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Performance of maize hybrids subject to different application depths under center pivot

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Abstract: With the hypothesis that irrigation can influence the maize lodging, the objective was to evaluate the effect of water depth and plant population on the performance of hybrids of this crop. The experiment was conducted in a field equipped with center pivot irrigation, in a randomized complete block design in a split-plot arrangement, with 6 irrigation levels (plots), 2 hybrids (subplots), 3 plant densities (sub-subplots) with 4 replications. Irrigation levels evaluated were a 0 (control treatment), 25, 50, 75, 100 and 125% of crop evapotranspiration (ETc). The evaluated hybrids were Dow 2B810 PW and MORGAN MG 652 PW, in plant densities of 56, 67 and 78 thousand plants per hectare, with 0.45 m spacing between rows. Maize productivity varies with the irrigation depth, reaching the highest values in the region, with 73% of the ETc. Irrigation also influences total plant height (TPH), as well as first ear insertion height (EIH), however, it shows no influence on plant lodging (LOD). Higher plant densities contribute to higher lodging rates, but it is more strongly related to the resistance characteristic of each hybrid.

Keywords: *Zea mays*, irrigation, lodging.

Performance de híbridos de milho submetidos a aplicação de diferentes lâminas de irrigação em pivô central

Resumo: Com a hipótese de que a irrigação pode influenciar no acamamento do milho, objetivou-se avaliar o efeito das lâminas de irrigação e da população de plantas na performance de híbridos desta cultura. O experimento foi conduzido em área de Pivô Central, com delineamento experimental em blocos casualizados em esquema de parcelas sub-subdivididas sendo, 6 níveis de irrigação (parcelas), 2 híbridos (subparcelas), 3 populações (sub-subparcelas), com 4 repetições. Os níveis de irrigação foram 0 (tratamento controle), 25, 50, 75, 100 e 125 % da evapotranspiração da cultura (ETc). Os híbridos avaliados foram, Dow 2B810 PW e MORGAN MG 652 PW, nas populações de 56, 67 e 78 mil plantas por hectare, com espaçamento entre linhas de 0,45 metros. A irrigação influencia a produtividade do milho, alcançando os maiores valores, na região de estudo, com 73% da reposição da ETc. A irrigação também influencia na altura total de plantas (ALT), bem como na altura de inserção da primeira espiga (AES), porém, não mostra influência alguma sobre o acamamento de plantas (ACM). Maiores populações de milho contribuem para maiores índices de acamamento de plantas, mas este fator está mais fortemente relacionado à resistência característica de cada híbrido.

Palavras chaves: *Zea mays*, irrigação, acamamento.

Introduction

The northern region of the Mato Grosso do Sul state is an important grain producer, and it suffers dry periods during the second maize crop. Thus, water availability is a limiting factor for crop development (Amado et al., 2009) that can be controlled by irrigation systems. According to Bergamaschi et al. (2006), water depths of 60% are sufficient to considerably increase the yield of corn grains.

Another important factor in the productivity of this crop is directly related to the density of plants. Vian et al. (2016), observed that high grain yields in the maize crop are conditioned by the final number of plants, with a uniform spatial distribution in the area and the least possible dominated plants, favoring the number of ears per area.

One care that must be taken when looking for the increase of ears per area, increasing the plant density, is that it can result in lodging. Spohr et al. (2005), when evaluating four maize hybrids, observed that there was a significant increase in lodging when increments were made in the plant densities.

Among the main reducing agents in grain yield, we highlight the wind and rain that promote the complex phenomenon of lodging, which causes tissue rupture, interrupting the vascularization of the stem and preventing the recovery of the plant, directly affecting the Essential anatomical structure for transporting water and nutrients, and the sooner it manifests, the lower will be the grain yield and quality (Easson et al., 1993).

According to Gomes et al. (2010), evaluating 85 maize genotypes in the agricultural region of the present study, found that resistance to lodging of plants and stem breakage is directly related to the growing site, and that the selection of these characters should be carried out based on experiments with a regional focus.

The occurrence of complex phenomena such as lodging, and their expression related to genetic, climatic, soil and cultural practices adopted (Cruz et al., 2003), show the need for studies that address the relationship between irrigation and lodging of maize plants, being these, limiting factors in crop yield.

Thus, under the hypothesis that irrigation may influence the performance of maize hybrids, the objective of the present study was to analyze the effect of water depths, and of the plant density on the performance of this crop.

Material and Methods

The present research was carried out in the experimental area of the Agricultural Research Support Foundation of Chapadão, in the city of Chapadão do Sul - MS, with the geographical coordinates latitude 18°46'49 "S and longitude 52°38'51" W, and altitude of 810 meters.

The climate of the region is defined as tropical with dry season, according to the classification of Köppen, with average annual temperature of 25 ° C and average annual rainfall between 1600 and 1800 mm. The soil of the area is classified as Dystrophic Red Latosol (clayey) (Santos et al., 2013).

The sowing of corn occurred on March 17, 2015, in cultural remains of soybeans, in a central pivot system area.

The was in a randomized complete block design in a split-plot arrangement, with six irrigation levels (0, 25, 50, 75, 100 and 125 % da ETc), two hybrids (Dow 2B810 PW e MORGAN MG 652 PW), three plant densities (56, 67 and 78 thousand plants per hectare) with 4 replications. The different irrigation levels were applied varying the velocity of the center pivot within each plot.

Sub-plots consisted of 5 planting rows spaced 0.45 m. In order to carry out the evaluation, the three central lines were classified as useful.

The methodology for the irrigation management was by meteorological data, through an automatic weather station of the National Institute of Meteorology (INMET), installed in the Chapadão do Sul city, near the experimental area where the research was carried out. Estimates of reference evapotranspiration (ETo) were obtained using the Penman-Monteith-FAO method, according to Allen et al. (1998). The crop evapotranspiration (ETc) was obtained by the product of reference evapotranspiration (ETo) and the crop coefficient (Kc).

In order to monitor the water balance, the crop coefficients of each subperiod (Table 1) were defined according to recommendations of Detomini et al. (2009), where the gradual variation of the passage from one subperiod to the other was performed as a function of days after emergence.

The soil texture was classified in the Soil Laboratory of the Agronomy Department of the Federal University of Mato Grosso do Sul, Chapadão do Sul Campus (UFMS / CPCS), defined as clayey (Table 2). Irrigations were carried out only when the availability of water approached the lower limit of the Readily Available Water (RAW).

Table 1. Crop coefficients (Kc).

Phenological stage and interval of days after emergence (DAE)	Kc (adm.)
Up to 4 leaves visible (0-18)	0.32
4 to 8 leaves visible and still attached to the stem (19-37)	1.07
8 to 12 leaves visible and still attached to the stem (37-50)	1.50
Tasseling, flowering and pollination (51-64)	1.43
Pollination ending to Dough (64-77)	1.25
Dough to Dent (78-89)	1.01
Dent to mid-dent (90-99)	0.39
Mid-dent to maturity (100-110)	0.23

Table 2. Soil physical properties.

Depth	Θ_{FC}	Θ_R	AWC	Ds	Pd	TP	Granulometric Fractions			Textural classification
(cm)	(cm^3 cm^{-3})		(mm cm^{-1})	(g cm^{-3})		(%)	Sand	Silt	Clay	
0 – 15	0.413	0.282	1.76	1.34	2.65	53.6	39.24	6.68	54.08	Argiloso
15 – 30	0.383	0.262	1.74	1.44	2.65	48.4	36.76	4.56	58.68	

Θ_{FC} – Water content at field capacity in water matrix potential (Ψ_m) of 0,1 bar; Θ_R – Residual water content Ψ_m de 15 bar; AWC – Available water content; Ds – Soil bulk density; Pd – Particle density; TP – Total pore space.

Harvesting was performed on August 03, 2015. The response variables, total plant height (TPH), first ear insertion height (EIH), lodging (LOD), rot corn grains (RCG) and yield (YIE) were analyzed by the Tukey test at 5% probability among hybrids and populations, and between water depth was analyzed using regression models.

The TPH was measured with the aid of a scale from the soil surface to the stem end, similar to EIH from the soil to first ear insertion.

LOD was determined by counting the total plants broken or lodging in the plot and dividing by the total number of plants of the respective plot, represented in percentage of fallen plants.

The RCG was the percentage of rot corn grains in the sample with 100 grams and YIE was the the weight collected in the useful portion, discounting the moisture value, correcting to 14%.

Results and Discussion

The water balance allows us to observe the variation of soil water storage (WS), as well as the readily available water (RAW), and that the humidity levels reached the lower limit of available water capacity (TAW) characterized as strong water deficit (Figure 1). With this, the control treatment represented by the rainfed condition had its productive potential reduced when compared to irrigated treatments.

The lack of rainfall in the second harvest is frequent. According to the Fundação MT (2015), the lower corn yields observed in the second harvests of the last years are justified by the lack of rainfall, proving that one of the main inputs is water. They also affirm that it is not enough to have the best hybrid on the market, the best investment in fertilization and the use of the most effective chemical products in phytosanitary management of the crop, when the restrictive factor is water.

From the seventy days after sowing (70 DAS), which comprises flowering to the grain filling, the water balance shows that the storage was maintained at the critical levels of humidity. According to Bergamachi et al. (2004), the oscillations in maize crops, from the main producing regions of Brazil, are associated to the availability of water, especially in the critical period of the crop, from the tasseling to the beginning of the grain filling.

Table 3 shows the mean square of the response variables, according to the variation factors studied, showing the differences between treatments, as well as the interactions that were significant.

Water depth influenced both ALT and AES. Yield was also directly affected by irrigation. Berconci et al. (2001) concludes that the greater efficiency of irrigation for grain yield occurred with irrigation levels around 80 to 85% of soil water capacity, and that irrigation above 85% of soil water capacity do not significantly interfere in grain yield.

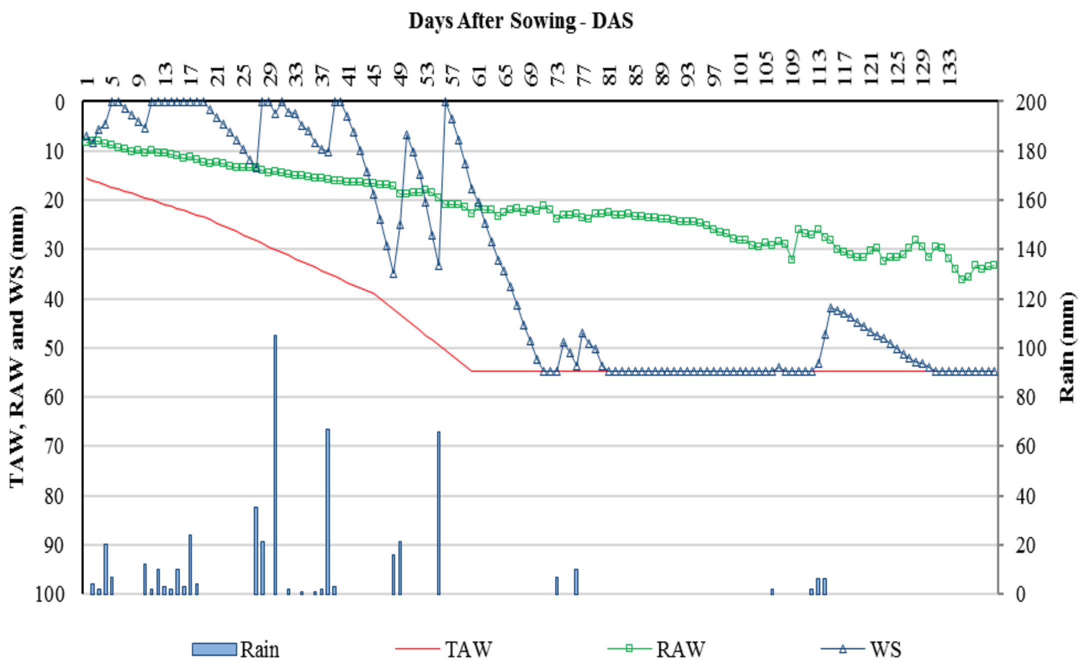


Figure 1. Water balance with average values of rainfall, total available water (TAW), readily available water (RAW) and soil water storage (WS), according to the days after sowing (DAS).

The regression models adjusted for the variables ALT, AES and PROD, allowed to reach the water depth for each variable with their maximum points, being 63, 74 and 73% of ETc, respectively (Figure 2). So, this water depth of maximum yield resulted in 10,335.3 kg ha^{-1}.

According to Bergonci et al. (2001) and Bergamaschi et al. (2004), it was found that in the intermediate condition of water depth equivalent to 60% of irrigation is enough to raise the soil moisture until soil water capacity.

In Matzenauer et al. (2002) and Bergamaschi et al. (2004) view of the adequate water supply, if it occurs close to the tasseling-grain filling, this is enough to obtain high yields.

The different hybrids showed influence on all response variables analyzed, but did not show interaction with the water depths (Table 3). The plant density also showed to influence some of the variables being, TPH, EIH and YIE, but also did not present interaction with the water depths. This shows that the lodging, which reached about 45% in some treatments, is not influenced by irrigation, but by the plants densities and the resistance characteristic of each hybrid.

According to Table 3, there was interaction between hybrids and the plant densities, for the lodging variable, as observed by Spohr et al. (2005), who, when evaluating four maize hybrids, observed that there was a significant increase in lodging when the population increase.

In Figure 3 it can be observed that the Dow 2B 810 PW hybrid shows a positive correlation with the plant density, as observed by Kappes et al. (2011), Sangoi et al. (2000) and Marchão et al. (2005), where the percentage of broken plants increases linearly as plant density increases. However, the Morgan MG 652 PW hybrid did not change. Although this second hybrid had no correlation with the plant density, it presents lower resistance to lodging in relation to Dow 2B 810 PW, confirming the existence of genetic variability among hybrids for resistance to lodging / breaking of plants, reported by Gomes et al. (2010), in their assertion that there is genetic variability for lodging resistance and corn stem breakage, and these characteristics interact significantly with the environment.

Thus, lodging more strongly related to the characteristic of the hybrid than with any other factors.

Table 4 shows that the highest yield was found in the largest plant density for the two hybrids studied. A factor that explains this situation is that when you have a higher number of plants, the amount of corncobs harvested will also be higher, which will lead to an increase in crop productivity, in this direction Merotto Junior et al. (1997) state that the use of high plant densities is feasible to increase yield of grains.

Table 3. Analysis of Variance of total plant height (TPH), ear insertion height (EIH), lodging (LOD), rot corn grains (RCG) and yield (YIE).

Variation factors	Degrees of freedom	Mean Square				
		TPH	EIH	LOD	RCG	YIE
Block	3	787.6**	624.3**	318.9	1.7	6,61E+6
W	5	805.1**	372.0**	1244.7 NS	5.2 NS	1.31E+7*
Res. (A)	15	46.8	80.0	527.9	2.4	3.30E+6
H	1	1853.8**	741.1*	4194.1*	58.7**	2.16E+7*
W*H	5	100.4NS	86.5 NS	498.6 NS	5.5 NS	4.45E+6 NS
Res. (B)	18	46.2	92.6	352.7	2.7	3.89E+6
D	2	39.8 NS	241.6*	2365.1*	7.2 NS	2.31E+7**
D*W	10	31.7 NS	43.1 NS	159.5 NS	2.9 NS	4.00E+6 NS
D*H	2	1.0 NS	166.2 NS	1722.8*	0.9 NS	1.65E+5 NS
D*W*H	10	92.2 NS	88.7 NS	272.9 NS	1.0 NS	1.35E+6 NS
Res. (C)	72	54	72.2	262.5	3.8	2.62E+6
Total	143					
CV(%) Plot		2.81	6.49	66.01	104.91	18.71
CV(%) Subplot		2.79	6.98	53.96	111.45	20.31
CV(%) Sub-subplot		3.02	6.17	46.54	133.07	16.69

NS: non-significant (P>0.05); *: significance (P<0.05); **: significance (P<0.01); CV: coefficient of variation; W: Water Depth; H: Hybrid; D: Plant density

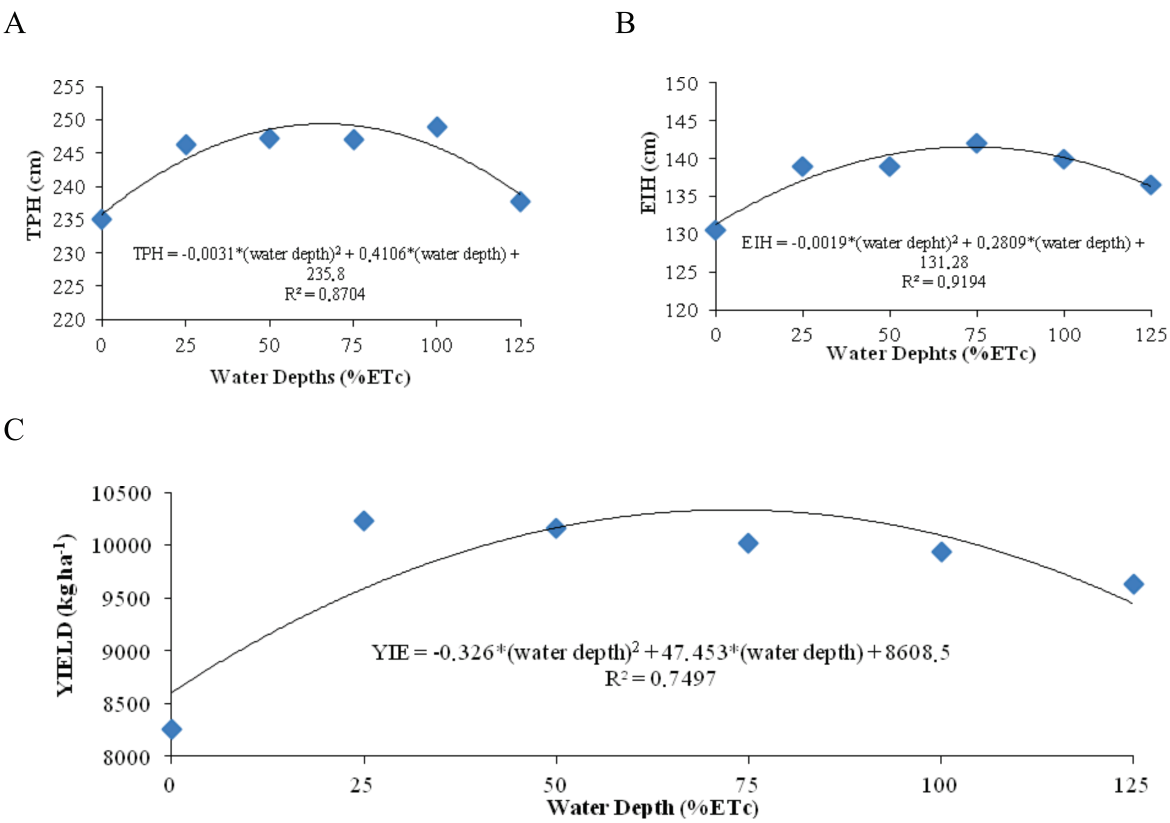


Figure 2. Regression models according to the different irrigation depths, for the response variables, total plant height (TPH), first ear insertion height (EIH) and productivity (YIE).

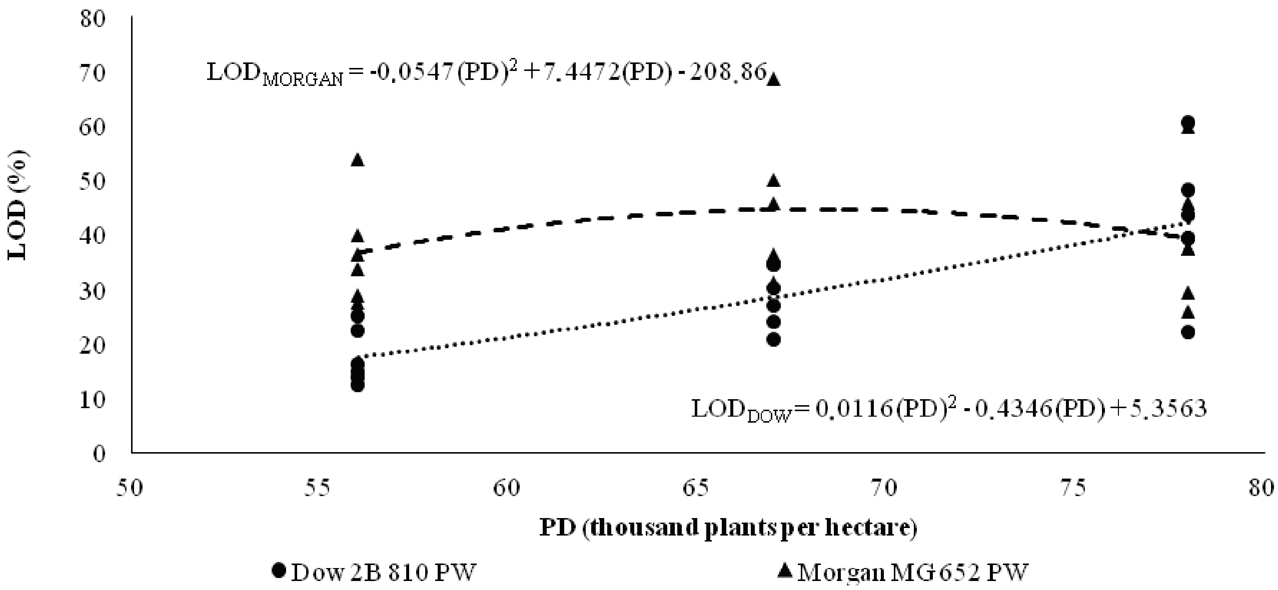


Figure 3. Correlation between lodging (LOD) and plant density (PD) for each hybrid tested.

Table 4. Mean values of total plant height (TPH), ear insertion height (EIH), lodging (LOD), rot corn grains (RCG) and yield (YIE) of the hybrids as a function of the plant densities.

Response variables	Hybrid	Plant Densities		
		1	2	3
TPH (cm)	Dow 2B810 PW	246.4 Aa	247.0 Aa	248.4 Aa
	MORGAN MG 652 PW	239.3 Ab	240.1 Ab	240.9 Ab
EIH (cm)	Dow 2B810 PW	133.6 Ab	133.3 Aa	139.8 Aa
	MORGAN MG 652 PW	141.7 Aa	138.1 Aa	140.5 Aa
LOD (%)	Dow 2B810 PW	17.5 Bb	28.5 ABb	42.3 Aa
	MORGAN MG 652 PW	36.7 Aa	39.3 Aa	44.6 Aa
RCG (%)	Dow 2B810 PW	0.45 Ab	1.00 Ab	1.04 Ab
	MORGAN MG 652 PW	1.67 Aa	2.03 Aa	2.62 Aa
YIE (kg ha^{-1})	Dow 2B810 PW	9337.9 Aa	10361.7 Aa	10583.5 Aa
	MORGAN MG 652 PW	8519.6 Ba	9497.0 ABa	9940.8 Aa

Means followed by lower case letters in the column and upper case in the row differ by Tukey's test ($p < 0.05$)

In this sense, França et al. (1990), when studying the behavior of three early cycle cultivars in four plant densities (40, 60, 80 and 100 thousand plants per hectare), under irrigated conditions, found a significant interaction among cultivars and plant densities for grain yield, thus verifying that the response to increasing plant population depends on the cultivar used.

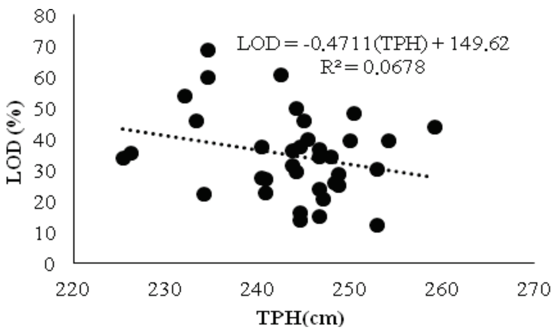
Both TPH and EIH had no correlation with LOD. This confirms the fact that the irrigation did not influence the lodging, since it affects these variables, however, they did not influence the LOD (Figure 4).

Although some authors report that ear insertion height and total plant height influence lodging, the present study showed that there was no correlation between these response variables.

Siqueira et. al (2009) state that the higher the ear is, the more susceptible the plant is to lodging. According to Brachtvogel et al. (2009), lodging is mainly related to the decrease of stem diameter, increase of plant height, increase of spike insertion and increase of plant height/ear insertion height ratio, observed when the plant densities rises.

However, Campos et al. (2010) studying the relationship of plant height and ear insertion with lodging and breaking of plants of forty-nine commercial maize cultivars in five different regions of the country did not observe any relation between plant height and ear insertion with the lodging rates, which corroborates the results of the present study.

A



B

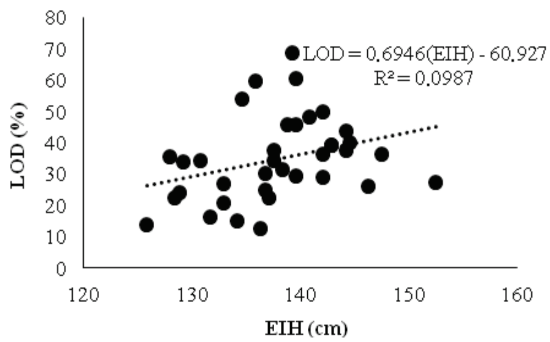


Figure 4. Correlation between lodging and total plant height (A) and lodging and ear insertion height (B).

The relationship between plant lodging and plant density increasing is therefore not related to TPH or even to EIH, and can be explained by Gross et al. (2006), who states that plant density interferes with the individual mass of the plants, resulting in a decrease of individual dry matter, namely of the stem, as a result of the competition between them by the resources of the environment. This leads us to infer that plants tend to become more susceptible to breaking and/or lodging with increasing plant density.

It is also worth noting that, when it comes to world production of maize hybrids, annual losses of 5 to 20% are estimated as a consequence of lodging and breaking of the stem.

Conclusions

Irrigation have no influence in maize lodging.

Larger maize populations contribute to higher lodging rates.

Maize lodging is directly related to the resistance characteristic of each hybrid.

The best productivity was achieved with the highest plant density reaching 10.584 ton ha^{-1}.

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