AGRONOMY SCIENCE AND BIOTECHNOLOGY

RESEARCH ARTICLE

Correlations between morpho-agronomic characters of soybean supplemented via leaf with micronutrients

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ABSTRACT

The use of foliar fertilizers has become the main innovation in the field of plant mineral nutrition. And the use of these micronutrients associated with multivariate tools can contribute to the technical development of agribusiness, especially in soybean. Therefore, the aim of this study was to verify the possible correlations between morpho-agronomic characters of soybean supplemented via leaf with micronutrients. The study was conducted under field conditions in the county of Mineiros, GO, Brazil. The experimental design used was in randomized blocks in a 3x5 factorial scheme corresponding to three soybean genotypes (Anta82, CD2737 and N7902) and five concentrations of leaf supplement, Triplus Anuais® with its guarantees of phosphorus 2%, boron 3.4%, molybdenum 1% and 0.35% nickel. The leaf supplement was applied in a single dose during pre-flowering (0, 300, 600, 900 and 1200 ml ha^{-1}). The highest yield potential was observed in the NS 7209 IPRO genotype at doses of 300 and 600 ml of leaf supplementation via Triplus Anuais. In addition, field adjustments to increase the averages of pods with two grains, grains per plant and mainly pods per plant, can increase the yield of genotypes.

Keywords: *Glycine max* (L.), leaf nutrition, multivariate analysis, fertilization, biological nitrogen fixation, canonical variables.

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INTRODUCTION

The soybean crop is widespread in Brazil, which stands out on the world stage as the second largest producer of this commodity, with an estimated production in the 2019/2020 crop season of 125 million tons (Companhia Nacional de Abastecimento [CONAB], 2020; Ferreira et al., 2022; Ferreira et al., 2022; Ferreira et al., 2022. This crop provides a good profitability for the grower, as long as it is grown using modern production techniques. The main growing region is found in the Cerrado, a place with characteristics of acidic soils, a large amount of toxic aluminum, low levels of nutrients and high phosphorus fixation, so that it is necessary to meet the nutritional requirements of this crop to obtain high yield, but it is very important to reduce production costs to increase profitability (Cavalli et al., 2016).

In order to increase the yield of soybean growing areas, several agricultural companies have launched products on the market to maintain their productive potential, delimiting highly responsive products when applied via foliar. Natural or synthetic substances, considered plant regulators, can be applied directly to plants in leaves, fruits and grains, causing changes in vital and structural processes, in order to improve quality and yield, in addition to facilitating the harvest (Silva et al., 2018a).

The main innovation in the area of plant mineral nutrition developed recently is foliar fertilizers, composed of macro and micronutrients, in solid form with high solubility power or in liquid form (Silva et al., 2018b). Micronutrients, in different growing situations, can become limiting to obtain adequate yield. The importance of using them is more necessary in intensive soil growing and especially in sandy soils (Nakao et al., 2018).

Among the nutrients, zinc is the micronutrient that most limits plant development in the natural condition of Brazilian soils, so that its supply is particularly important for the growing of plants in Brazilian soils, especially those from the cerrado. Phosphorus restrictions at the beginning of plant development can cause irreversible damage to the crop (Cavalli et al., 2016). Molybdenum is of fundamental importance to all vegetables due to its participation in the role of enzymatic cofactor, especially in nitrogenase, an enzyme responsible for biological nitrogen fixation (Oliveira et al., 2017). However, the use of micronutrients by growers is still very low. Generally, when they occur, they are positioned in phenological phases of less expressive use by the plant.

Many factors are important for the success of foliar fertilization, paying attention to the following factors: required nutrient, dose, correct crop stage, fertilizer formula and method of application, in addition to local weather conditions (Cavalli et al., 2016). The evolution in the preparation of new formulations, with many options for use in the field, makes leaf fertilization an increasingly indispensable tool for increasing yield rates (Varanda et al., 2018a). Smaller particles, on a nanometer scale, can improve agricultural practices, such as plant nutrition. These have technological properties based on specific characteristics, such as size, distribution and morphology, when compared to larger particles of the source material.

Research work on soybeans has developed new varieties and growing technologies, resulting in successive increases in yield (Silva et al., 2018a). Studies with foliar fertilization of micronutrients in soybean crop are reported in the literature: application of foliar fertilizer together with herbicides increased the grain mass (Moraes et al., 2017), increase in the number of pods per plant and grain mass. In addition, studies demonstrate positive effects of foliar fertilization on the performance of other crops such as cassava (Bester et al., 2020), beans (Ferreira et al., 2021), oats (Silva et al., 2019), corn (Ferreira et al., 2021), soybean (Frota et al., 2020) and *Physalis peruviana* (Pedó et al., 2018).

Multivariate methods, which evaluate many characteristics simultaneously, can effectively contribute to the identification of practical field situations, presenting itself as another tool for the technical development of agribusiness. The study of the correlations of phenotypic characteristics has become fundamental, as it allows the visualization of specific changes that may result in losses of others during the selection process (Cargnin, 2019).

In this context, the supplementary application of foliar fertilizers with micronutrients has great potential in soybean crop. This consideration stems from the need to seek new strategies that will provide high crop yields (Nakao et al., 2018). There is a large supply of fertilizers on the market, but many products that fail to achieve the desired technical and economic efficiency due to lack of scientific evidence. In view of the above, the objective was to describe the correlations between morpho-agronomic traits in soybean crop supplemented via foliar with micronutrients.

MATERIAL AND METHODS

The study was conducted at the Luís Eduardo de Oliveira Salles Experimental Farm, located in the county of Mineiros, GO, Brazil. Geographically it is at 17º 58 ’S latitude and 45º 22’ W longitude and approximately 800 m altitude. Average temperature of 22.7 °C and average annual rainfall of 1695 mm, occurring mainly in spring and summer, from November to February. The experimental area is classified as Aw type (hot to dry) (Köppen & Geiger, 1936).

Soil analysis was performed in the 0-20 cm layer according to the methodology proposed in the (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2009), verifying the following characteristics: hydrogen potential 5.7; calcium 3, magnesium 0.8, aluminum 0.2, hydrogen + aluminum 2, cation exchange capacity 5.9, in cmolc dm^{-3}; potassium 53, phosphorus 59, sulfur 1.7, boron 0.2, copper 1.4, iron 51, manganese 23, zinc 8.3, sodium 1.5, in mg dm^{-3}; clay 223, silt 50, sand 728, organic matter 20 and organic carbon 12, in g dm^{-3}. The soil was classified as a Quartzarenic Neosol (Entisol) (Embrapa, 2013).

The experimental design used was in randomized blocks in a 3x5 factorial scheme corresponding to three soybean genotypes (Anta82, CD2737 and N7902), and five doses of micronutrients via leaf supplement (0, 300, 600, 900 and 1200 ml ha^{-1}), in 4 repetitions, totaling 15 treatments and 60 experimental units, each plot was dimensioned with four rows spaced 0.5 m and 6 m long, totaling 3 m^2. The main morpho-agronomic characteristics of the soybean genotypes were described in Table 1.

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

Cultivar		Maturity group	Seed genetics	Thousand grain mass (g)	Growth	Cycle (days after emergence)
Commercial	Common					
ANTA 82	ANTA82	7.4	TMG	170	Semideterminate	127-132
CD 2737 RR	CD2737	7.3	Coodetec	164	Indeterminate	112-114
NS 7209 IPRO	N7902	7.3	Nidera	160	Indeterminate	103-113

The soil preparation was carried out with harrowing and plowing the area at a depth of 20 cm. Sowing of soybeans occurred on 11/16/2017, with 16 grains distributed per linear meter in the furrow (population of 320,000 plants ha^{-1}). Simultaneously, 205 kg ha^{-1} of Phusium® was applied as a phosphate source. The top dressing was carried out on 11/28/2017 applying 116 kg KCl ha^{-1}. As a foliar supplement of micronutrients, Triplus Anuais® was used with its guarantees of phosphorus 2%, boron 3.4%, molybdenum 1% and nickel 0.35%. The leaf supplement was applied in a single dose in the phenological phase R1: pre-flowering with the appearance of the first buds, using a cone-type 2.0 bar constant pressure (CO_2) knapsack sprayer, with a spray volume of 335 L ha^{-1}, in the mild hours of the day (7 - 9 AM), with an average ambient temperature of 25 ºC, relative humidity above 60% and winds below 5 km h^{-1}. The crop treatments necessary for the control of weeds, pathogens and insects were carried out whenever necessary, following good local practices.

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. Also, thousand grain mass (TGM, grams), and yield (YI, sc ha^{-1}) were determined 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 leaf supplement. 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 biplot canonical variables 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 RY and TGM; while group 2 was composed of STD, PH, FRH, POG, PTWG, PTHG, PFG, PPP and GPP (Cruz et al., 2012). The analyzes were performed using the R Core Team (2019) statistical program.

RESULTS AND DISCUSSION

The interaction between the factors analyzed resulted in 15 treatments that differed from each other, as shown by the multivariate analysis of variance. Such divergences had their peers grouped into clusters. Character contributions were measured and their affinities with treatments were defined. Thus, the correlations between the morpho-agronomic traits of soybean genotypes supplemented via leaf were described below.

The multivariate analysis of variance revealed significance among the treatments resulting from the interaction (G x LS) ($p \leq 0.01$), by the test of Roy's largest eigenvalue (Table 2). This result confirms the divergent behavior between the treatments analyzed, probably due to the distinct genetic performance and the oscillations of their means, when supplemented via leaf. According to Silva et al. (2015) multivariate analysis techniques are efficient for verifying similarities, or differences in yield variability.

Table 2. Multivariate analysis of variance applied to the effects of the interaction of 3 soybean genotypes x 5 doses of leaf supplementation for the characters stand, plant height, first reproductive node height, pods with one grain, pods with two grains, pods with three grains, pods with four grains, pods per plant, grains per plant, thousand grain mass and yield, with significance based on the Roy Test at 5% probability. UNIFIMES, Mineiros, GO, Brazil, 2020.

SV	DF	Roy approx	F num	Df den	DF	Pr(>F)	
G x LS	14	381.07	1143.21	14	42	2e-16	**
Blocks	3	0.85	2.63	11	34	0.01497	
Residue	42						

** significant at 1% probability by the Roy's Greatest Root test. Soybean genotypes x foliar supplementation G x LS.

In the distinction, it was possible to observe that the number of grains per plant (GPP) was responsible for the greatest divergence among the treatments proposed by the interaction (G x LS) with a value of 46.10%, followed by the components; thousand grain mass (TGM), yield (YI), pods with one grain (POG) and pods with two grains (PTWG) with averages of 21.23, 9.93, 6.64 and 6.29%, respectively. It was possible to verify that among the three main performance components [GPP, TGM and stand (STD)], only GPP and TGM answered in 67.63% of the divergence, and the STD was not measured by the low contribution (Figure 1). In this context, Torres et al. (2015) identified that the parameter with the greatest influence, and, consequently, the most intense contribution to genetic divergence, was the number of pods per plant (PPP). The identification of the parameters that contribute to the divergence can point to high-performance biotypes, contributing to their easy identification in the field.

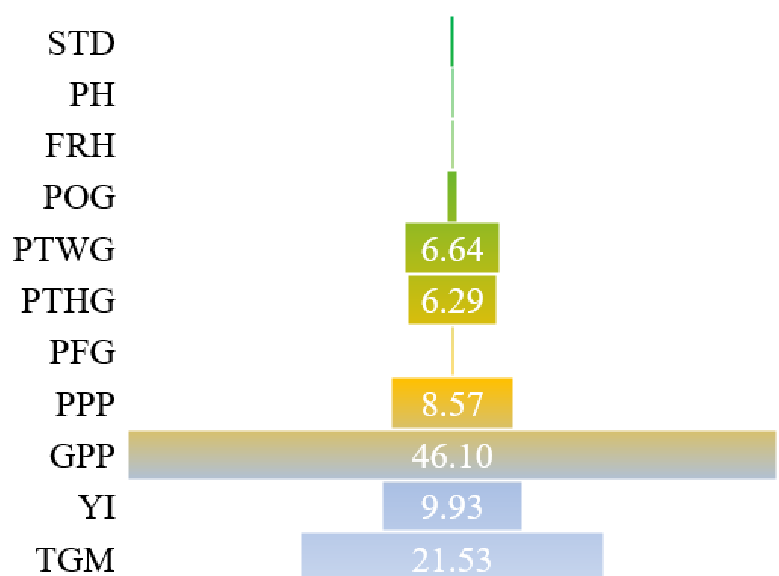

Figure 1. Relative contribution of agronomic characters to divergence in the interaction 3 soybean genotypes x 5 doses of leaf supplementation, by the method proposed by Singh (1981). UNIFIMES, Mineiros, GO, Brazil, 2020. Characters: stand STD, plant height PH, first reproductive node height FRH, pods with one grain POG,

pods with two grains PTWG, pods with three grains PTHG, pods with four grains PFG, pods per plant PPP, grains per plant GPP, thousand grain mass TGM and yield YI.

When analyzing the dendrogram, the treatment distinction was observed by grouping two distinct clusters mediated primarily by the genotype factor, that is, the addition of different doses of leaf supplementation had little influence on this variable (Figure 2). Cluster B was composed of all treatments with the N7902 and CD2737 genotype, corresponding to 66.66% of the individuals, such affinity is attributed to the cycle and the maturity group similar to each other. In cluster A, the treatments with the N7902 genotype were grouped, which presented low averages in the characters stand (STD), plant height (PH), first reproductive node height (FRH), pods with one grain (POG), pods with three grains (PTHG), pods with four grains (PFG) as well as, PTWG, PPP, GPP, TGM and YI (Figure 2). Hackenhaar et al. (2019) also reported genetic variability between soybean genotypes, as well as, Torres et al. (2015) and Al-Hadi et al. (2017), who differed their treatments in soybean crop through clusters. It is known that multivariate analysis acts as a useful tool to quantify the degree of divergence between biological populations at the genotypic level and to evaluate the relative contribution of different components to the total divergence at the inter and intra cluster levels (Mahbub et al., 2016).

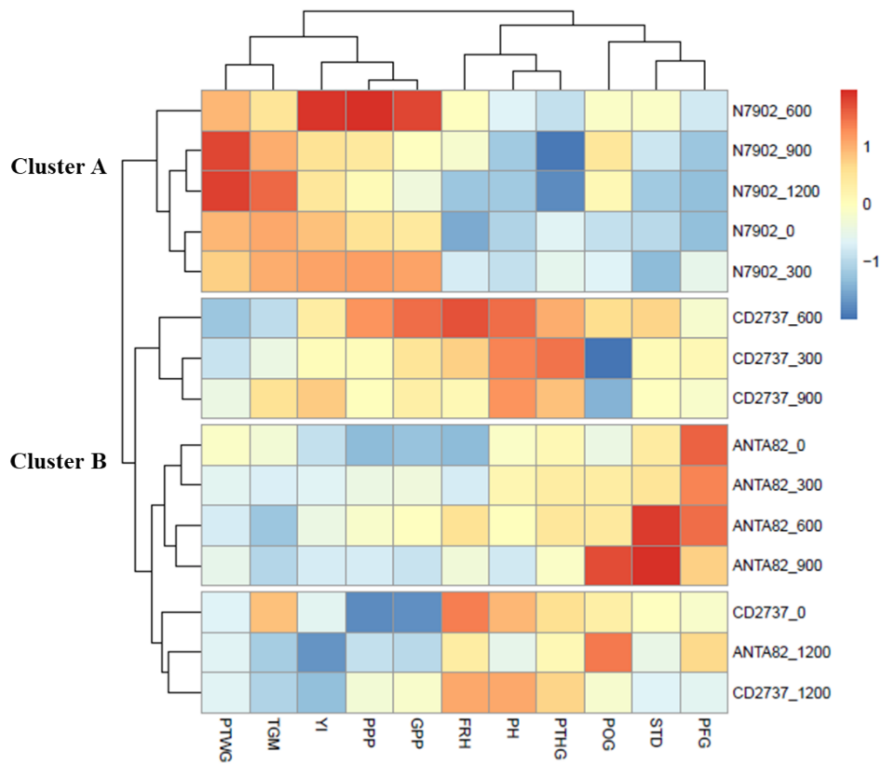

Figure 2. Dendrogram resulting from the interaction 3 soybean genotypes x 5 doses of leaf supplementation based on 11 phenotypic characters (stand, plant height, first reproductive node height, pods with one grain, pods with two grains, pods with three grains, pods with four grains, pods per plant, grains per plant, thousand grain mass and yield) using the average Euclidean distance and the UPGMA grouping method. The value of the cofenetic correlation coefficient (r) is 0.89 and the cut-off point (K) is 4.37. UNIFIMES, Mineiros, GO, Brazil, 2020.

The analysis of canonical variables responded with 93.2% of the total variation of the data, noting that the variables YI and PPP showed similarity in size and expressiveness in the combinations of N7902_600 and N7902_300. This demonstrates the adjustment of the concentration of leaf supplementation for high yields among the analyzed soybean genotypes. In this way, the first two canonical variables explain satisfactorily the variability manifested between the analyzed genotypes, allowing to interpret the phenomenon, with considerable simplification, by means of a two-dimensional dispersion graph of the obtained scores (Figure 3). Correa and Gonçalves, (2012), observed that the first two canonical variables explain more than 80% of the total variation contained in the original data set (97.94% of the accumulated total variance).

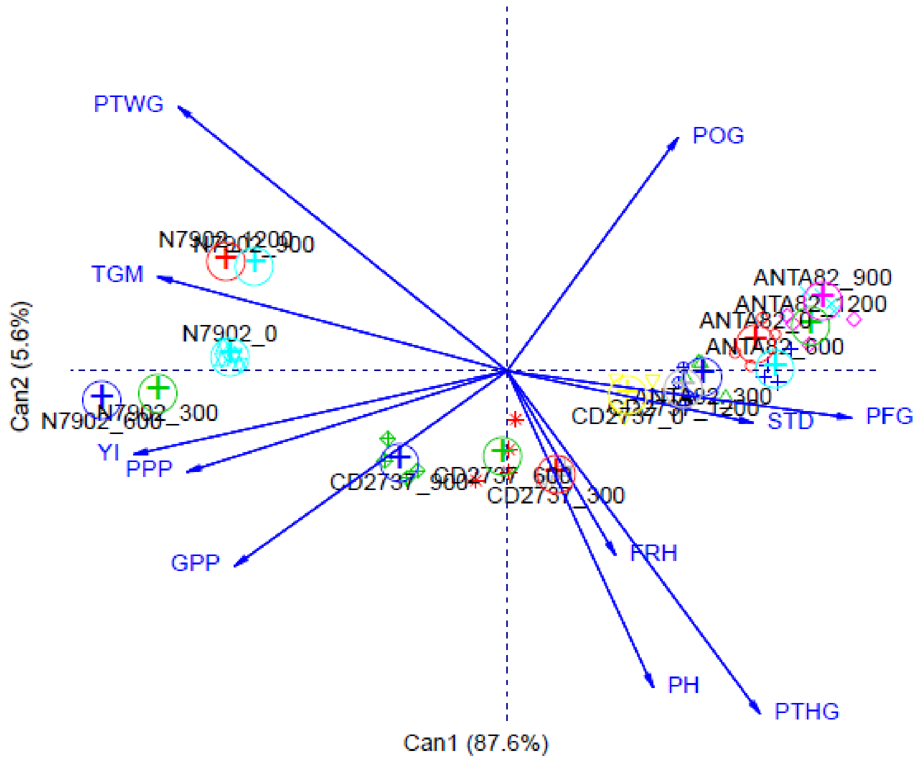

Figure 3. Analysis of canonical variables in soybean genotypes supplemented via leaf. UNIFIMES, Mineiros-GO, Brazil, 2020. Characters: stand STD, plant height PH, first reproductive node height FRH, pods with one grain POG, pods with two grains PTWG, pods with three grains PTHG, pods with four grains PFG, pods per plant PPP, grains per plant GPP, thousand grain mass TGM and yield YI.

Canonical correlations allow the realization of the correlation between groups of variables of interest (Carvalho et al., 2021). So agronomic and physiological characteristics were significant (P≤0.01, chi-square test) in the first and second canonical pairs, showing dependent relationships between the two groups of characteristics, with total correlations of these pairs of factors considered high (r = 0.99 and r = 0.90), respectively (Table 3). The first canonical pair demonstrates that, in order to increase yield levels, it is necessary to increase the plant stand in the field and the presence of large plants (PH and FRH), and that have the highest possible number of PTHG, PPP and GPP.

Therefore, the grain filling represented in the TGM and reported in the second canonical pair, was negatively influenced by the variables STD, PH, FRH, POG, PTHG and PFG, on the other hand, positively by PTWG, PPP and GPP (Table 3). The canonical correlation analysis also made it possible to efficiently draw inferences about agronomic characteristics in a study carried out by Pereira et al. (2017), Leamy et al. (2016) and Rigo et al. (2018). In this context, the canonical correlation analysis demonstrates to be the most adequate technique to measure the relationships between two sets of characteristics, both between groups of characteristics of primary and secondary yield, as well as in groups of physiological and agronomic characteristics (Cargnin, 2019).

Table 3. Loads of production components (group 1) and explanatory of production (group 2) in the canonical correlations (r) of soybean genotypes, supplemented via leaf. UNIFIMES, Mineiros-GO, Brazil, 2020.

Characters	Canonical pair	
Group 1	U1	U2
YI	**0.60**	**0.80**
TGM	**-0.18**	**0.98**
Group II	V1	V2
STD	**0.30**	**-0.72**
PH	**0.14**	**-0.47**
FRH	**0.17**	**-0.48**
POG	**-0.18**	**-0.48**
PTWG	-0.09	**0.89**
PTHG	**0.15**	**-0.70**
PFG	-0.04	**-0.82**
PPP	**0.81**	**0.46**
GPP	**0.88**	**0.32**
R	0.99	0.90
P	<0.01	<0.01

Characters - Group I: thousand grain mass TGM and yield YI; Group II: stand STD, plant height PH, first reproductive node height FRH, pods with one grain POG, pods with two grains PTWG, pods with three grains PTHG, pods with four grains PFG, pods per plant PPP and grains per plant GPP.

Different results have been described by Nakao et al. (2018), when using different combinations and doses of B and Zn, applied via leaf in soybean crop, where they did not improve the nutritional leaf contents, the components of soybean grain production and yield, as well as the physiological quality of the grains. The same was observed by Gonçalves et al. (2017), with the application of sources of Cu and Mn not altering the yield of the soybean crop, they only influence the leaf contents. The application of leaf boron increased the morphological and reproductive parameters analyzed (Varanda et al., 2018a; Varanda et al., 2018b).

CONCLUSIONS

The highest yield potential was observed in the NS 7209 IPRO genotype at doses of 300 and 600 ml of leaf supplementation via Triplus Anuais. In addition, field adjustments to increase the averages of pods with two grains, grains per plant and mainly pods per plant, can increase the yield of genotypes.

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