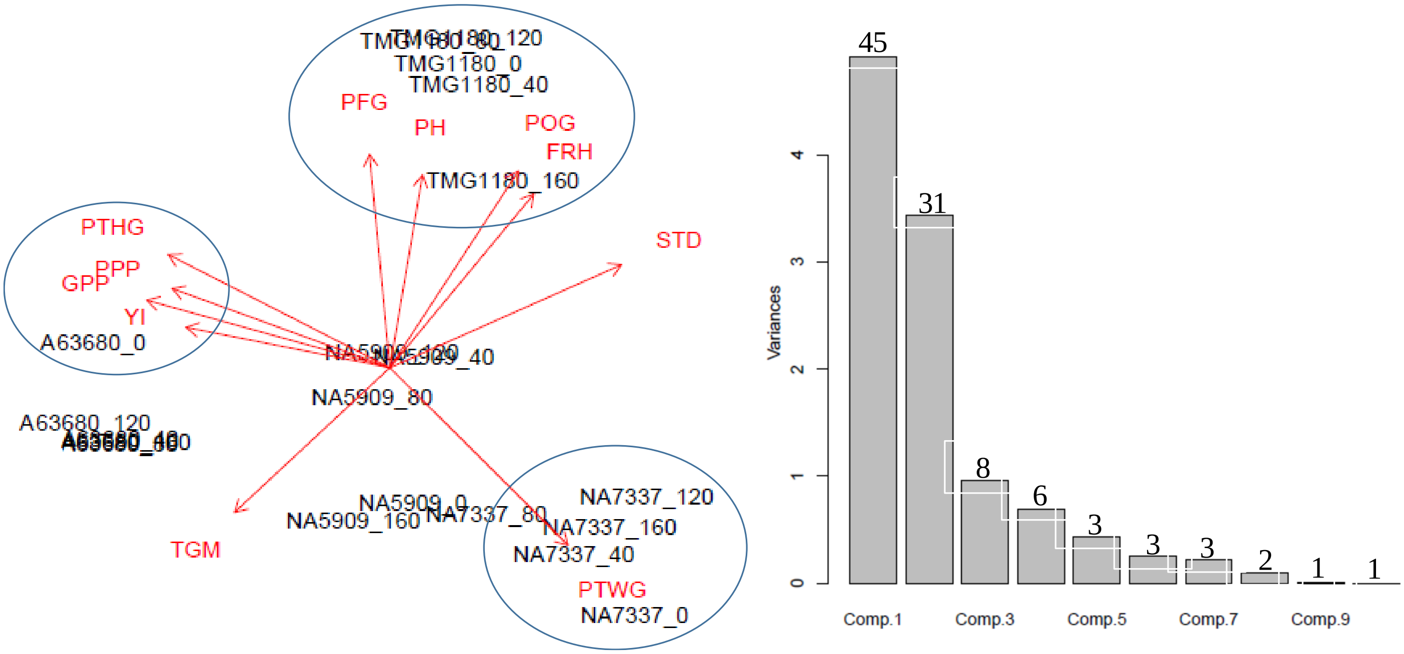


**Figure 3.** Principal component analysis applied to soybean genotypes fertilized with phosphate doses.

In the direct and indirect effects of the explanatory characters on those of production, the regression coefficients (r) were adjusted and validated by the probabilities (p) of both canonical pairs. The first canonical pair (U1 x V1) describes that the reduction in the thousand grain mass TGM is linked with the reduction of PTWG and increase of the other characters. The second canonical pair (U2 x V2) reports that the increase in yield YI is correlated to the increase in GPP, PPP and PTHG, as well as the reduction in STD, FRH, POG, PTWG and PH (Table 3). This analysis describes how the morphological characters should behave in the soybean plant, when high levels of profitability are desired with a focus on improving TGM and YI. This is what Bárbaro et al. (2007), when confirming that correlation studies, contribute to the identification of characters that can be used in indirect selection for grain yield.

In the classification of treatments for the MTSI (multitrait stability index) (Figure 4), considering the selection of 15% intensity, the treatments selected were A63680_120, A63680_80 and A63680_40 (MTSI = 0.45, 0.93 and 1.34, respectively). The MTSI shows the cutoff point (red circle) considering the intensity of the selection (Olivoto et al., 2019). The treatments were selected due to high averages in the number of vegetables per plant (PPP), number of grains per plant (GPP), weight of a thousand grains (TGM) and yield (YI), as described by Zuffo et al. (2020). The selected treatments have averages higher than the general average, in addition to being environmentally stable and can be used in several situations. It is worth mentioning that the MTSI index provides improvements in a set of characteristics favorable to the established ideotype (Woyann et al., 2019). For Szareski et al. (2018) the differential effects of the genotype x soybean production environment interaction influences by more than 68% the multivariate index of vigor of the seeds produced. The multi-character index was also used successfully by Batista et al. (2018) in the selection of rhizobacteria for soybean culture.

**Table 3.** Loads of production components (group 1) and explanations of production (group 2) in the canonical correlations (r) of soybean genotypes fertilized with phosphate fertilizer doses.

| Character | Canonical pair | |
|---|---|---|
| Group 1 | U1 | U2 |
| YI | 0.29 | 0.96 |
| TGM | -0.52 | 0.86 |
| Group II | V1 | V2 |
| STD | 0.31 | -0.76 |
| PH | 0.65 | -0.12 |
| FRH | 0.50 | -0.36 |
| POG | 0.59 | -0.56 |
| PTWG | -0.61 | -0.50 |
| PTHG | 0.41 | 0.69 |
| PFG | 0.62 | -0.01 |
| PPP | 0.52 | 0.60 |
| GPP | 0.44 | 0.71 |
| r | 0.99 | 0.79 |
| p | <0.01 | <0.01 |

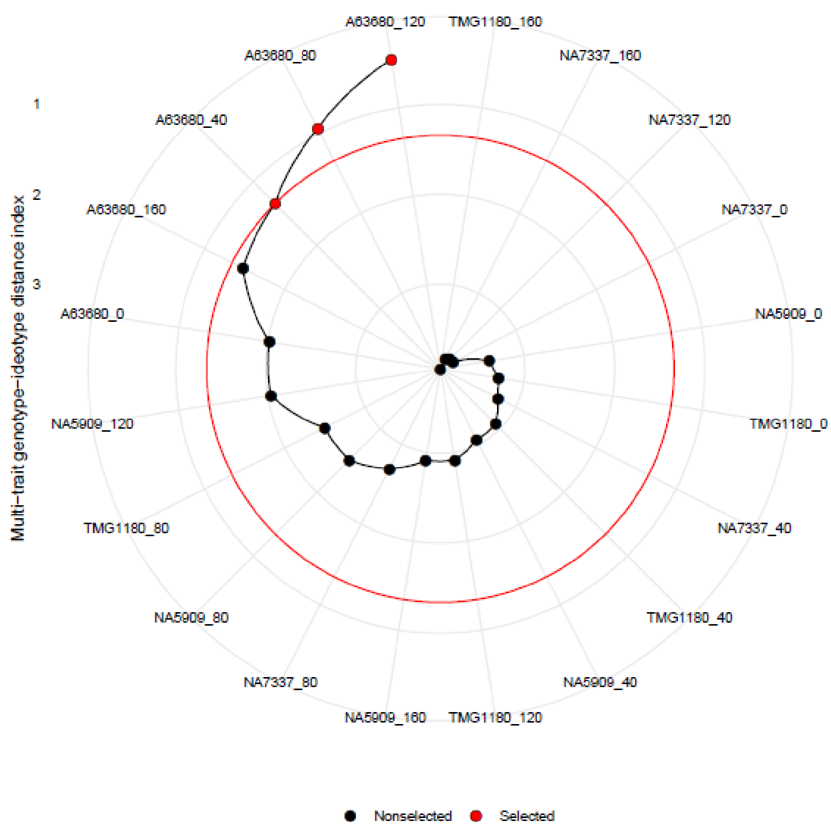


**Figure 4.** Classification of treatments and treatments selected for the multitrait stability index considering a selection intensity of 15%.

Other strategies to improve and sustain soybean production in P-deficient soils with minimal and efficient application have become a research priority according to Uzokwe et al. (2017), like the reality of Cerrado soils that naturally have low levels of this chemical element. According to Singh et al. (2019), P fertilization is a high-cost practice in agricultural production and a potential risk of water pollution.

The study demonstrated the distinct and interactive behavior between genetics and phosphorus concentration, as well as the existing correlations and contributions of the characters to the soybean crop. However, there are inquiries, thus pointing out, the importance of other studies that provide an ideal adjustment on the probable phosphate dose as a balance between triple superphosphate content to be applied to the soil with soybean yield. In addition, it is noted that this adjustment may vary with the environment, which enhances the ideal of regionalization of research in favor of increasing the veracity of information when used by the rural producer.

## CONCLUSIONS

The genetic factor is largely responsible for the soybean yield indices; however, this was also influenced by the triple superphosphate concentrations as a phosphate source.

In order to increase the yield of the soybean crop, it is necessary to reduce the plant stand and height, as well as to increase the average of pods with three grains, pods per plant and grains per plant.

For high yields, it is recommended to cultivate the A63680 soybean genotype in doses of 120 kg $ha^{-1}$ of $P_2O_2$, and the doses of 80 and 40 kg $ha^{-1}$ of $P_2O_2$ can also be used.

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