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GREEN EAR AND GRAIN YIELD OF MAIZE GROWN AT SOWING DENSITIES[1]

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ABSTRACT - One of the characteristics of maize cultivation in the Northeast region of Brazil is the diversity of production systems. One can find from large companies, which adopt modern cultivars and relatively high sowing densities, to small properties, with traditional cultivars grown at low sowing densities (cultivation in pits spaced more than 1.0 m). The objective with this work was to evaluate the effects of sowing density (30, 40, 50, 60, or 70 thousand plants ha^{-1}) on green ear yield and grain yield of maize cultivars (AG 405 and BR 106). Green ears and grain are assessed and marketed differently. Consequently the optimum densities for obtaining each product may be different. In addition, maize cultivars may respond differently to increased density. Densities were achieved by maintaining a constant spacing between rows (1.0 m) and varying the spacing between pits within the same row. Cultivars and sowing densities were combined in a factorial scheme, arranged in a random block design with five replications. The maximum yield of marketable husked green ears of cultivars AG BR 405 and 106 were obtained with densities of 59 and 62 thousand plants ha^{-1}, respectively. The maximum grain yield of cultivars AG 405 and BR 106 were obtained with densities of 61 and 70 thousand plants ha^{-1}, respectively. In general, to produce marketable green ears, cultivar BR 106 was better in terms of number of ears, but the other cultivar was better in terms of ear weight. Cultivar AG 405 responds better to increased density for grain production.

Key words: *Zea mays*. Green maize. Plant population.

RENDIMENTOS DE ESPIGAS VERDES E DE GRÃOS DE MILHO CULTIVADO EM DENSIDADES DE SEMEADURA

RESUMO - No nordeste do Brasil, uma das características da exploração do milho é a diversidade de sistemas de produção. Existem desde grandes empresas, que adotam cultivares modernas e densidades de semeadura elevadas, a pequenas propriedades, nas quais é praticada a agricultura familiar, com cultivares tradicionais cultivadas em baixas densidades (cultivo em covas espaçadas por mais de 1,0). O objetivo foi avaliar os efeitos da densidade de semeadura (30, 40, 50, 60 e 70 mil plantas ha^{-1}) sobre os rendimentos de espigas verdes e de grãos de cultivares de milho (AG 405 e BR 106). Espigas verdes e grãos são comercializados diferentemente. Consequentemente, as densidades ótimas para cada produto podem ser diferentes. Além disso, as cultivares podem responder diferentemente ao aumento da densidade. As densidades foram obtidas mantendo-se constante o espaçamento entre fileiras (1,0 m) e variando-se o espaçamento entre covas de uma mesma fileira. Cultivares e densidades foram combinadas em esquema fatorial, no delineamento de blocos ao acaso com cinco repetições. Os rendimentos máximos de espigas verdes comercializáveis das cultivares AG 405 e BR 106 foram obtidos com as densidades de 59 mil e 62 mil plantas ha^{-1}, respectivamente. Os rendimentos máximos de grãos das cultivares AG 405 e BR 106 foram obtidos com as densidades de 61 mil e 70 mil plantas ha^{-1}, respectivamente. Para produzir espigas comercializáveis, a cultivar BR 106 foi melhor em número de espigas, mas a cultivar AG 405 foi melhor em massa de espigas. A cultivar AG 405 responde melhor ao aumento da densidade na produção de grãos.

Palavras-chave: *Zea mays*. Milho verde. População de plantas.

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INTRODUCTION

In the Brazilian Northeast, maize (*Zea mays* L.) is grown for green ear production and grain production under dryland conditions or as an irrigated crop. The grains in the green ears are milky, having a moisture content between 70 and 80%. Green maize is a much appreciated product by people in the Brazilian Northeast, and is also used in the preparation of typical regional dishes.

One of the characteristics of maize exploration in the region is the frequent use of the same crop to produce green ears and to produce grain. However, it is known that green ears and dried grain are appraised differently. In the production of green ears, there is an interest in big and large-grained ears. These characteristics are also desirable when producing dried grain, but in this case there is greater interest in the grain. Thus, small ears with few grains or that have been attacked by pests are discarded in the commercialization of green ears, but they are completely taken advantage of when the interest is in the dried grains. Consequently the optimum sowing densities for obtaining each product may be different. In addition, sowing density studies are also interesting because maize yield response to density depends on genotypic and environmental influences for green maize (BARBIERI et al., 2005; SILVA et al., 2007; VIEIRA et al., 2010) or grain production (PIANA et al., 2008; SHIOGA; OLIVEIRA; GERAGE, 2004). Therefore, there is no single recommendation for ideal sowing density for all conditions (PENARIOL et al., 2003), especially since the maize can be explored with the objective of baby maize, green ear, grain and/or fodder. Plant population represents the agronomic-management factor that changed most during the past six decades as a result of tolerance of newer hybrids to high plant populations (TOLLENAAR; LEE, 2002).

Many papers (PIANA et al., 2008; BRACHTVOGEL et al., 2009; DOUG et al., 2009; MODOLO et al., 2010; SERPA et al., 2012; SHAFI et al., 2012) have demonstrated the beneficial influence of higher sowing densities on dry maize grain yield. With regard to green maize, few papers (BARBIERI et al., 2005; SILVA et al., 2007) have been found in the literature relating to this subject. These papers have shown that in common maize (SILVA et al., 2007; VIEIRA et al., 2010) or sweet maize (BARBIERI et al., 2005), green ear yield increases can be obtained by increasing sowing density. In baby maize (husked maize ears, harvested two to three days after silk emergence), the effects of increased sowing densities are contradictory. Some authors (LONG et al., 2009) verified positive effects of sowing density, whereas other (KHEIBARI et al., 2002) did not observe any effects.

The improved grain yield per unit area of modern maize hybrids, among other factors, is due to the increased optimum plant population rather than the improved grain yield per plant. Traits associated with tolerance to various stresses, including high plant populations, and the efficiency of capture and use of resources rendered modern hybrids more productive (TOKATLIDIS; KOUTROUBAS, 2004).

The objective with present work was to evaluate the effects of sowing density on green ear yield, grain yield and other characteristics of two maize cultivars.

MATERIAL AND METHODS

The research was carried out in an area of Experimental Farm 'Rafael Fernandes' (experimental farm), located about 20 km away from the municipal seat of Mossoró-RN (5° 11' S Latitude, 37° 20' W Longitude, and 18 m elevation). According to W.C. Thorntwaite, the climate in the region is DdÁá, that is, semi-arid and megathermal (CARMO FILHO; OLIVEIRA, 1989).

The analysis of a soil sample from the experiment area, classified according to the Brazilian Soil Classification System as Argissolo Vermelho-Amarelo Eutrófico (EMBRAPA, 2006) and as Ferric Lixisol according to the Soil Map of the World (FAO, 1988), indicated: pH = 6.2; Ca = 1.40 $cmol_c^{-1}$ dm^{-3}; Mg = 0.20 $cmol_c$ dm^{-3}; K = 0.10 $cmol_c$ dm^{-3}; Na = 0.01 $cmol_c$ dm^{-3}; Al = 0.00 $cmol_c$ dm^{-3}; P = 40 mg dm^{-3}; Org. Matt. = 1.20 g kg^{-1}. The soil was tilled by means of two harrowings, and was fertilized at sowing with 40 kg ha^{-1} N (ammonium sulfate), 60 kg ha^{-1} P_2O_5 (single superphosphate) and 30 kg ha^{-1} K_2O (potassium chloride). The fertilizers were applied in 10-cm-deep furrows made alongside and below the sowing furrows. Sowing was performed on 03.16.2008, and four seeds/pit were used. A replanting operation was performed six days after sowing to eliminate gaps of about 2%. A thinning operation was performed 29 days after sowing, leaving the more vigorous plants in each pit. Pest control was performed by three deltamethrin sprays (5,0 g ha^{-1} a.i.), at 10, 16 and 22 days after sowing. Weed control was achieved by two hoeings, performed at 20 and 41 days after sowing. Sidedressing applications were performed at 29 and 44 days after sowing with 40 kg N ha^{-1} (ammonium sulfate). Soil tillage was done with a tractor; a back-pack sprayer was used to control pests; invasive plants were controlled with a hoe, and other operations were accomplished by hand.

Two cultivars (BR 106 and AG 405) were submitted to densities of 30, 40, 50, 60, and 70 thousand plants/ha (1.49, 2.50, 3.50 and 4.50 pits per linear meter for densities of 30, 40, 50, 60 and 70 thousand plants ha^{-1}). Cultivar BR 106 is an open-pollination variety developed by Embrapa (The Brazilian Agricultural Research Corporation). Cultivar AG 405 is a double cross developed by Sementes Agroceres. The different densities herein mentioned were achieved by maintaining a constant spacing between rows (1.0 m) and varying the spacing between pits within the same row. Cultivars and plant populations were combined in a complete factorial scheme, arranged in a random block design with five replicates. Each plot consisted of four 6.0 m long rows. The usable area was considered as the space occupied by the two central rows, with the elimination of one pit at each end.

One of the useful rows was used to evaluate green ear yield, and the other to evaluate grain yield. Other characteristics, besides these, were evaluated in both rows. Harvest of green ears was performed in four steps, during the period from 69 to 76 days after sowing. Green maize yield was evaluated by the number and total weight of green unhusked ears, and by the number and weight of both marketable unhusked and husked ears. Ears with a length equal to or above 22 cm and without signs of attack by pests were considered as marketable unhusked ears. Ears with a length equal to or above 17 cm, displaying suitable grain set and health for selling purposes were considered marketable husked ears. After the green maize was harvested, the following characteristics were evaluated: plant and ear height, stalk diameter, dry matter of the above-ground part (stalk + leaves + tassel), number of tassel branches and leaf area. Except for green maize yield and number of tassel branches (estimated based on the usable plants in the plot), dry matter of the above-ground and stalk diameter (evaluated on six plants), and leaf area (estimated based on two plants, using an electronic leaf area measuring device), all other characteristics were estimated based on ten plants randomly selected from the usable area of each plot. The distance from ground level to the insertion point of the highest leaf blade was considered as plant height. Ear height was considered as the distance from ground level to the first ear's insertion node. Stalk diameter was measured with a caliper rule below the ear insertion node.

Harvest of mature ears was performed 100 days after sowing. After harvesting, evaluations were also made for the number of ears/ha (based on ears harvested from usable plants), number of kernels/ear (in 15 ears), 100-grain weight (in five 100-grain samples) and grain yield (of usable plants, corrected for a moisture content of 15.5%).

The data were submitted to the variance homogeneity test prior to the analyses of variance and regression (BARTLETT, 1937). Because count data tend to follow the Poisson distribution, count data were transformed to square root prior to the statistical analysis (Bartlett, 1947). The means were compared at 5% probability by Tukey's test whenever the F test values from the analysis of variance were significant. Regression equations was selected based on the following criteria: biological explanation of the phenomenon observed, simplicity of the equation, significance of the coefficients at 5 % probability by *Student*'s *t* test and coefficient of determination value.

RESULTS AND DISCUSSION

The increase in sowing density in both cultivars reduced the average leaf area and stalk diameter, as observed by Penariol et al. (2003), but it did not alter the number of tassel ramifications (Table 1). Cultivar AG 405 was superior to cultivar BR 106 with regard to stalk diameter in densities of up to approximately 37 thousand plants ha^{-1}. After that density, there was no difference between the two cultivars. Cultivar AG 405 was also superior with regard to the number of tassel ramifications, in all sowing densities, but there was no difference between them with regard to average leaf area.

Increased sowing density increased plant height and ear height (Table 1) in both cultivars. Shafi et al. (2012) also observed increases in plant height of maize cultivars with increased sowing density. The cultivars did not differ concerning these characteristics over the range of tested sowing densities. Increasing sowing density increased plant height and ear height probably due to competition for light. Competition for light responses of the crops to avoid competitive interactions are developing characteristics to avoid shading, such as low ratios roots / shoots, thinner stalks and stronger apical dominance with low intensity branching characteristics favoring height growth of the stalk, allowing them to rise above the branches of neighboring plants (KEGGE e PIERIK, 2009). Morphological changes to avoid shading occur before the shading occurs, ie, before the density photosynthetic photon flux become limiting (RAJCAN et al., 2004). Shafi et al. (2012), such as observed in the present study, also observed an increase in plant height with increasing density. However, in some cases, plant density did not affect plant height and ear height of two cultivars (SILVA et al., 2007). The discrepancies in relation to sowing density effects on plant height are certainly due to the different sowing densities tested by different authors, among other environmental factors, but also resulted from the characteristics of the cultivars evaluated. Begna et al. (1997) demonstrated that non -leafy, shorter cultivars withstood higher densities better. The influence of leafiness on tolerance to high densities has also been verified by Sangoi e Salvador (1998).

The weight of the fresh biomass of the above-ground part also increased in both cultivars with increased sowing density (Table 1). Despite the reductions in stalk diameter and leaf area, the increased plant height and the greater number of plants per unit of area contributed to increased fodder productivity. There was no difference between cultivars concerning this characteristic.

Table 1. Sowing density effects on green ear yield and other characteristics of maize cultivars.

Characteristics (y)	Cultivars	Sowing density effects (d, i.e., 30, 40, 50, 60, and 70 thousand plants ha^{-1})	R^2
Leaf area (cm^2 leaf^{-1})	AG 405	$y^2 = 149470.7 – 0.0982^{**} x^3$	89
	BR 106	$y = 393.1 – 0.0165^{**} x^2$	81
Stalk diameter (cm)	AG 405	$y = 1.47 + 25.54^{**}/x$	97
	BR 106	$y = 1.51 + 17.97^{**}/x$	77
Number of tassel branches (no. tassel^{-1})	AG 405	$y = 17.0$	-
	BR 106	$y = 14.0$	-
Plant height (cm)	AG 405	$y = 271.0 – 325.7^{**}/x^{0.5}$	93
	BR 106	$y = 252.2 – 269.4^{**}/x^{0.5}$	80
Ear height (cm)	AG 405	$y^2 = 17647.9 – 194827.0^{**}/x$	93
	BR 106	$y = 145.5 – 204.3^{**}/x^{0.5}$	97
Fresh biomass of the above-ground part (kg ha^{-1})	AG 405	$y = 17985.8 + 0.0374^{**} x^3$	99
	BR 106	$y^2 = - 85379000.0 + 13110900.0^{**} x$	94
Total no. of ears ha^{-1}	AG 405	$y = 10662.6 + 818.1^{**} x$	99
	BR 106	$y = 90990.1 – 1503400^{**}/x$	92
Number of marketable unhusked ears ha^{-1}	AG 405	$y^2 = - 487800000 + 50442200^{**}x$	98
	BR 106	$y = 9363.8 + 5334.4^{**} x^{0.5}$	89
Number of marketable husked ears ha^{-1}	AG 405	$y = - 2756.2 + 1395.9^{**} x – 11.8^{**} x^2$	99
	BR 106	$y = 13075.3 + 686.2^{**} x – 5.5^{**} x^2$	98
Total ear weight (kg ha^{-1})	AG 405	$y = 8316.6 + 93.8^{**} x$	100
	BR 106	$y = 9227.0 + 0.8516^{**} x^{2.5} – 0.0888^{**} x^3$	75
Weight of marketable unhusked ears (kg ha^{-1})	AG 405	$y = 13773.5 – 526520.0^{**}/x^{1.5}$	96
	BR 106	$y = 12212.2 – 270884.7^{*}/x^{1.5}$	47
Weight of marketable husked ears (kg ha^{-1})	AG 405	$y = 4516.9 + 2.27^{**} x^2 –0.0296^{**} x^3$	96
	BR 106	$y = 36428.1 – 631.3^{**} x + 4.01^{**} x^2 – 477098.9^{**}/x$	81

*Significant at 10% probability by t test. **Significant at 5% probability by t test.

There were also increases in the total weight of green ears and marketable green ears, husked and unhusked, with the increased sowing density (Table 1). With regard to total weight, the increased yield was linear in cultivar AG 405, but in the other cultivar this yield reached a maximum at around 64 thousand plants ha^{-1}. With regard to the weight of marketable husked green ears, the results in both cultivars were very similar: there was an increase in yield due to increased density, but the increases were progressively smaller. With regard to marketable unhusked green ears, there were increases with densities of up to 51 thousand plants ha^{-1} and 38 thousand plants ha^{-1} in cultivars AG 405 and BR 106, respectively. There was no difference between the cultivars with regard to total and marketable unhusked ear weights. But in the weight of marketable husked ears, cultivar AG 405 was better than the other cultivar up to a sowing density of 69 thousand plants ha^{-1}.

The effects of sowing density on the characteristics employed to evaluate green maize yield observed in this work were in agreement with those obtained by other authors (SILVA et al., 2007). Those authors observed that the effect of increased sowing densities was positive at a nitrogen rate similar to the rate used in this work. However, in the absence of this fertilizer, increases in sowing density reduced green ear yield.

Grain yield increased in both cultivars with increased sowing density (Table 2). Many papers (PIANA et al., 2008; BRACHTVOGEL et al., 2009; DOUG et al., 2009; MODOLO et al., 2010; SERPA et al., 2012; SHAFI et al., 2012) have demonstrated the beneficial influence of higher sowing densities on dry maize grain yield. In cultivar AG 405, a maximum yield would be observed with a density of 61 thousand plants ha^{-1}. In the other cultivar, maximum yield, in the range of evaluated densities, occurred with a sowing density of 70 thousand plants ha^{-1}. This interaction cultivars x sowing densities, for grain yield was also observed by other authors (SHAFI et al., 2012).

Increased yields in the two cultivars would be due to increases in the number of ears ha^{-1}, as long as there was a reduction in the number of grains ear^{-1} and there was no change in the weight of 100 grains, with the increased sowing density (Table 2). The increased sowing density also reduced ear length in both cultivars (Table 2). The cultivars did not differ in the number of ripe ears ha^{-1}. Cultivar AG 405 was superior to cultivar BR 106, with regard to the number of grains ear^{-1}, up to a density of 50 thousand plants ha^{-1}. Above that, the cultivars did not differ. In all tested densities, cultivar AG 405 was superior with regard to the weight of 100 grains and ear length.

Table 2. Sowing density effects on grain yield and other characteristics of maize cultivars.

Characteristics (y)	Cultivars	Sowing density effects (x, i.e., 30, 40, 50, 60, and 70 thousand plants ha^{-1})	R^2
Grain yield (kg ha^{-1})	AG 405	$y = - 1191.74 + 259.61^{**} x – 2.13^{**} x^2$	98
	BR 106	$y = 6536.93 – 2600000/ x^2$	98
Number of mature ears ha^{-1}	AG 405	$y = 7110.80 + 853.84^{**} x$	98
	BR 106	$y = - 20060.49 + 2169.76^{**} x – 13.47^{**} x^2$	98
Number of grains ear^{-1}	AG 405	$y = 528.9 – 2.45^{**} x$	99
	BR 106	$y = 388.64 – 0.00015^{**} x^3$	83
Weight 0f 100 grains (g)	AG 405	y = 36.7	-
	BR 106	y = 33.3	-
Mature ear length (cm)	AG 405	$y = 19.50 –0.0740^{**} x$	99
	BR 106	$y = - 2.18 - .4118^{**} x + 5.1637^{**} x^{0.5}$	97

**Significant at 5% probability by t test.

The negative effects of increased sowing density on some traits or from an optimal density, observed in the present study, could be due mainly to a reduced availability of nutrients and light, since no competition for water must have occurred because the experiment was irrigated. However, other factors could be involved. Soil water content is higher in maize plots infested with weeds than in plots that were kept weed-free (THOMAS; ALLISON, 1975). This could be a suggestion that, in sowing density studies, the negative effects of increased densities may not be caused only by water availability, but also by a reduced capacity of the root system in absorbing water. It also suggests that, even in irrigated crops, increased sowing densities could reduce yields by reducing the root system's capacity to absorb water. Similar reasoning as suggested for water competition could be applied to competition for nutrients and light. In relation to light, the smaller yields observed at higher densities could be due to smaller photosynthetic rates, caused by mutual shading, but also by a smaller leaf area (Table 2) produced and/or by accelerated leaf senescence. An increased sowing density increases light attenuation in the maize canopy (BORRÁS; MADDONI; OTEGUI, 2003), reduces leaf area index (LAI) (BAVEC; BAVEC, 2002), and increases leaf senescence (Borrás et al., 2003).

CONCLUSIONS

The maximum yield of marketable husked green ears of cultivars AG BR 405 and 106 were obtained with densities of 59 and 62 thousand plants ha^{-1}, respectively. The maximum grain yield of cultivars AG 405 and BR 106 were obtained with densities of 61 and 70 thousand plants ha^{-1}, respectively. In general, to produce marketable green ears, cultivar BR 106 was better in terms of number of ears, but the other cultivar was better in terms of ear weight. Cultivar AG 405 responds better to increased sowing density for grain production.

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