# MODELOS MULTIVARIADOS E CANÔNICOS APLICADOS AO MILHO: BENEFICIOS DO ADUBO VERDE com *Vigna unguiculata* L.

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## RESUMO

Visando aumentar a produtividade e manter o equilíbrio do sistema de cultura do milho, o objetivo deste trabalho foi analisar as correlações fenotípicas do feijão caupi como alternativa ao adubo verde na cultura do milho. O estudo foi realizado na zona rural de Mineiros, GO, Brasil. O solo foi classificado como Neossolo Quartzarênico. O delineamento experimental foi o de blocos casualizados no fatorial 6x2, correspondendo a seis híbridos de milho [Syn7613, 20A78, DKB310, CD3770, P3250 e P3646] e dois métodos de fertilização [(Green Adure System - GMS: Caupi Bean Straw - *Vigna unguiculata* L.) e (Sistema de Fertilização convencional - CFS: formulado 8-25-15)], em 4 repetições. Na implementação do CFS, foram utilizados 480 kg $ha^{-1}$ de fórmula 8-25-15; enquanto que para o GMS, 231 kg $ha^{-1}$ de MAP e 124 kg $ha^{-1}$ de KCl foram utilizados para compensar os elementos P e K do CFS. O manejo cultural pertinente ao controle de pragas foi realizado utilizando as melhores práticas de manejo integrado de pragas. Os dados obtidos foram submetidos às premissas do modelo estatístico, verificando a normalidade e homogeneidade das variâncias residuais, bem como a aditividade do modelo. Modelos uni e multivariados foram utilizados. As análises foram realizadas na interface Rbio e R, além dos Genes de Software. Na análise das correlações fenotípicas, identificou-se que o híbrido de milho CD3770 foi eficiente quando utilizado caupi como alternativa ao adubo verde.

PALAVRAS-CHAVE: *Zea mays*, cobertura do solo, culturas de cobertura.

# MULTIVARIATE AND CANONICAL MODELS APPLIED TO CORN: BENEFITS OF GREEN MANURE WITH *Vigna unguiculate*

## ABSTRACT

Aiming at increasing productivity and maintaining the equilibrium of the corn crop system, the objective of this work was to analyze the phenotypic correlations of cowpea as an alternative of green manure in corn crop. The study was conducted in rural Mineiros, GO, Brazil. The soil was classified as Quartzarenic Neossol. The experimental design was randomized blocks in factorial 6x2, corresponding to 6 corn hybrids [Syn7613, 20A78, DKB310, CD3770, P3250 and P3646] in two fertilization methods [(Green Manure System - GMS: Caupi bean straw - *Vigna unguiculata* L.) and (Conventional Fertilization System - CFS: formulated 8-25-15)], in 4 repetitions. In the implementation of CFS, 480 kg $ha^{-1}$ of formula 8-25-15 were used; whereas for the GMS, 231 kg $ha^{-1}$ of MAP and 124 kg $ha^{-1}$ of KCl were used to compensate for the P and K elements of the CFS. The cultural management pertinent to pest control were performed using the best practices of integrated pest management. The obtained data were submitted to the assumptions of the statistical model, verifying the normality and homogeneity of the residual variances, as well as the additivity of the model. Uni and multivariate models were used. The analyzes were performed at the interface Rbio and R, besides the Software Genes. It was identified in the analysis of phenotypic correlations that the CD3770 corn hybrid was efficient when used cowpea as an alternative of green manure.

KEYWORDS: *Zea mays*, soil coverage, green manure.

## 1 INTRODUCTION

Corn (*Zea mays*) is one of the main cereals grown in the world, and its importance is characterized by the diversity of forms of its use, ranging from animal and human feed, to high technology industries. It is estimated that there are over 3,000 corn derivatives for both human and industrial consumption, representing around 21% of human nutrition on the planet (Seab / Deral, 2018).

Corn crop in Brazil occupies 27% of the country's cultivated area with a production of 81.4 million tons representing 38% of the total production of 21 grain produced in the country and with an average yield of 4.9 t $ha^{-1}$ between the main harvest and off season harvest in the 2018/19 agricultural year (Conab, 2019).

Aiming at increasing productivity and maintaining the balance of the corn cultivation system, the use of cover crops is an alternative for the region (Maia et al., 2013). The insertion of cover crops acts to promote nutrient cycling in the agroecosystem (Boer et al., 2007), making them more available for cultivated crops (Ziech et al., 2015). Thus, the objective of this work was to analyze the efficiency of multivariate and canonical models applied to corn crop in a green manure production system, using cowpea bean.

## 2 BIBLIOGRAPHY REVIEW

Among the grain crops produced in Brazil, the corn crop stands out for its importance, both economically and socially. Moreover, it is essential to enable the no-tillage system due to its ability to add residues to the system, which provides increased organic matter content in the topsoil, improving aggregate stability and consequently giving greater soil resistance to erosion (Cassol, 2019).

In Brazil, the first official record on green manure dates from 1919 with a concept that made explicit a "chemical vision", which required the incorporation of plant mass in the soil, aiming to improve its fertility, having in the 90s to have a more “holistic” view where aspects of soil (physical, chemical and biological protection and recovery), animals (fodder), man (food, 19 fibers, seed production, etc.) and the environment (decreased environmental impacts of agriculture and carbon sequestration - C). The definition also incorporates the possibility of using other botanical families incorporated or not incorporated in the soil (Wutke et al., 2014).

Soil cover plants in grain production systems are still limited to few properties, making it indicative of a lack of understanding of the advantages that this technique can provide to the production system by improving soil quality (Cassol, 2019).

The use of cover crops provides several benefits for cultivation systems, such as soil protection against erosion, nitrogen N (in the case of legumes), reduction of spontaneous plants through the suppressive and/or allelopathic effect, avoiding the incidence of direct sunlight, providing moisture maintenance and avoiding temperature fluctuations. The “aggressive” root system decompresses and structures the soil (aggregation and aeration) increasing water infiltration (Ambrosano et al., 2014).

Legumes form symbiotic associations with N-fixing bacteria, performing biological nitrogen fixation, and present low C/N ratio, which may favor rapid decomposition and mineralization, with significant N contribution to the soil system (Partelli et al., 2011), which may lead to reductions in N rates in corn (Kappes et al., 2015). Grasses, on the other hand, can soften N losses, promoting their recycling and longer soil cover due to their high C/N ratio (Perin et al., 2004).

Modifying monoculture for agroecological systems is a dynamic process that is unique to each property, requiring the replacement of synthetic inputs by natural inputs, such as the replacement of synthetic fertilizers with green manure, coupled with a set of practices in order to redesign landscape (Padovan, 2006; Padovan and Campolin, 2011).

## 3 MATERIAL AND METHODS

The study was conducted at the Luiz Eduardo de Oliveira Sales Experimental Farm, in the municipality of Mineiros - GO, located between the geographic 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 mostly in spring and summer. The predominant climate is warm, semi-humid and notably seasonal, with rainy summer and dry winter, being classified as “Aw” (KÖPPEN and GEIGER, 1936). The soil of the experimental area was classified Quartzarenic Neossol (Entisol), with light texture, gently undulating to flat topography and good drainage (Embrapa, 2013).

Prior to the installation of the experiment, soil collection and analysis was performed in the 0-20 cm surface layer and the following characteristics were observed: 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 performed at the UNIFIMES Soil Chemistry and Fertility Laboratory, according to the methodology of (Embrapa, 2009).

The experimental design was randomized blocks in factorial 6x2, totaling 12 treatments, corresponding to 6 corn hybrids [Syn7613, 20A78, DKB310, CD3770, P3250 and P3646] in two fertilization methods [(Green Manure System - GMS: cowpea straw (Vigna unguiculata) and (Conventional Fertilization System - CFS: formulated 8-25-15)], in 4 repetitions. Each plot consisted of 4 rows of 4 meters in length 0.5 m apart and density of 3 seeds per linear meter, relating a population of 60,000 plants $ha^{-1}$ (Ferreira et al., 2019b). The main morphoagronomic characteristics of the evaluated corn hybrids are shown in Table 1.

**Table 1. Main morphoagronomic characteristics of the evaluated corn hybrids. Mineiros-GO, UNIFIMES, Brazil, 2019**

| Hybrid | | Cycle[1] | Grains | | |
|---|---|---|---|---|---|
| Commercial | Common | | TGM[2] | Color[3] | Texture[4] |
| Syn7613 | Syn7613 | E | 300-400 | YE-ORISH | SMHARD |
| 20A78 PW | 20A78 | E | 300-400 | YE-ORISH | SMHARD |
| DKB 310 PRO 3 | DKB310 | SME | 404 | YE-ORISH | SMHARD |
| CD 3770 PW | CD3770 | E | 300-400 | YE-ORISH | SMHARD |
| CD 3770 PW | P3250 | E | 300-400 | YE-ORISH | SMHARD |
| P3646YHR | P3646 | E | 300-400 | YE-ORISH | SMHARD |

[1] Cycle: SE-super early; E-Early; SEE-semi-early. [2]TGM: thousand grain mass (g). [3]Grain color: ORISH-Orangish; YE-yellow; OR-Orange. [4]Grain Texture: SMDENT-semidentate; SMHARD-semi-hard.

The entire experimental area was initially prepared in the conventional system using plowing and harrowing. The CFS was kept free of weeds until the sowing of corn hybrids. In the CFS, cultivar BRS Paraguaçu of cowpea bean was sown with distance of 0.5 m between rows and density of 8 seeds per linear meter, relating a population of 160,000 plants ha$^{-1}$. In CFS, cowpea bean straw was managed according to the principles of laminar composting (Primavesi, 2002).

The sowing of corn hybrids occurred on 02/17/2017 according to Ferreira et al. (2019). It CFS implementation, 480 kg ha$^{-1}$ of formula 8-25-15 were used; whereas for the GMS, 231 kg ha$^{-1}$ of MAP and 124 kg ha$^{-1}$ of KCL were used to compensate for the CFS elements P and K, respectively.

The relevant cultural management for weed and pest control were performed whenever necessary, using the best practices of integrated pest management (Valicente, 2015). For these, a cone-type 2.0 bar constant pressure ($CO_2$) knapsack sprayer was used, applying a spray volume of 335 L ha$^{-1}$ during the warm hours of the day, with an average ambient temperature of 25 ºC, relative air humidity above 60% and winds below 5 km h$^{-1}$.

At the end of the experiment, the following characteristics were measured: plant height PH in cm; ear insertion height EIH in cm; stem diameter SD in mm; leaf area index LAI in cm$^2$; number of rows per ear NRE in units; number of grains per row NGR in units; number of grains per ear NGE in units; and yield YI with moisture of 13% in grains in t ha$^{-1}$. The obtained data were submitted to the assumptions of the statistical model, verifying the normality and homogeneity of the residual variances, as well as the additivity of the model.

Afterwards, the analysis of variance was performed in order to identify the interaction between the corn hybrids x fertilization, and to verify significant interaction, they were broken down to the simple effects and in the absence with main effects through the Scott-Knott means grouping test, at 5% probability. Subsequently, the variables of each fertilization method were submitted to Pearson's correlations in order to understand the association tendency, and its significance was based on 5% probability by the t test. The canonical correlations were estimated between group 1 (NGE and YI) and group 2 (PH, EIH, SD and LAI), with significance between the groups of characters evaluated based on chi-square statistics. After genetic dissimilarity by the Mahalanobis algorithm, the residual matrix was weighted, the distances dendrogram was constructed through the UPGMA cluster, and the biplot canonical variables method was used to visualize the general variability of the experiment and multivariate trends. The analyzes were performed in Rbio R interface (Bhering, 2017), and in Software Genes (Cruz, 2016).

## 4 RESULTS AND DISCUSSION

The interaction between factors H x F was significant for ear insertion height - EIH, leaf area index - LAI, yield - YI (p <0.01), number of rows per ear - NRE, number of grains per row - NGR and number of grains per ear - NGE (p <0.05) (Table 2). Corroborating with Costa et al (2015), Kopper et al. (2017), Oliveira et al. (2005), Ferreira et al. (2011) and Partelli et al. (2011); however Camara et al. (2016) found no statistical difference between corn hybrids in a similar work.

**Table 2. Summary of analysis of variance (MS and CV (%)) for plant height - PH, ear insertion height - EIH, stem diameter - SD, leaf area index - LAI, number of rows per ear - NRE, number of grains per row - NGR, number of grains per ear - NGE and yield - YI.Mineiros-GO, UNIFIMES, Brasil, 2020**

| FV | DF | PH | EIH | SD | LAI | NRE | NGR | NGE | YI |
|---|---|---|---|---|---|---|---|---|---|
| H x F | 5 | 302.80$^{ns}$ | 366.76$^{**}$ | 0.06$^{ns}$ | 13652583.78$^{**}$ | 3.49$^{ns}$ | 9.16$^{ns}$ | 8058.61$^{*}$ | 1274.55$^{**}$ |
| Hybrids (H) | 5 | 1922.37$^{**}$ | 647.04$^{**}$ | 0.04$^{ns}$ | 9031809.07$^{**}$ | 0.82$^{ns}$ | 35.78$^{**}$ | 9341.52$^{*}$ | 2017.69$^{**}$ |
| Fertilizations (F) | 1 | 211.68$^{ns}$ | 590.10$^{**}$ | 0.32$^{*}$ | 1951870.97$^{**}$ | 12.25$^{**}$ | 7.09$^{ns}$ | 26843.35$^{**}$ | 2677.29$^{**}$ |
| Blocks | 3 | 451.72 | 162.33 | 0.04 | 46951.28 | 0.63 | 2.22 | 1658.20 | 77.00 |
| Residue | 33 | 391.35 | 66.19 | 0.04 | 14038.49 | 1.44 | 3.77 | 2915.54 | 57.28 |
| CV (%) | | 10.24 | 18.57 | 17.34 | 14.62 | 12.51 | 15.73 | 14,93 | 13.34 |

** signoficant at 1% probability by F test; *significant at 5% probability by F test; ns not significant at 5% probability by F test. SV source of vriation; DF: degree of freedom

Hybrids 20A78 and P3250 presented smaller EIH (Figure 1A) in the CFS. Among the hybrids, DKB310 presented the highest LAI in the CFS, as was the hybrid CD3770 in the GMS (Figure 1B). NGE was higher in hybrids 20A75 and P3646 when grown in GMS (Figure 1C). These increases in GMS are attributed to Oliveira et al. (2005) maintaining soil cover, dampening the impact of raindrops, reducing crust formation, decreasing runoff, allowing greater infiltration of water into the soil and maintaining moisture. According to Possamai et al. (2001) plants with high EIH and PH presented advantages in harvest, with reduction in mechanized harvest losses, among other factors. Plants with higher LAI may be more efficient in capturing environmental resources. According to Taiz et al. (2017), factors such as light, water, carbon dioxide, oxygen, soil nutrient content and availability, temperature and toxins can affect plant growth and development.

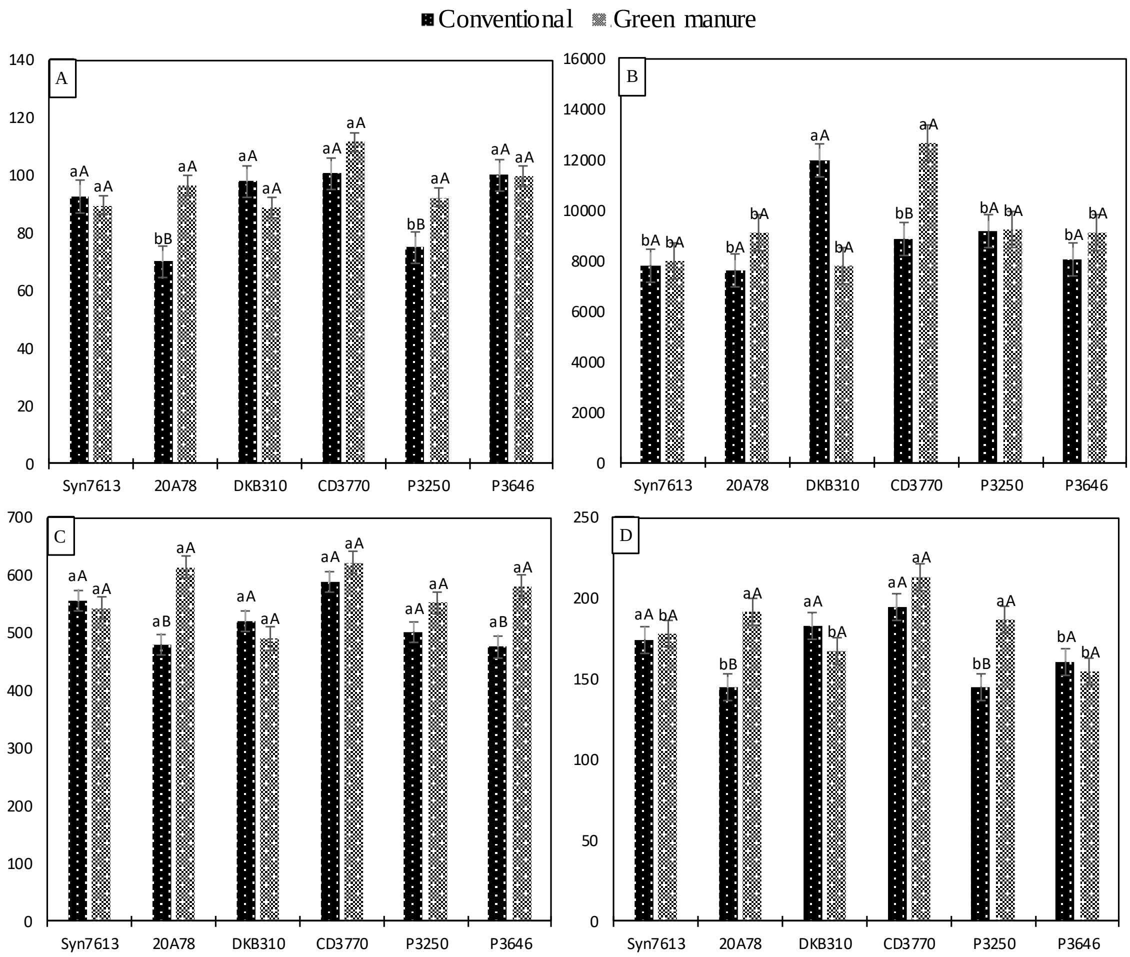


**Figure 1. Breakdown of C x F interaction for EIH ear insertion height in cm (A), LAI leaf area index in cm² (B), number of grains per ear NGE in units (C) and YI yield in sc ha⁻¹ (D) of corn hybrids with conventional fertilization CFS (▩) and green manure GMS (▩). Mineiros, GO, UNIFIMES, Brazil, 2020.**

Means followed by the same lower case letter between hybrids and upper case letters within the hybrid and between the fertilization methods do not differ from each other by the Scott-Knott test at 5% probability.

The most prominent hybrid for YI was CD3770 for both fertilizer systems; such systems differed only for the 20A75 and P3250 hybrids with the highest averages found in the GMS (Figure 1D). Positive effects on YI of corn crop in succession to species of the fabaceae family were also observed in other studies, as in Giacomini et al. (2004), verified in three consecutive harvests higher YI by 40% and Padovan (2016) with higher ear mass production and YI of grains in agroecological systems. However, Corsini (2018) observed that the vegetal covers provided adequate biomass for the maintenance of straw and minimum tillage, but did not interfere with YI. Ferreira et al. (2019a) with low environmental impact protected N found optimization points for this element, as well as distinct configurations among corn hybrids.

For the PH variable the hybrids 20A78 and P3250 were smaller in the CFS (Figure 2A). NGR was more representative in the hybrid CD3770 for both fertilizer systems (Figure 2B). The stem diameter - SD decreased in hybrids 20A78 and CD3770 when cultivated in CFS (Figure 2C). The 20A75 hybrid was influenced by the fertilization system, with the GMS providing higher NRE for this (Figure 2D). According to Valderrama et al. (2011), the NRE is a genetic characteristic of each genotype, therefore, showing no variations. Lopes et al. (2017) described that how grain size and other ear characteristics are established by genes located on many chromosomes is therefore subject to hybrid choice.

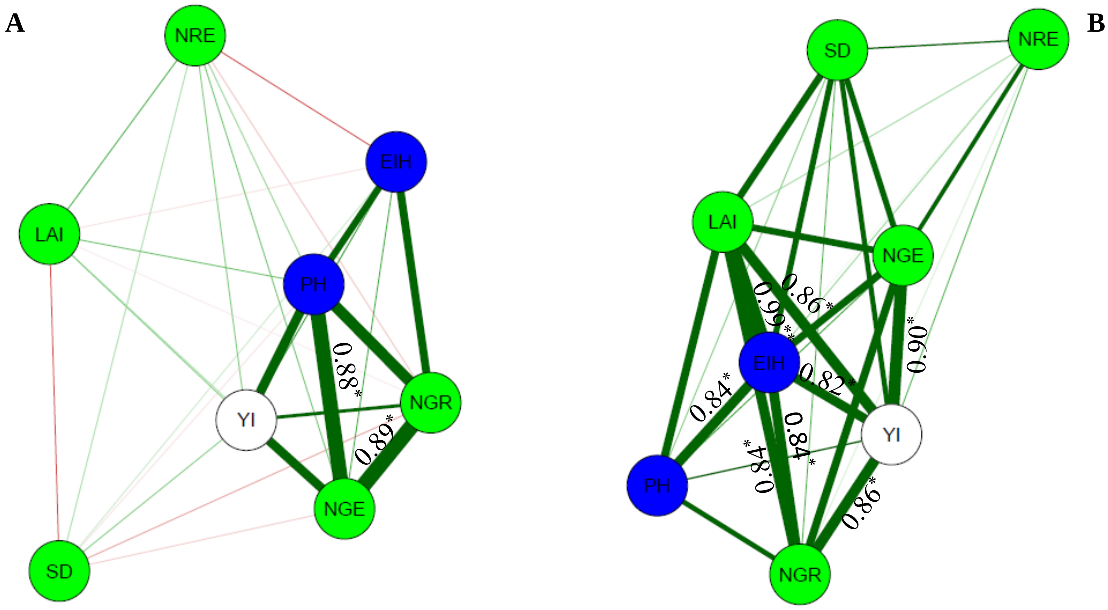


**Figure 2. Network of linear correlations for the characters of corn hybrids with conventional fertilization CFS (A) and green manure GMS (B). Mineiros, GO, UNIFIMES, Brasil, 2020.**

Variables: plant height - PH; ear insertion height - EIH; stem diameter - SD; leaf area index - LAI; number of rows per ear - NRE; number of grains per row - NGR; number of grains per ear - NGE; and yield - YI. Significance: * 5% probability; ** 1 probability; ns: not significant.

The correlation network with Pearson's correlation coefficient revealed 10 positive and significant correlations, 2 in the CFS and 8 in the GMS. The NGExNGR and NGExPH pairs in the CFS and GMS reported in the EIHxPH, LAIxEIH, NGRxEIH, YIxEIH, NGRxLAI, YIxLAI, YIxNGR, and YIxNGE pairs (Figure 3). The relative contribution of each character to genetic divergence is of great importance to identify the characters with the highest contribution and also to assist in the disposal of those who contribute little to the discrimination of genotypes, thus reducing labor, time and cost spent on experimentation (Correa and Gonçalves, 2012).

In Table 3, the canonical correlations between variables of the corn hybrids showed significance (p≥0.01) by the chi-square test and high correlation in the two canonical pairs of the CFS (r=0.9998 and r=0.8399), as well as, in GMS system (r=1.0036 and r=0.8086). The correlations showed that in the CFS, for the first canonical pair, NGE corresponded positively to PH and EIH, and negatively to SD and LAI, and in the second canonical pair, YI corresponded positively to PH, EIH, SD and LAI (Table 3).

For Kopper et al. (2017), YI was directly affected only by the EIH, showing that plants with ears inserted at a higher height tend to produce more. Correlations in corn hybrids were also reported by Carvalho et al. (2016) when estimating correlation coefficients and consequences of direct and indirect effects by multivariate techniques in different seed treatments. Carvalho et al. (2015) and Zanatto et al. (2016) also observed correlations between the morphological and yield components in the sorghum crop.

Biologically, we can verify that plants with high PH and EIH with reduced SD and LAI enable the highest NGE, and that high YI is obtained by increasing the variables PH, EIH, SD and LAI in corn hybrids in CFS. For the GMS, the corn hybrids will increase the NGE and YI with the increase of the components PH, EIH, SD and LAI (Table 3).

**Table 3. Canonical loads of the productivity (group 1) and morphological (group 2) characters in the canonical correlations (r) between the groups of corn hybrids with conventional fertilization CFS and green manure GMS. Mineiros, GO, UNIFIMES, Brasil, 2020**

| Character[1] | Canonical pair | | Character[1] | Canonical pair | |
|---|---|---|---|---|---|
| Group 1 | 1st | 2nd | Group 1 | 1st | 2nd |
| | Conventional | | | Green | |
| NGE | 0.77352 | 0.63377 | NGE | -0.2144 | 0.97675 |
| YI | 0.20301 | 0.97918 | YI | -0.626 | 0.77983 |
| Group 2 | | | Group 2 | | |
| PH | 0.60202 | 0.78281 | PH | -0.4528 | 0.53173 |
| EIH | 0.22189 | 0.79966 | EIH | -0.4793 | 0.82953 |
| SD | -0.4479 | 0.4088 | SD | -0.298 | 0.88358 |
| LAI | -0.0006 | 0.34197 | LAI | -0.5828 | 0.78698 |
| r | 0.9998 | 0.8399 | r | 10.036 | 0.8086 |
| p | <0.0100 | <0.0027 | p | <0.0100 | <0.0122 |

[1] Group 1: number of grains per ear - NGE and yield - YI; Group 2: plant height - PH, ear insertion height - EIH, stem diameter - SD, leaf area index - LAI.

Both fertilization systems had the formation of two clusters, with an isolated cluster represented by the hybrid Syn7613 in the CFS and CD3770 in the GMS (Figure 4). Silva et al. (2016) estimating the genetic divergence between half-siblings progenies using hierarchical methods observed the formation of 11 clusters, as well as Alves et al. (2015), which accounted for the formation of 4 clusters. Nardino et al. (2017) testing the genetic dissimilarity between 25 corn hybrids, in five growing environments in southern Brazil, observed the formation of 9 distinct clusters. The results of the cluster analysis using the UPGMA methods can serve as a basis for future work involving the study of genetic diversity for corn crop (Silva et al., 2016).

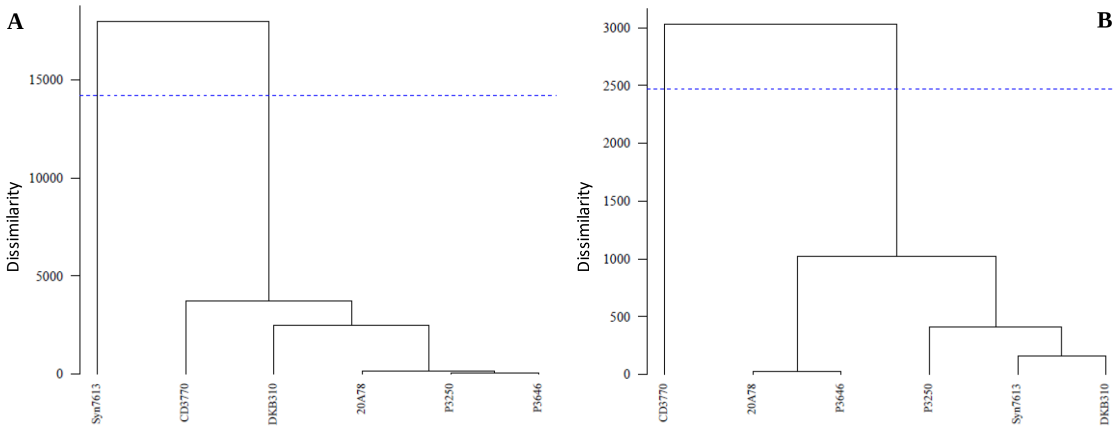


**Figure 4. Dendrogram representative of the dissimilarity between corn hybrids, obtained by the UPGMA clustering method, using the generalized Mahalanobis distance, of corn hybrids with conventional fertilization CFS (A) and green manure GMS (B). Mineiros, GO, UNIFIMES, Brasil, 2020.**

Variables: number of rows per ear - NRE, number of grains per row - NGR, number of grains per ear - NGE and yield - YI.

The analysis of canonical variables for the CFS explains in the first axis 56.79% and in the second 22.40% accounting for the explanation of 79.20 of the total variation of the data. Highlight for the hybrid DKB310 in variable YI (Figure 5A). Studies in the literature report the canonical explanation rates for corn as Varella et al. (2019) who obtained an explanation of 85% of the total variance in the sum of the two canonical axes, as well as Prazeres and Coelho (2016) with a sum of 83%. For the GMS, the hybrid CD3770 had influence on the variables LAI, NGR, PH, EIH, NGE and YI (Figure 5B). Ferreira et al. (2011) and Partelli et al. (2011) concluded that green manure is a good alternative to complement the supply of N. Varella et al. (2019) state that using canonical variables, one can estimate the prediction of nitrogen for the corn crop.

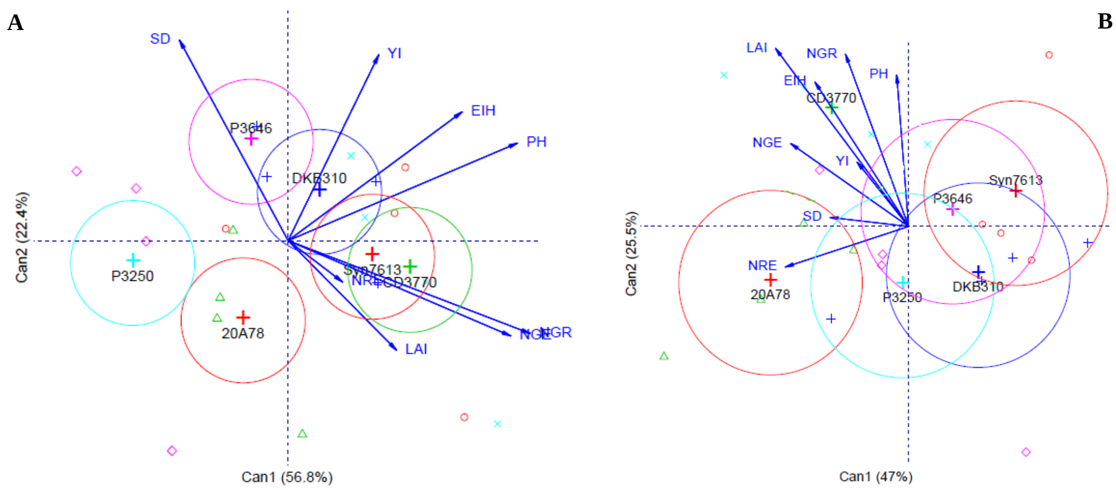


**Figure 5. Analysis of canonical variables of corn hybrids with conventional fertilization CFS (A) and green manure GMS (B). Mineiros, GO, UNIFIMES, Brazil, 2020.**

Variables: plant height - PH, ear insertion height - EIH, stem diameter - SD, leaf area index - LAI, number of rows per ear - NRE, number of grains per row - NGR, number of grains per ear - NGE and yield - YI.

The Scott-Knott grouping test was applied initially for significant interactions and later for the main effects, reporting the behavior of corn hybrids within each production system. Pearson's linear correlation demonstrated that the variables have direct links, whether positive or negative, and that through the canonical variables it can be observed that these variables are more expressive in different hybrids. Biologically, it was possible to observe that the number of grains per ear and the yield were influenced by the plant's morphological components through canonical correlations. The dissimilarity test distinguished the hybrids within each system in groups.

## 5 CONCLUSIONS

It was identified, in the analysis of phenotypic correlations, that the corn hybrid CD3770 was efficient when using cowpea as an alternative for green manure.

Among the variables analyzed, the hybrid most influenced by conventional fertilization and green manure management was 20A75, which is more representative when grown in the green manure system.

In the conventional system, the yield and number of grains per ear of the corn hybrids were mainly determined by the plant height and ear insertion height, whereas in the green manure system the variables of ear insertion height and stem diameter had greater expressiveness, in this order.

Multivariate tools are efficient in choosing the hybrid and the recommended fertilization system.

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