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CROP PRODUCTION

Agricultural traits and popping expansion of the popcorn hybrid IAC 125 under different plant densities and irrigation water depth levels

Oelcio José Stipp[1], Omar Possato Junior[1], Evandrei Rossi[1], Jocimar Costa Rosa[1], Renan Santos Uhdre[1*], Diego Ary Rizzardi[1], Paulo Sergio Lourenço de Freitas[2] and Ronald José Barth Pinto[2†]

[1]Programa de Pós-graduação em Genética e Melhoramento, Universidade Estadual de Maringá, Avenida Colombo, 5790, 87020-900, Maringá, Paraná, Brazil. [2]Departamento de Agronomia, Universidade Estadual de Maringá, Maringá, Paraná, Brazil. †In memoriam. *Author for correspondence. E-mail: renan_uhdre@hotmail.com

ABSTRACT. Popcorn (*Zea mays* L. *everta*) is a specialty crop with a higher aggregate economic value than that of common maize. In Brazil, national literature is still incipient and contradictory in terms of plant population management and water requirements. Furthermore, the interaction between these factors has not been reported, despite the increasing cultivation of popcorn. The objective of this trial was to determine whether agricultural traits and popping expansion from hybrid IAC 125 could be affected by plant density and levels of irrigation water, in addition to determining the significance level of the interaction between both factors. We investigated five plant populations (40,000, 55,000, 70,000, 85,000, and 100,000 plants ha^{-1}) and five different levels of water depth in 2014/2015 [574.86 (without supplementary irrigation), 609.86, 644.86, 679.86 (control), and 714.86 mm] and 2015/2016 [857.4 (without supplementary irrigation), 867.26, 886.60, 916.78 (control), and 959.81 mm] using a complete block design with split-plot, comprising a main plot (for plant populations) and subplot (for water depth), with six replicates for each set. We found increasing linear effects from grain yield under population density and levels of water depth, but this interaction was not significant. Moreover, the popping expansion for the main effects and the interaction between plant populations and water depth, were not significant.

Keywords: *Zea may* L.; plant population; interactive effects; yield components.

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Introduction

Popcorn (*Zea mays* L. subsp. *everta)* acreage has been increasing in many agricultural countries, and the United States has achieved the highest production in recent years (USDA, 2020; Caranhato et al., 2022). In Brazil, the crop has been thriving as an alternative to various crops and increased the profits of plant growers due to its higher aggregate economic value than common maize (Kirst et al., 2013). In the specialty maize group, the main popcorn trait is popping expansion at high temperatures (>180°C), producing a soft and tasteful snack that is much appreciated worldwide (Pinto et al., 2007). The estimates indicate an input of U$ 15 billion by 2023 by reinforcing consumption. Further studies are also required to achieve this goal (Dawande, 2018).

Nonetheless, few cultivars are available in the national market, despite the importance of popcorn grain in Brazil. This fact, combined with lots of contradictory information about plant population, irrigation management, and interaction between these factors, is still required to determine the crop yield and popping expansion, and corroborate the small number of cultivars and acreage available to produce popcorn (Avila et al., 2011; Beiragi, Ebrahimi, Mostafavi, Golbashy, & Khorasani, 2011; Franco et al., 2014).

The off-season production has been increasing because of the advantage of obtaining better marketing prices. However, during this period, the production drop is attenuated due to droughts in some regions, and supplementary irrigation becomes essential (Silva et al., 2012). This break is related to the high sensitivity of corn to water deficit occurring during critical periods of development, such as bolting and grain filling, because water is essential for the absorption and transport of nutrients (Carvalho et al., 2013; Fenner et al., 2015).

Many experiments to obtain high crop yields were conducted in Brazil. They investigated plant populations, hybrids, and crop cycles under different levels of management (Silva, Sangoi, Vieira, & Marchesi, 2012; De Souza et al., 2013; Sangiovo et al., 2022). Ávila et al. (2011) in their study on popcorn hybrids grown in irrigation depth, observed that the hybrid IAC 125 in the presence of irrigation and in the variation of Kc above the reference for the corn is generally more responsive. However, contradictory information has been found between factors such as plant density and water management, and there is no information about the interaction between these factors.

Furthermore, studies on locally available genotypes are necessary to improve agricultural traits for better technical information about plant populations and supplementary irrigation, as well as the interaction between them. We aimed to determine whether higher densities of hybrid plants 'IAC 125' and supplementary irrigation can improve agricultural traits or whether they can be affected by the interactive effects of these factors without affecting popping expansion. Thus, the objective of the current study, performed during the two growing seasons, was to verify whether the agricultural traits and the popping expansion of the hybrid 'IAC 125' could have influenced the plant population and levels of water depth, or whether they have some level of interaction.

Material and methods

During the growing seasons of 2014/2015 and 2015/2016, we carried out two experiments on Latosol Red Distroferric (Oxisoil) at the Iguatemi Research Farm (23°25' S, 51°57' W and altitude of 550 m) in the State University of Maringá (Nitsche, Caramori, Ricce, & Pinto, 2019). The weather was Cfa according to the Koppen classification. Data on the temperature and rainfall during the experiments are shown in Figures 1 and 2, respectively.

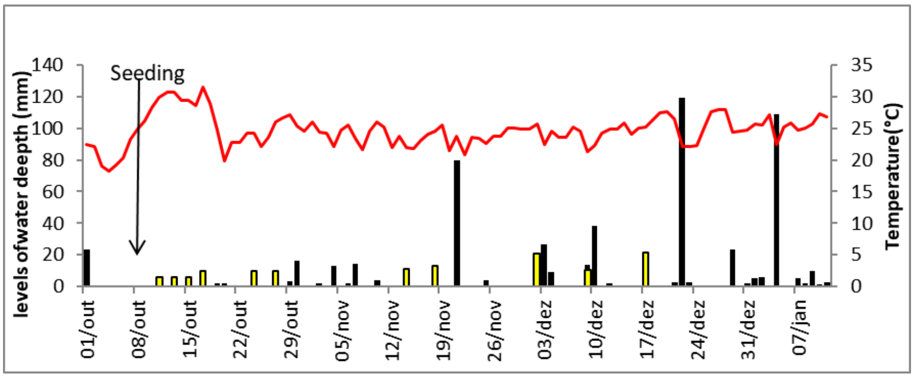

Figure 1. Black bars = weekly rainfall (mm), red line = average temperatures (ºC), and yellow bars = irrigation (Control, L3) during the experimental period in the growing season 2014/2015, at the Iguatemi Research Farm, and amid the popcorn cropping. Data was collected from the Digital Meteorological Station established on the experimental area.

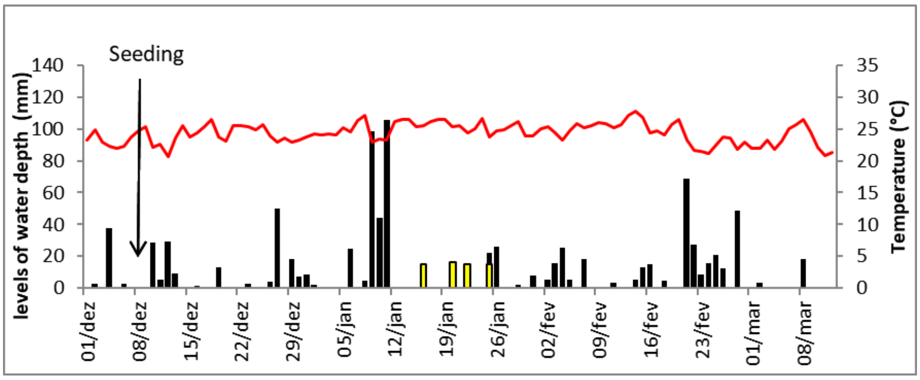

Figure 2. Black bars = weekly rainfall (mm), red line = average temperatures (ºC), and yellow bars = irrigation (Control, L3) during the experimental period in the growing season 2015/2016, at the Iguatemi Research Farm, and amid the popcorn cropping. Data collected from the digital Meteorological Station established in the experimental area.

The treatments investigating the hybrid IAC-125 involved a combination of two factors following a factorial 5 × 5 with six replications. These factors were plant population with five levels (40,000, 55,000, 70,000, 85,000, and 100,000 plants ha^{-1} and plant rows 0.9 m apart) and five irrigation water depths (also rainfall). The levels of plant population were thinned approximately 14 days after emergence at stages V2 and V3 when the collar was visible. The first experiment (2014/2015) focused on the following levels of irrigation water depth: 574.86 (without supplementary irrigation), 609.86, 644.86, 679.86 (the Control), and 714.86 mm. The second experiment (2015/2016) focused on the following levels of irrigation water depth: 857.4 (without supplementary irrigation), 867.26, 886.60, 916.78 (control), and 959.81 mm. The Naan-Dan brand sprinkler impact model 5022 was used, with a nozzle and 3.0 bar operating pressure with water distributions in the perpendicular direction to the sprinkler line, using a sprinkler irrigation system with sprinklers every 6 m on the main line (Line Source Sprinkler System) (Hanks, Keller, Rasmussen, & Wilson, 1976).

The traits evaluated in both trials (2014/2015 and 2015/2016) were plant height (PH, m), ear height (EH, m), stalk diameter (SD, mm), ear length (EL, cm), ear diameter (ED, mm), grain per ear row (GER, unit), number of grain rows (NGR, unit), the biomass of 1000 grains (BM1000, g), crop yield (Y, kg ha^{-1}), and popping expansion (CE, mL g^{-1}). The traits PH, EH, SD, EL, ED, GER, and NGR were randomly measured using metal ruler and digital calipers from five plants at each split-plot. Stalk diameters were measured at the middle of the second internode above the ground, and BM1000 was determined following the method described by Brazil (1992). The Y (kg ha^{-1}) was determined from the total biomass at each split plot, with a uniform humidity of 14%. The CE was determined using grains from the middle of the ears. From every split-plot, we took two 30-g samples with water contents ranging from 13 to 14%. We used an electrical machine with an automatically temperature controlled at 280°C for two minutes and ten seconds. Thereafter, the volume was measured using a graduated cylinder of 2,000 mL capacity. The CE is the ratio between the expanded volume and grain biomass.

The experimental design consisted of six randomized complete blocks with split plots. The plant population was the main factor randomly distributed in each plot, and the level of water depth was the subplot factor. The experimental plot consisted of 6-m long and 13.5-m wide plant rows. Each plot was divided into five parts with two plant rows in each split-plot (useful area of 10.8 m^2) and one border row between each one. The homogeneity of variance was verified using Bartlett's test, and the normality of the error was verified using the Shapiro-Wilk test. We applied ANOVA when these basic assumptions were found and then fit the polynomial regression to verify dependence of the trait on the factors. The significance level was considered at $p \leqslant 0.05$, while using the statistical software Sisvar 5.0 (Ferreira, 2011).

Results and discussion

In 2014/2015, irrigation met the initial plant water requirements. The subsequent periods of rainfall with rare drought episodes justified the supplementary irrigation (Figure 1). In 2015/2016, the water conditions were sufficient in the first 35 days of plant growth, unlike that within 35–50 days (stage V8) when one episode of water deficit was supported by irrigation (Figure 2). We found significant effects of EL, NGR, BM1000, and Y ($p < 0.05$) on plant densities and levels of irrigation water, but NR had a significant effect ($p < 0.05$) only on water depth (Table 1). In 2015/2016, the EL, GNR, and Y traits were significantly different ($p < 0.05$) for the main effects, but the SD and BM1000 traits showed significant effect only on plant density (Tables 2 and 3).

Table 1. Analyses of variance for agricultural traits from the popcorn hybrid IAC-125 at different plant densities and water depths in the growing season 2014/2015, in Maringá, Paraná State, Brazil.

	p-values							
SV	df	ED	EL	NR	NGR	BM1000	Y	PE
Blocks	5	-	-	-	-	-	-	-
Densities (D)	(4)	0.863 ^{ns}	0.009 *	0.918 ^{ns}	0.027 *	0.066 ^{ns}	0.007 *	0.413 ^{ns}
LR	1	0.602 ^{ns}	0.001 *	0.952 ^{ns}	0.012 *	0.037 *	0.000 *	0.959 ^{ns}
QR	1	0.862 ^{ns}	0.537^{ns}	0.919 ^{ns}	0.281 ^{ns}	0.065 ^{ns}	0.429 ^{ns}	0.159 ^{ns}
LF	2	0.662 ^{ns}	0.332 ^{ns}	0.642 ^{ns}	0.112 ^{ns}	0.446 ^{ns}	0.672 ^{ns}	0.386 ^{ns}
Error (a)	20	-	-	-	-	-	-	-
Depth (L)	(4)	0.377 ^{ns}	0.000 *	0.11 ^{ns}	0.006 *	0.114 ^{ns}	0.000 *	0.786 ^{ns}
LR	1	0.208 ^{ns}	0.000 *	0.672 ^{ns}	0.011 *	0.079 ^{ns}	0.000 *	0.304 ^{ns}
QR	1	0.960 ^{ns}	0.021 *	0.012 *	0.007 *	0.042 *	0.066 ^{ns}	0.950 ^{ns}
LF	2	0.270 ^{ns}	0.103 ^{ns}	0.612 ^{ns}	0.713 ^{ns}	0.882 ^{ns}	0.099 ^{ns}	0.723 ^{ns}
D x L	16	0.812 ^{ns}	0.583 ^{ns}	0.759 ^{ns}	0.987 ^{ns}	0.771 ^{ns}	0.236 ^{ns}	0.654 ^{ns}
Error (b)	100	-	-	-	-	-	-	-
Average	-	32.49	16.66	14.69	36.32	147.53	3322.13	39.79
CV(a)%	-	3.01	4.67	5.15	4.07	6.08	14.54	5.58
CV(b)%	-	3.07	4.43	4.67	4.42	6.42	10.81	5.47

*Significant ($p < 0.05$); ^{ns}: non-significant; RL: linear regression; RQ: quadratic regression; LF: lack of fit; Y: grain yield (kg ha^{-1}); ED: ear diameter (mm); EL: ear length (cm); NR: number of grain rows; GNR: grain number in rows; BM1000: biomass of one thousand grains (g); PE: popping expansion (mL g^{-1}).

Table 2. Analyses of variance for agricultural traits in the popcorn hybrid IAC-125 at different plant densities and levels of water depth in the growing season 2015/2016, in Maringá, Paraná State, Brazil.

SV	p-values					
	df	PH	EH	SD	ED	EL
Blocks	5	-	-	-	-	-
Densities (D)	(4)	0.247 ns	0.168 ns	0.000 *	0.521 ns	0.009 *
RL	1	0.091 ns	0.150 ns	0.000 *	0.543 ns	0.001 *
RQ	1	0.122 ns	0.072 ns	0.410 ns	0.349 ns	0.481 ns
LF	2	0.935 ns	0.518 ns	0.205 ns	0.382 ns	0.541 ns
Error (a)	20	-	-	-	-	-
Levels of Depth (L)	(4)	0.005 *	0.000 *	0.000 *	0.258 ns	0.247 ns
RL	1	0.000 *	0.000 *	0.152 ns	0.124 ns	0.047 *
RQ	1	0.000 *	0.000 *	0.773 ns	0.687 ns	0.281 ns
LF	2	0.014 *	0.000 *	0.000 *	0.250 ns	0.870 ns
D x L	16	0.857 ns	0.547 ns	0.526 ns	0.855 ns	0.124 ns
Error (b)	100	-	-	-	-	-
Average	-	1.93	1.04	15.65	30.91	15.37
CV(a)%	-	6.14	8.56	8.27	4.15	7.37
CV(b)%	-	4.95	8.45	9.87	5.58	6.64

*Significant ($p < 0.05$); ns, non-significant; RL, linear regression; RQ, quadratic regression; LF, lack of fit; PH, plant height (m); EH, ear height (m); SD, stalk diameter (mm); ED, ear diameter (mm); EL, ear length (cm).

Table 3. Analyses of variance of data for agriculture traits from the popcorn hybrid IAC-125 growing under different plant densities and levels of water depth in the growing season 2015/2016, Maringá, Paraná State, Brazil.

SV	p-value					
	df	NR	NGR	BM1000	Y	PE
Blocks	5	-	-	-	-	-
Density (D)	(4)	0.157 ns	0.157 ns	0.070 *	0.020 *	0.913 ns
RL	1	0.039 *	0.027 *	0.011 *	0.007 *	0.912 ns
RQ	1	0.129 ns	0.554 ns	0.160 ns	0.239 ns	0.828 ns
LF	2	0.992 ns	0.507 ns	0.923 ns	0.136 ns	0.647 ns
Error (a)	20	-	-	-	-	-
Levels Depth (L)	(4)	0.121 ns	0.000 *	0.550 ns	0.004 *	0.902 ns
RL	1	0.137 ns	0.000 *	0.225 ns	0.002 *	0.622 ns
RQ	1	0.117 ns	0.027 *	0.306 ns	0.534 ns	0.805 ns
LF	2	0.257 ns	0.137 ns	0.775 ns	0.076 ns	0.692 ns
D x L	16	0.101 ns	0.896 ns	0.875 ns	0.800 ns	0.722 ns
Error (b)	100	-	-	-	-	-
Average	-	13.89	36.51	111.05	1476.6	34,05
CV(a)%	-	6.79	6.98	8.43	20.51	6.08
CV(b)%	-	5.91	5.61	7.13	17.09	7.16

*Significant ($p < 0.05$); ns: non-significant; RL: linear regression; RQ: quadratic regression; LF: lack of fit; NR: number of rows; NGR: number of grains in the row; BM1000: biomass of one thousand grains (g); Y: crop yield (kg ha^{-1}); PE: popping expansion (mL g^{-1}).

These results corroborate reports from different experiments where the authors, fitting regression models, highlighted agricultural traits from popcorn affected by plant density and levels of irrigation water depth (Leonello, Cazetta, & Fornasieri Filho, 2009; Ávila et al., 2011). The current regression models, coefficients of determination (R^2), critical points of traits from plant densities, and levels of irrigation water depths are shown in Table 4.

We did not observe significant effects ($p > 0.05$) on the interaction between plant density and levels of water depth for any of the traits (Tables 1, 2, and 3), and the ED from the main effects and the interaction between them, in both growing seasons (Tables 1 and 2). These results corroborate the report by Sangiovo et al. (2022), who also evaluated commercial hybrids of popcorn plants growing at different densities. They also did not find any differences in ED. Brachtvogel, Pereira, Cruz, and Bicudo (2009) fit a decreasing linear model to describe the ED ($p < 0.05$), unlike Ávila et al. (2011), who studied depth of water and fit an increasing linear model despite the lower angular coefficient.

Published data on plant densities and water levels are still contradictory and require additional studies. Another constraint is the lack of information on the interaction of both factors, which have only been evaluated under the effects of individual treatments. Thus, in both growing seasons (Tables 1 and 3), there were non-significant effects ($p > 0.05$) on PE based on the main effects and their interaction, indicating a positive response. Ávila et al. (2011), who evaluated the effects of water levels on the popcorn hybrids Jade and IAC-125, reported no effect on the popping expansion from Jade, and instead, reported a linear effect from IAC-125. Rossato, Cazetta, Barbosa, and Fornasieri Filho (2013), who evaluated three popcorn hybrids, did not find any effect on plant density and highlighted the stability of this trait for crop management. This is negligibly influenced by the environment because of the high heritability determined by a few genes (Coan et al., 2019). Thus, the quality of the popcorn product was unchanged with different plant populations, water levels, or both.

Table 4. Polynomial models, R^2, critical points, and maxima or minima responses of agriculture traits from the popcorn hybrid IAC 125 under different density of plants and levels of water depth in the growing seasons 2014/2015 and 2015/2016, Maringá, Paraná State, Brazil.

Growing season 2014/2015	Models for plant densities	R^2 (%)	Critical Points	Responses
EL	$\hat{Y}$= 17.493 - 0.000012X	84.99	-	-
NGR	$\hat{Y}$ = 37.429 - 0.000016X	55.50	-	-
BM1000	$\hat{Y}$ = 152.9271 + 0.000077X	47.53	-	-
Y	$\hat{Y}$ = 2777.4538 + 0.007781X	92.29	-	-
Growing season 2015/2016				
SD	$\hat{Y}$ = 18.726 - 0.000044X	94.93	-	-
EL	$\hat{Y}$ = 16.601156 - 0.000017X	89.97	-	-
NR	$\hat{Y}$ = 14.46044446 - 0.000008X	66.06	-	-
NGR	$\hat{Y}$ = 38.145333 - 0.000023X	76.21	-	-
BM1000	$\hat{Y}$ = 118.1781 + 0.000102X	77.69	-	-
Y	$\hat{Y}$ = 1457.4028 + 0.004132X	60.40	-	-
Growing season 2014/2015	Models for the depth of water			
EL	$\hat{Y}$= - 19.4161 + 0.108619X - 0.000081X^2	81.65	Maximum 670.48 mm	17 cm
NR	$\hat{Y}$= - 18.3006 + 0.104122X - 0.000082X^2	87.24	Maximum 634.89 mm	14.89 un
NGR	$\hat{Y}$= - 52.6166 + 0.272578X - 0.000207X^2	95.48	Maximum 658.40 mm	37.11 un
BM1000	$\hat{Y}$ = 501.5375 – 1.1397X + 0.00091X^2	96.70	Minimum 626.20 mm	145.47g
RG	$\hat{Y}$= - 295.658420 + 5.7729X	73.70	-	-
Growing season 2015/2016				
AEL	$\hat{Y}$ = 11.32744 + 0.004515X	73.55	-	-
NGR	$\hat{Y}$ = - 269.160848 + 0.6579X - 0.00035X^2	81.8	Maximum 931.34 mm	37.42 un
Y	$\hat{Y}$= - 175.000 + 2.140932X	65.16	-	-

The 2015/2016 growing season did not have a significant effect ($p > 0.05$) on the traits PH and EH based on their main effects and interactions because of the stability of the IAC-125 (Table 2), despite the literature (Brachtvogel et al., 2009; Ávila et al., 2011) indicating that higher plant densities and irrigation increased plant and ear height. In Parana State, Batista et al. (2019) studied plant density and nitrogen doses applied to off-season plants; they did not find differences, supporting the results of the current experiment. In fact, Calonego, Poleto, Domingues, and Tiritan (2011) also reported no effect of plant density on these traits when they studied hybrids IAC-112 and IAC-125. Mendes et al. (2013) stated that some modern hybrids are more stable under higher plant densities.

In 2015/2016, the traits PH, EH, and SD had a lack of fit significant to the levels of water deficit (Table 2). Thus, none of the polynomial models under test fit the data. The mean values of PH (1.93 m), EH (1.04 m), and SD (15.65 mm) of hybrid IAC-125 were similar at different water depths. These results were different from the reports of Ávila et al. (2011), who found the maximum of 92.7 cm of EH under the level of 160 mm from the hybrid IAC-125 and linear pattern for the hybrid Jade with increase of 0.023 cm for each mm of the applied water.

The SD in the current experiment disagrees with the results of Oliveira, Melo, Cardoso, and Lambert (2014), who investigated levels of irrigation water in maize crops and evaluated vegetative traits, such as stalk diameter, and found larger diameters fitting a quadratic model with the maximum from levels of approximately 150% of evapotranspiration. In 2015/2016, the SD and density of plants were better explained by the decreasing linear models ($p < 0.05$) (Table 4). This result means that every thousand plants reduced the SD by 0.04 mm, and the current reduction was 15.5%. Calonego et al. (2011), Takasu et al. (2014a), Foloni et al. (2014), and Batista et al. (2019) described the relationship between SD and plant densities following the pattern where higher densities indicate lower SD, which is consistent with the current observations.

In both growing seasons, the EL fit a decreasing model ($p < 0.05$) for plant density (Table 4), indicating that each increase of 15,000 plants corresponded to a decrease of 0.18 cm (2014/2015) and 0.0355 cm (2015/2016) in EL. This reduction from hybrid IAC-125 corroborated previous reports (Takasu et al., 2014a; Batista et al., 2019). Our results can be explained by the positive association between plant density and competition for light, water, and nutrients, which affects the vegetative growth of plants (Brachtvogel et al., 2009).

In 2014/2015, the EL under the effect of the levels of water depth increased after 574.86 mm. The maximum EL of 17 cm was observed at 670.48 mm of water depth, and thereafter, it decreased (Table 4). Subsequently, in 2015/2016, we observed an increase in EL with higher levels of water depth. The equation in Table 4 indicates that for each mm of water level, there was an increase in EL by 0.004515 cm because of the angular coefficient. Thus, the maximum EL was 15.66 cm, but the results from the current experiment disagree with the findings of Ávila et al. (2011), who did not report significant differences in the average EL of IAC-125 under increasing water levels. Furthermore, a maximum NR of 14.89 was achieved by the estimated level of water depth of 634.89 mm (Table 4). However, in 2015/2016, we found significant effects of water depth on plant density, and this relationship was better explained by a decreasing linear model ($p < 0.05$) (Table 4). This result suggests that every thousand plants reduced the ear grain number by 0.008. The results of the current study corroborate the findings of Takasu, Rodrigues, Goes, Arf, and Haga, (2014b) and Ben, Peiter, Robaina, Parizi, and Silva, (2016), who reported a reduction in the number of grain rows with the increase in plant population. However, Batista et al. (2019) did not find significant differences in NR trait that showed an average of 16.91 rows.

In both growing seasons, the trait NGR was fit by a significantly decreasing linear model ($p < 0.05$) based on plant density (Table 4), implying that for every thousand plants added to the population, the number of grains in the ear row of popcorn IAC-125 decreased by 0.016. Similarly, adding 15,000 plants ha^{-1} reduced grain size in the ear row by 0.345. Contrastingly, De Souza (2013), who evaluated plant densities from 40,000 to 100,000 using an increase of 15,000, reported a quadratic model with a maximum response of 57,68 plants ha^{-1} and a maximum of 36.4 grain in each ear row. Similar responses were found by Batista et al. (2019) and Takasu et al. (2014a), who reported a significant reduction in the average number of grains in the ear rows after increasing the plant density, which was attributed to competition for light, water, and nutrients, as well as the EL because the increases in the population reduced the EL.

As to the level of water depth in 2014/2015, the trait NGR was maximally affected by water depth of 658.40 mm with 37.11 grains in ear rows (Table 4). In the next growing season, the major effect of the water depth levels was found at 931.94 mm, inducing a maximum of 37.42 grains per row (Table 4). After reaching this level, the values decreased. Plant responses to the water depth levels recorded in the current study agree with the findings reported in literature because the water and air available in the root system are crucial for plant responses (Franco et al., 2014; Minuzzi & Ribeiro Jr., 2012). Maize plants respond to available water, but they are sensitive to the air available amid the root system (Pereira, Rosa Junior, Rosa, & Fedatto, 2012).

The equation for describing the relationship between BM1000 and density of plants (Table 4) suggests that each 10,000 plants ha^{-1} added to the crop population reduced the BM1000 by about 0.77 g in 2014/2015 and 1.2 g in 2015/2016. These results indicate that under high plant densities, intra-specific competition increases, which reduces the components of crop production (e.g., BM1000), which is consistent with findings reported in previous reports (Takasu et al., 2014b; Foloni et al., 2014; Rossato Junior et al., 2013; Mendes et al., 2013). Batista et al. (2019) studied plant densities from 45,000 to 55,000 plants ha^{-1}, and Takuso et al. (2014b) studied densities from 40,000 to 100,000 plants ha^{-1}; they did not report differences in the biomass of one thousand grains. The relation of BM1000 and water depth levels in 2014/2015 was as follows. The effect on BM1000 decreased after the level of 574.86 mm, and the minimum threshold estimated was 626.20 mm, with the minimum response of 145.47 g from the BM1000 (Table 4), which increased at levels higher than 626.20 mm. These results differ from those reported by Ávila et al. (2011), who found quadratic responses with maximum thresholds in BM1000 while evaluating common maize hybrids under irrigation.

In 2014/2015, the relationship between Y and plant density suggested that each 1,000 plants ha^{-1} increased crop yield by 7.8 kg ha^{-1}. The crop yield estimated by the model (Table 4) under the maximum plant density was approximately 3,556.0 kg ha^{-1}. In the growing season 2015/2016, the equation (Table 4) suggests that each 1,000 plants increase crop yield by 4.2 kg ha^{-1} with productivity of 1,870.6 kg ha^{-1}, as per the model of maximum density. Serpa et al. (2012) studied plant densities of common maize hybrids sowed in August-September (the end of winter season in south Brazil), with and without irrigation, and found that each additional plant by square meter increased the grain yield by 660 kg ha^{-1} or by 21% with 10.4 plants m^2. However, in some cases, the responses in maize plant are not necessarily linear, as reported by Kappes et al. (2011) and Melo, Corá, and Cardoso (2011), when the increase in plant density had quadratic responses.

The relationship between Y and irrigation water level was better described by the linear model ($p < 0.05$) in both growing seasons (Table 4). Thus, each mm of water input induced increase of 5,772.9 kg ha^{-1} in 2014/2015 and 2,140.9 kg ha^{-1} in 2015/2016 based on the angular coefficients (Table 4). These results corroborate those of Ávilla et al. (2011), which also fitted an increasing linear model. Ben et al. (2016), who evaluated the irrigation levels and plant density of common maize during the off-season, found an increase in crop yield because of the increased soil humidity, which induced 100% of the crop evapotranspiration.

Conclusion

We found an increased linear effect for crop yield of the popcorn hybrid IAC 125 in the plant population from 40,000 to 100,000 plants ha^{-1} at different levels of water depth. However, we did not find significant effects of popping expansion based on the main effects and interaction between factors in both growing seasons.

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