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Performance of second-crop maize hybrids in different population densities

Alessandro Ulrich[1], Thalles Luis Martins Sousa[2], Amanda Gonçalves Guimarães[3], Wagner Thompson[4], Adalfredo Rocha Lobo Junior[5], Anderson Barbosa Evaristo[6]

[1] Universidade Federal dos Vales Jequitinhonha e Mucuri (UFVJM), doutorando no Programa de Pós-Graduação em Produção Vegetal. alessandro.ulrich@ufvjm.edu.br.

[2] Instituto de Ciências Agrárias da Universidade Federal dos Vales Jequitinhonha e Mucuri (ICA/UFVJM), Graduação em Agronomia. thalles.luis@ufvjm.edu.br.

[3] Universidade Federal de Santa Catarina (UFSC), Centro de Ciências Rurais. Coordenadoria Especial de Ciências Biológicas e Agronômicas. amanda.goncalves@ufsc.br.

[4] KWS Sementes. wagner.tompson@kws.com.

[5] Instituto de Ciências Agrárias da Universidade Federal dos Vales Jequitinhonha e Mucuri (ICA/UFVJM), Professor Adjunto do curso de Agronomia. adalfredo.lobo@ufvjm.edu.br.

[6] Instituto de Ciências Agrárias da Universidade Federal dos Vales Jequitinhonha e Mucuri (ICA/UFVJM), Professor Adjunto no curso de Agronomia e no Programa de Pós-Graduação em Produção Vegetal. anderson.evaristo@ufvjm.edu.br.

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Abstract

The cultivation of second-crop (off-season) maize (*Zea mays* L.) has progressed in Brazil. However, the maize plant population recommendation for the second crop is drastically reduced. This work was developed with the objective of evaluating the agronomic performance of maize hybrids subjected to different plant populations in the off-season maize. The experiment was cultivated in a no-tillage system in the second crop of the 2019/2020 agricultural year in Unaí-MG and carried out according to a randomized block design in subdivided plots, with the five simple maize hybrids KWS (K9105VIP3, K9960VIP3, K9606VIP3, K9555VIP3, and K8774PRO3) considered as parcels and four populations (35,000; 50,000; 65,000 and 80,000 plants ha^{-1}), considered as subplots. Maize hybrids did not influence ($P>0.05$) the variables. The populations of 35,000, 65,000 and 80,000 plants ha^{-1} resulted in the highest ($P<0.05$) number of rows, number of grains per row, and ear length. Increasing plant population influenced ($P<0.05$) positively the grain yields up to the population of plants of 68,200 plants ha^{-1} with a grain yield of 9,302 kg ha^{-1}. Population densification, even increasing competition for resources, negatively influencing most plant and ear characters, increases grain yield due to the greater amount of ear per area.

Keywords: Grain yield. Plant density. Off-season maize. *Zea mays* L.

Introduction

Maize (*Zea mays* L.) gains worldwide prominence among cereals for animal and human food, industrial and energy use of biofuels. Brazil is the third largest maize producer in the world with an estimated production of 109 million tons in the harvest 2020/21, second only to the United States, which is the world's largest producer, and China. Its consumption has increased in recent years, projecting a record global consumption for 2021/22 of 1,142.2 million tons (FIESP, 2021).

In Brazil, there has been a shift in maize cultivation from the harvest to the off-season due to the profitability of soybeans and the excellent combination of soybean and maize crop succession. The area for the cultivation of maize from the second-crop has evolved from 3,317.7 thousand hectares in 2003/2004 to 13,755.9 thousand hectares in 2019/2020 in the autumn-winter period. In the same period, the State of Minas Gerais increased the planted area of 26 thousand to 450.8 thousand hectares. Regarding the harvest and off-season in the same region, the average grain yield was similar in 2019 and 2020, with 6,486 kg ha^{-1} and 6,326 kg ha^{-1} respectively (CONAB, 2021).

Technological development for the availability of genetic materials from maize hybrids allows them to be recommended for both crop and off-season cultivation, however, the reduction of plant population in off-season maize is large, making it necessary to use more efficient management systems associated with the choice of genetic material, management practices, spatial arrangement and a plant population to obtain the highest grain yield in maize cultivation (ALMEIDA JÚNIOR et al., 2017).

Thus, the proper selection of the plant arrangement is a relevant management technique to improve grain yield due to different interactions between genotype and environment (FOLONI et al., 2015). The hypothesis is that the increase in plant density, offset by intraspecific competition, will increase maize components in grain yield. Some statistical analyzes may help in these conclusions, such as correlation, which makes associations between characteristics so that you can indirectly select one feature over another (PEREIRA et al., 2018).

In this context, it is necessary to study the behavior of maize hybrids at different population densities, due to the possible influence of the environment on the performance of the crop. Therefore, this work was developed with the objective of evaluating the agronomic performance of maize hybrids subjected to different plant populations and estimating the associations between traits in cultivation in the second crop (off-season maize).

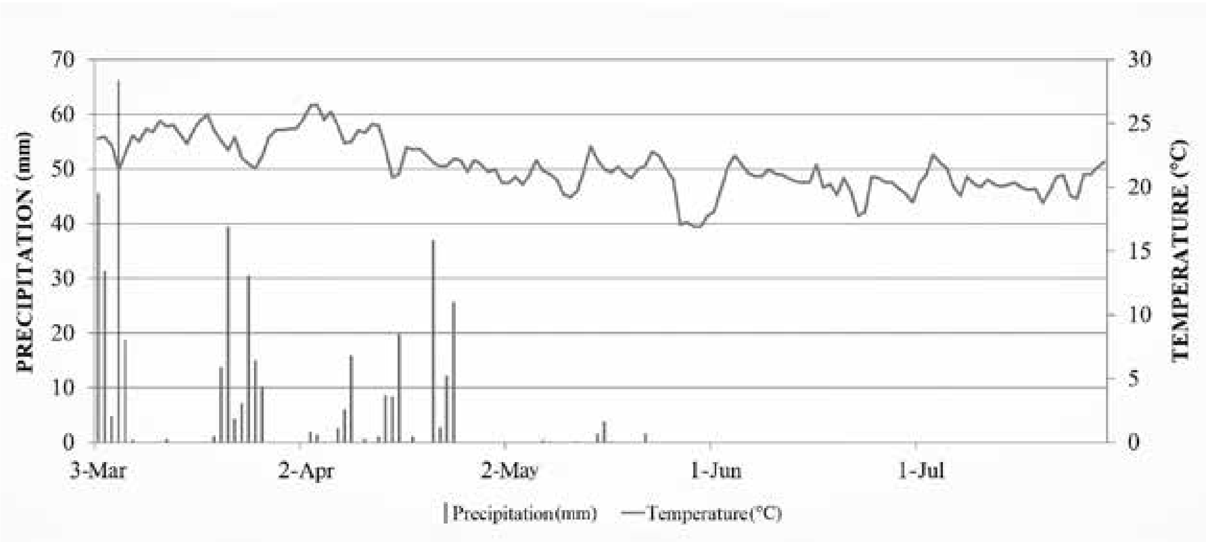
Material and methods

Experiment location and installation

The experiment was carried out at Fazenda Primavera, in the second crop (off-season) of the agricultural year 2020/2021, in Unaí-MG, located in the geographic coordinates of 16°25’27” S and 47°7’11” W with the altitude of 985 m. The local climate is classified as Aw according to Köppen and Geiger (1928), wet tropical rainy season in summer and dry winter. The rainfall and temperature data for the region from the day of sowing to the day of harvest are shown in Figure 1 (INMET, 2020).

The soil in the area is classified as dystrophic red latosol (EMBRAPA, 2006), clayey texture, which was prepared in a no-tillage system in an upland area, following the soybean crop. The experimental design was a randomized block in split-plot schemes, with five maize hybrid plots (K9105VIP3; K9960VIP3; K9606VIP3; K9555VIP3 and K8774PRO3) and four plant populations as the subplots (35,000; 50,000; 65,000 and 80,000 thousand plants ha^{-1}), in three repetitions. All hybrids used have crop recommendations for the harvest season, spring-summer, with a recommended population

Figure 1. Average temperature (°C) and daily rainfall (mm) during the period of the experiment in the agricultural year 2019/20 obtained by Instituto Nacional de Meteorologia (INMET, 2021). UFVJM, Unaí - MG, Brazil (2022).



between 60,000 to 65,000 plants ha^{-1} and in the off-season, autumn-winter, between 45,000 to 55,000 plants ha^{-1} (KWS, 2021). The experimental unit consisted of four rows of maize spaced 0.5 meters and 5 meters long, thus being an area of 10 m^2 per subplot. All characteristics measured were performed in the two central rows, discarding the border.

Sowing was carried out on 3rd March 2020, manually with the help of a jab-planter, at a depth of 0.04 m, spaced on the line according to the desired plant populations (35,000 plants ha^{-1} with 1.75 plants per m and 57.1 cm; 50,000 plants ha^{-1} with 1.75 plants per m and 40.0 cm; 65,000 plants ha^{-1} with 3.25 plants per m and 30.8 cm; and 80,000 plants ha^{-1} with 4.0 plants per m and 25.0 cm), being distributed two seeds per pit in the two central lines of each subplot.

The opening of the furrows and the distribution of the fertilizer were carried out with a specific seeder for the "no-till" system, where mineral fertilizer was deposited in the planting furrow in the amount of 250 kg ha^{-1} of fertilizer formulated with nitrogen and phosphorus 13% N – 33% P. The cultural treatments followed the recommendations of the farm's planning by the technical indications for the cultivation of maize.

Characteristics evaluated

For the evaluation of morphophysiological characters, evaluations were made to the 44 DAS (days after sowing) at the stadium R1, randomly evaluating five plants from the usable area of each plot: i) ear insertion height (EIH); ii) plant height (PH), with measuring tape (measuring from the insertion of the ear or flag leaf to the ground); ii) chlorophyll *a*, *b* and *a/b* (Chl a, Chl b, and Chl a/b), used a Clorofilog Falker in the center of the flag sheet; and iv) stem diameter (SD), with the electronic caliper on the third plant internode.

The harvest was carried out at 147 DAS and after threshing the ears, they were evaluated as follows: i) ear diameter (ED) in installments with electronic caliper; ii) length of the ear (LE) measuring with tape from base to apex; iii) the count of rows of grains per ear (RGE); iv) a number of grains per row (NGR), five ears per parcel; v) thousand-grain weight (WTG) making four weighing of fifty grains of each treatment converting to one thousand grains at 13% moisture; and vi) grain yield (GY) of grain, in which the ears of all the plants of the two central lines were collected (5 m^2, useful area of the experimental unit), after harvesting the ears were threshed, weighed, and the moisture measurement of each plot was performed, converting to the moisture of 13%, to calculate grain yield in kg ha^{-1} about grain yield.

Statistical analysis

Analyses of variance were performed for all variables, and when an effect was detected at a significance level of 5% for the qualitative factor maize hybrid, the Duncan test was applied to discriminate the means. Now, when a significant effect was detected for the quantitative factor plant population, a regression analysis was performed to check the best model (linear, quadratic, or cubic) that fit the data. Analysis of variance and data regression was conducted using the package *ExpDes* of the software R (RSTUDIO TEAM, 2020).

Through the software Genes (CRUZ, 2016), the phenotypic correlation (r_F) among the characteristics, for each of the plant populations, was estimated according to the following expression: $rF = COVF(X,Y) / (\sqrt{\sigma^2 FX}.\ \sigma^2 FX)$, on what: $COVF(X,Y)$ corresponds to the estimate of the covariance phenotypic among traits X and Y; $\sigma^2 FX$ corresponds to the estimate of the phenotypic variance of characteristic X; and $\sigma^2 FY$ corresponds to the phenotypic variance of the trait Y. The statistical test used for the significance of the phenotypic correlation was the test *t* of *Student* (CRUZ et al., 2012).

Results and discussion

Morphophysiological characterization of different plant populations of maize

Only the plant population factor had a significant effect ($P < 0.05$) on all studied variables, except for the plant height characteristic (Table 1). With the increase in the population of 35,000 to 80,000 plants ha^{-1} the stem diameter linearly decreased (Figure 2a), agreeing with the works of Brachtvogel et al. (2012) and Zucareli et al. (2019), who also observed a decrease in stem diameter with increasing populations of 30, 45, 60, 75, 90 and 105; 40, 60, 80 and 100 thousand plants ha^{-1}, respectively. Plants when subjected to high populations due to intraspecific competition, seek growth above the canopy to avoid shading and capture sunlight, thus the photoassimilates are intended to promote accelerated growth, thus reducing other parts of the plant such as the stem diameter (TAIZ, ZEIGER, 2017).

With increasing population, ear insertion height increases linearly (Figure 2b), collaborating with some authors who have also observed this same effect in populations ranging from 50, 60, 70, 80, and 90 thousand plants ha^{-1}; or with 40, 60 and 80 thousand plants ha^{-1} (KAPPES et al., 2011; DA SILVA et al., 2014).

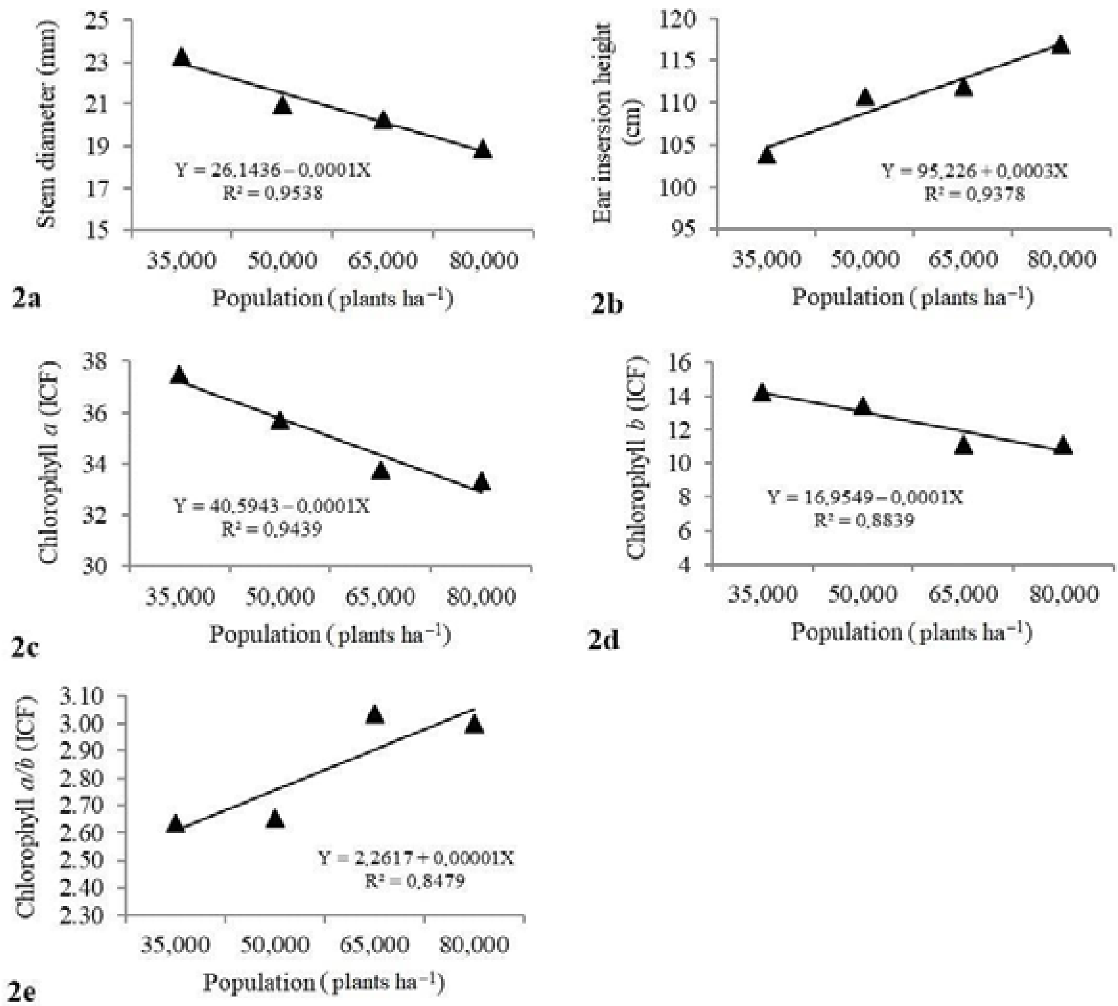
The hybrids studied remained within the recommended value of ear insertion height (EIH), K8774PRO3 with 105-115 cm; K9105VIP3 with 125-135 cm; K9606VIP3 with 125-135 cm; and K9555VIP3 and K9960VIP3 of 140-155 cm, a factor that is important because plants with greater EIH may be more susceptible to lodging and breaking. The smallest EIH, is the target for breeders, because the maize destined 50% of its total phytomass to the grains at the end of the cycle, with this, the greater the relation of the ear insertion height and plant height, the farther its center of gravity and a greater chance of stalk lodging and breaking. The fact of the increase in ear insertion can also be explained

Table 1. Analysis of variance performed for the morphophysiological and agronomics variables from different maize hybrids and plant populations under cultivation in the second crop. UFVJM, Unaí - MG, Brazil (2022).

Variables	Source of variation				
	Hybrid (H)	Population (P)	H × P	Average	CV %
Chl a (ICF)	0.1915	**<0.0001**	0.2045	35.07	11.95
Chl b (ICF)	0.6203	**<0.0001**	0.5503	12.48	41.23
Chl a/b (ICF)	0.8964	**<0.0001**	0.7904	2.91	26.94
ED (mm)	0.8207	**<0.0001**	0.1467	49.18	5.28
EIH (cm)	0.8191	**0.0002**	0.7378	110.81	13.92
EL (cm)	0.3996	**<0.0001**	0.2281	16.52	15.51
GY (kg/ha)	0.6702	**<0.0001**	0.1546	8,214.8	19.72
NGR	0.2620	**<0.0001**	0.7817	26.94	17.02
PH (cm)	0.9914	0.0506	0.5274	220.59	8.51
RGE	0.7284	**0.0012**	0.7964	15.27	14.45
SD (mm)	0.9970	**<0.0001**	0.8612	20.86	12.77
WTG (g)	0.6601	**<0.0001**	0.1516	298.61	11.73

Legend: CV = coefficient of variation; Chl a = chlorophyll *a*; Chl b = chlorophyll *b*; Chl a/b = chlorophyll *a/b*; ED = ear diameter; EIH = ear insertion height; EL = ear length; GY = grain yield; NGR = number of grains per row; PH = plant height; RGE = number of grain rows per ear; SD = stem diameter; WTG = weight of a thousand grains.

Figure 2. Regression analysis to assess the effects of plant populations on morphophysiological characteristics: 2a. stem diameter (SD); 2b. ear insertion height (EIH); 2c chlorophyll *a* (Chl a); 2d. chlorophyll *b* (Chl b); 2e. chlorophyll *a/b* (Chl a/b). UFVJM, Unaí - MG, Brazil (2022).



by the intraspecific competition of plants for luminosity, where the plant grows in search of light and consequently the ear insertion height also grows together. In the work of Calonego et al. (2011), with populations of 45, 60 e 75 thousand plants ha^{-1}, found that with the greatest number of plants per hectare, there was greater growth in plant height, and consequently in the ear insertion height.

Plant height was not significantly different ($P > 0.05$) for any studied factor (Table 1), agreeing with Kopper et al. (2017) who also did not find a significant effect for plant height in different populations of 60,000 e 70,000 plants ha^{-1}.

For the contents of chlorophyll, *a* and *b*, the increase in plant population linearly decreased these contents (Figures 2c and 2d), unlike the relationship between chlorophylls *a*/*b* which increased along with the increased plant density (Figure 2e). Chlorophyll is the main pigment in photosynthesis, where the absorption of light in the blue and red wavelengths, reflects other wavelengths, more evident the green. Generally, in plants, the chlorophyll *b* is 1/3 the amount of chlorophyll *a* and its function is more linked to the transfer of photons for chlorophyll *a*, being important in periods of low light (CID, TEIXEIRA, 2017).

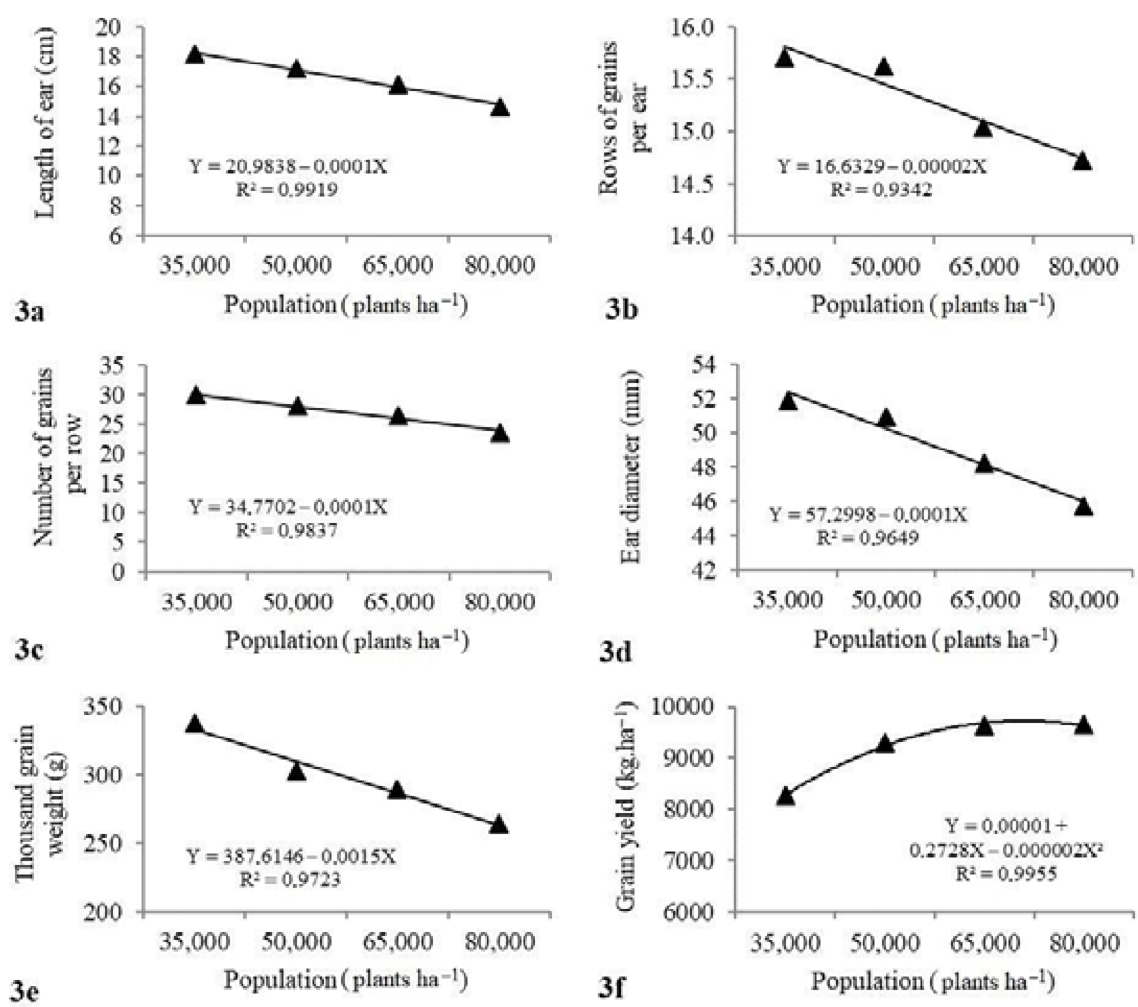
The increase in population density caused a linear decrease in the length of the ear (Figure 3a), showing that the increase in population promotes intraspecific competition for environmental resources, thus compromising other plant structures. Plants spaced equidistantly favor a good development of the ears since they minimally compete for water, light, nutrients, and area (PINTO et al., 2019).

The number of grains per row (NGR) can be directly interfered with by the length of the ear and, consequently in the production of the culture. According to Fancelli (2015), when the plant has twelve fully unfolded leaves, this is when the ear length is set. Soon any injury or adversity and even intraspecific competition at this stage may compromise the length of the ear (LE), causing a drop in production.

The result of this work corroborates with Kappes et al. (2011), who observed an evident progressive reduction in ear length due to the increase in population, justifying the intraspecific competition for water, light, and nutrients.

With the increase in plant population, the ear diameter linearly decreased (Figure 3b), and the increase in population may have resulted in greater intraspecific competition, mainly by water, light, nutrients, and area, but grain yield was not reduced.

Figure 3. Regression analysis to assess the effects of plant populations on agronomic traits: 3a. length of the ear (LE); 3b. rows of grains per ear (RGE); 3c. number of grains per row (NGR); 3d. ear diameter (ED); 3e. thousand-grain weight (WTG); 3f. grain yield (GY). UFVJM, Unaí - MG, Brazil (2022).



The number of rows of grains per ear (RGE) decreased linearly as the plant population increased per hectare (Figure 3c). Da Silva et al. (2014) observed a reduction in the number of rows of grains from 6.7% in the population of 80,000 plants ha^{-1} about the density of 40,000 plants ha^{-1}, data that corroborate the results of this study, where was found the reduction in the number of rows in 9.8% in population from 80,000 plants ha^{-1} to 35,000 plants ha^{-1}.

With the increase in the population of 35,000 plants ha^{-1} for 80,000 plants ha^{-1} the number of grains per row decreased 23% (Figure 3d). This result is in line with those obtained in the study of Fumagalli et al. (2017).

The thousand-grain weight decreased linearly as the plant population increased (Figure 3e), which may be due to the stress caused by shading at high plant densities, the plants were unable to make up for the deficiency of photoassimilates in the leaf. Therefore, high population density promotes intraspecific competition for environmental resources, changing the rate and period of grain filling (RUGET, 1993), and the maintenance and adjustment of the plant structures. However, at low densities, the production of the individual plant is usually high, but the grain yield per area is small (PEREIRA et al., 2018).

A similar result was obtained by Wilhelm (2017), where the thousand-grain weight decreased with population increase, ranging from 317 to 370 g. This decrease was due to the lack of resources available to the plant by intraspecific competition, producing smaller ears, with less grain and low weight, providing lower grain yield per plant. On the other hand, Kopper et al. (2017) observed that in the largest population studied (70,000 plants ha^{-1}) the thousand-grain weight was superior, assigning this result to the smallest amount of grain on the ear.

About grain yield, this was not influenced by hybrids or interaction of factors, just by the plant population, with an average of 8,214.8 kg ha^{-1} (Table 1). Such grain yield values of maize grain of the second crop are considered high, according to the grain yield average of the state Minas Gerais (6,326 kg ha^{-1}) and Brazil (5,456 kg ha^{-1}) to the crop 2019/2020 (CONAB, 2021). With regression analysis, the quadratic response was observed, as the density of plants increased (ha^{-1}), grain yield increased together to a critical point, with an estimated maximum production of 9,302 kg ha^{-1} with 68,200 plants ha^{-1} (Figure 3f).

Hybrids show greater grain yield and are more resistant to adverse conditions, by competition between plants, as they are more suitable for high population densities. It can also bring attributes essential for densification as smaller size, subperiod tasseling stage-ear faster, more erect maize leaves, and high production capacity.

This way, despite the production components thousand-grain weight (WTG), length of the ear (LE), ear diameter (ED), number of rows of grains per ear (RGE), and number of grains per row (NGR) have been negatively affected, possibly by intraspecific competition, the increase in plant population up to 68,200 plants ha^{-1} increased grain yield.

The loss in production components occurs with the increase in population, however, such losses are compensated by the increase of plants and consequently, a greater number of ears per area, as grain yield is not affected. Thus, in crops with a high population and good growing conditions, additional ears result in higher grain yield when increasing the number of grains per area (BRACHTVOGEL et al., 2009; KAPPES et al., 2011), to some critical points (FOLONI et al., 2015).

A similar result has been presented in the literature for different populations of 40 up to 100 thousand plants ha^{-1} (CALONEGO et al., 2011; FARINELLI, CERVEIRA, 2014; TAKASU et al., 2014), which they observe linear growth in grain yield when the plant population increases.

Excessive plant density can lead to intraspecific competition for water, light, and nutrients, being able to stimulate apical dominance, which increases female sterility, reduces the index and size of ears, and consequently the grain yield by area (FUMAGALLI et al, 2017). However, on the other hand, in low populations occurs the reduction of interception of sunlight according to Sangoi et al., 2013, and grain yield per area it's smaller, even with the production per plant individually being favored (PEREIRA et al., 2018). So, in high population densities, the grain yield is compensated per the increment of the number of plants per area.

Phenotypic correlations between morphophysiological characteristics and agronomics

The correlations significant phenotypic were different in some pairs of characteristics, this evidences the influence of the responses of population levels on the development of maize plants (Figure 4).

Estimates of phenotypic correlation consider the genotype and the phenotypes, that is, genotypes can be modified physiologically and morphologically according to the conditions imposed by the growing environment, as noted by Cruz et al. (2012) and Foloni et al. (2015). And with that, it is possible to use the indirect selection of a characteristic without the need of evaluating the other by making more efficient and faster gains when compared with direct selection.

In the population of 35,000 plants, grain yield (GY) had significant positive correlations with the following characteristics RGE (Figure 4a), demonstrating that selecting plants that have a bigger number of grains per row (NGR) will provide great productivity of grain. In the population of 50,000 plants, the grain yield (GY) was not significantly correlated with any other characteristic and so not being able to select indirectly one characteristic of another, but it presents a correlation with less magnitude (thinner line), for the variables of NFE (green lines - Figure 4b).

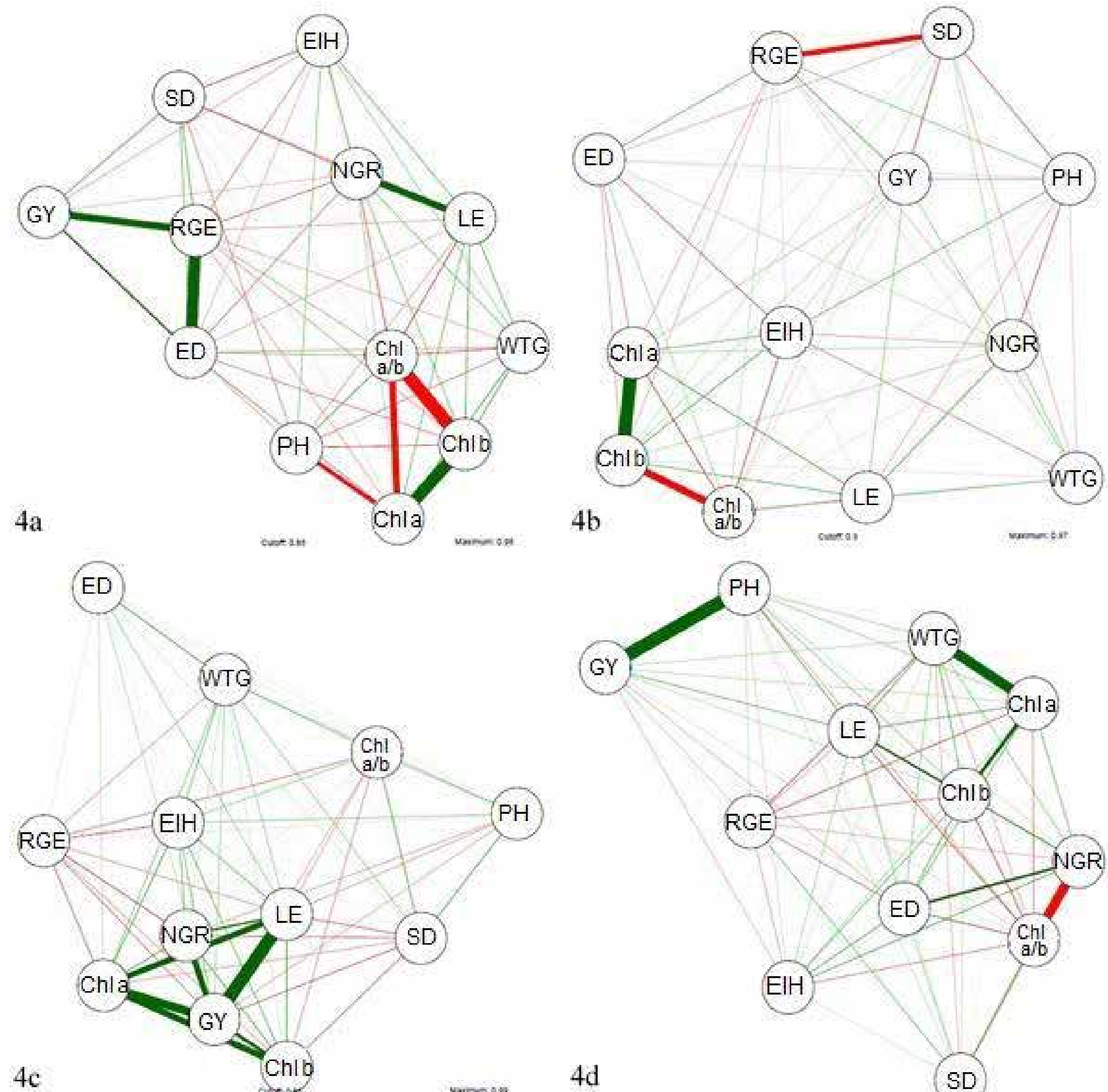
The population of 65,000 plants had a positive correlation of GY with the variables of Chl *a*, Chl *b*, NGR, and LE (thick green lines - Figure 4c). So, the application of the best population arrangement increases the grain yield of the maize crop, since it improves the interception of solar radiation by plants (VITORAZZI et al., 2017).

In 80,000 population density plants, the significant and positive correlation of GY was only with ALT (thick green line - Figure 4d). The high population of plants interferes directly with plant height or reduction in ear diameter (PINTO et al., 2019), making plants seek light, resulting in a larger size. This provides the production of grains with greater masses, going against the results observed in the study of Saraiva et al. (2019), in which although there is greater competition for resources, grain yield can be increased with the greatest amount of ear per area.

The correlation GY with the characteristics EIH, LE, NGR has already been observed by other works such as Fiorini et al. (2018); Guimarães et al. (2019); Pinto et al. (2019); and Saraiva et al. (2019). In the work of Pereira et al. (2018), studying the cultivar of maize "AI Avaré" using 45,000 and 65,000 ha^{-1} of plants, verified that the number of ears per hectare, the number of grains per row and the mass of one hundred grains served to estimate maize grain yield.

Therefore, due to these changes introduced in the phenotypes of current hybrid maize, it becomes essential to always reassess practical management guidelines for new genotypes, between them the spacing and the population of maize hybrids considering the zoning regional agricultural.

Figure 4. Phenotypic correlations of twelve characteristics on the variables of ear insertion height (EIH); plant height (PH); length of the ear (LE); chlorophyll *a* (Chl a); chlorophyll *b* (Chl b); chlorophyll *a/b* (Chl a/b); stem diameter (SD); ear diameter (ED); rows of grains per ear (RGE); the number of grains per row (NGR); thousand-grain weight (WTG); grain yield (GY), evaluated in five maize genotypes, to 4a. the population of 35,000 plants; 4b. the population of 50,000 plants; 4c. the population of 65,000 plants; and, 4d. the population of 80,000 plants. Red lines represent a negative correlation, and green is a positive correlation. Wide line thickness indicates a high and significant correlation. UFVJM, Unaí - MG, Brazil (2022).



Conclusions

1. The increase in plant population in the culture of maize negatively affected the studied variables, the height of ear insertion, stem diameter, chlorophylls, and ear characteristics;

2. The population increase to 68,200 plants ha^{-1} positively influenced the maximum grain yield, which was 9,302 kg ha^{-1};

3. Maize hybrids K9105VIP3, K9960VIP3, K9606VIP3, K9555VIP3 and K8774PRO3 did not differ from each other for any variable studied;

4. Indirect selection, except the population of 50,000 plants ha^{-1}, for the characteristic grain yield, when cultivated in the population of 35,000, 65,000, and 80,000 plants ha^{-1}, respectively significant in plants with a greater

number of grains per row and ear diameter; high chlorophyll *a* and *b*; numbers of grains per ear row; ear length; and taller plants.

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