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Agronomic performance of maize hybrids under supplemental irrigation depths

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ABSTRACT: The choice of a maize hybrid, considering the technology level and irrigation management, contributes to the improvement of the plant productivity and water use efficiency (WUE). Thus, the objective of this study was to evaluate the effects of irrigation depths on production components, grain yield, technical efficiency, and WUE in maize hybrids. The experiment was conducted in Santiago, RS state, Brazil, in the 2015/2016 and 2016/2017 crop seasons, using a randomized block design in factorial scheme, consisting of five irrigation depths (0, 50, 75, 100 and 125% of crop evapotranspiration - ETc) and four maize hybrids in crop season I (2015/2016), and six maize hybrids in crop season II (2016/2017). The number of ears per plant, number of grains per ear, 100-grain weight, grain yield, and WUE were evaluated. The irrigation depths affected the 100-grain weight, grain yield and WUE in both crop seasons, and the number of grains per ear in crop season I. The irrigation depths increased the productive performance of the maize hybrids from 9.9 to 41% when using irrigation depths of maximum technical efficiency, which varied from 90.1 to 105.4% ETc. The AG9025, P1630 and DKB290 maize hybrids presented the best agronomic performances, with grain yields from 13,609.1 to 16,281.3 kg ha^{-1}.

Key words: water deficit, *Zea mays* L., water use efficiency, genotypes, grain yield

Desempenho agronômico de híbridos de milho sob lâminas de irrigação suplementar

RESUMO: A escolha do híbrido de milho, considerando o nível de tecnologia e o manejo de irrigação, contribui com a melhoria da produtividade e da eficiência do uso da água. Assim, objetivou-se neste trabalho avaliar a influência de lâminas de irrigação nos componentes de produção, na produtividade, na máxima eficiência técnica e na eficiência do uso da água em híbridos de milho. O experimento foi conduzido no município de Santiago/RS, nas safras de 2015/2016 e 2016/2017. Utilizou-se o delineamento experimental de blocos ao acaso, em esquema fatorial, com cinco lâminas de irrigação (0, 50, 75, 100 e 125% da evapotranspiração da cultura - ETc) e quatro híbridos de milho na safra I (2015/2016) e seis híbridos na safra II (2016/2017). As variáveis avaliadas foram: número de espigas por planta, número de grãos por espiga, massa de 100 grãos, produtividade de grãos e eficiência do uso da água. As lâminas de irrigação influenciaram, nas duas safras, a massa de 100 grãos, a produtividade e a eficiência do uso da água e, o número de grãos por espiga na safra I. A irrigação aumentou o desempenho produtivo dos híbridos, entre 9,9 e 41% na lâmina de máxima eficiência técnica sendo que esta variou entre 90,1 e 105,4% da ETc. Os híbridos AG 9025, P 1630 e DKB 290 apresentaram os melhores desempenhos agronômicos, com produtividades entre 13.609,1 e 16.281,3 kg ha^{-1}.

Palavras-chave: déficit hídrico, *Zea mays* L., eficiência do uso da água, genótipos, produtividade de grãos

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Introduction

Water deficit caused by poor rainfall distribution is one of the main factors limiting grain yield in maize crops. Kopp et al. (2015) evaluated 4 sowing times in the state of Rio Grande do Sul, Brazil, from 1992 and 2012, and found that grain yield decreases can reach 55%, without irrigation. This has stimulated producers to invest in irrigation systems to increase and be sure of obtaining higher maize grain yields.

However, agriculture competes for water with other productive sectors, thus, management strategies to save water without decreasing grain yield of irrigated crops are needed, especially for maize, whose water consumption is 500 to 800 mm (Doorenbos & Kassam, 1994; Mantovani et al., 2013). Thus, the use of reduced water depths or deficit irrigation managements may improve water use efficiency (WUE) without affecting significantly crop grain yield (Gheysari et al., 2015).

The use of maize hybrids that present high grain yield and WUE should also be considered. Kaman et al. (2011) found different grain yields and WUE when evaluating maize genotypes and irrigation managements in a clayey soil in Adana, Turkey.

According to Sangoi et al. (2006), these different responses in use efficiency of environmental resources are influenced by genetic characteristics specific to each genotype. Thus, the choice of a cultivar, considering the technology level and irrigation management, contributes to the improvement of productivity and WUE (Silva et al., 2015).

The objective of this study was to evaluate the effects of different irrigation depths on production components, grain yield, technical efficiency, and WUE in maize hybrids.

Material and Methods

Two field experiments were carried out in the 2015/2016 (I) and 2016/2017 (II) crop seasons at the experimental area of the Liberdade Farm, in Santiago, RS state, Brazil (29º 9' 50'' S, 54º 51' 32'' W, and altitude of 439 m). The soil of the region was classified as Ultisol (Streck et al., 2008), with 34% sand, 17% silt, and 49% clay. The region presents a humid-subtropical climate (Cfa), according to the Koopen classification, with average temperature of 17.9 ºC, and average precipitation of 1,769 mm (Moreno, 1961). The mean maximum, mean, and mean minimum temperatures, and mean air humidity during the experiments were: 27.4, 22.5 and 17.6 °C, and 80% (crop season I), and 28.1, 22.9 and 17.7 °C, and 81% (crop season II), respectively.

Sowing was carried out on October 5, 2015 (crop season I) and on October 30, 2016 (crop season II), with spacing of 0.50 m between rows and density of 8.5 seeds m^{-2}. The experimental units (EU) consisted of four 12-meter sowing rows, with an evaluation area of 8 m^2 EU^{-1}.

The experiment was conducted in a randomized block design in factorial scheme and four repetitions of five supplemental irrigation depths with water replenishments based on the crop evapotranspiration (ETc): 0% (T0), 50% (T1), 75% (T2), 100% (T3) and 125% (T4), in both crop seasons, and four maize hybrids in crop season I (Agroceres 9025 PRO3 – AG 9025; Agroceres 9045 PRO3 – AG 9045; Dekalb 240 PRO3 - DKB 240 and Syngenta Status Viptera 3 - Status) and six maize hybrids in crop season II (Pionner 1630 Herculex – P 1630; Agroceres 9025 PRO3 – AG 9025; Agroceres 8780 PRO3 – AG 8780; Dekalb 177 PRO3 – DKB 177; Dekalb 230 PRO3 – DKB 230 and Dekalb 290 PRO3 – DKB 290), with four repetitions.

The distribution of the EU, treatments and blocks are shown in Figure 1.

Fertilization was carried out according to the recommendations described in the manual of fertilization and liming for the states of Rio Grande do Sul and Santa Catarina, Brazil (CQFS, 2004), considering an expected grain yield of 16 Mg ha^{-1}. A composite sample of soil was collected from the experimental area at depth of 0 to 20 cm, for chemical characterization where it showed pH of 5.2, 5.2 $cmol_c$ dm^{-3} of Ca, 1.7 $cmol_c$ dm^{-3} of Mg, 0.1 $cmol_c$ dm^{-3} of Al, effective CEC of 7.6 $cmol_c$ dm^{-3}, CEC at pH7 of 11.0 $cmol_c$ dm^{-3}, base saturation of 68.3%, SMP index of 6.2, 2.8% of organic matter, 44% of clay, 18.9 mg dm^{-3} of P (Mehlich) and 0.645 mg dm^{-3} of K (Mehlich).

Potassium chloride (80 kg ha^{-1}) was applied to the soil in both crop seasons; planting fertilization consisted of 430 kg ha^{-1} of the formulated fertilizer 5-18-18 (NPK). Topdressing N fertilization was divided into two applications (V3 and V7 stages) of 200 kg ha^{-1} of N (urea).

Irrigation was performed using a conventional sprinkler system with sprinklers spaced 12 × 12 m, with one main line and five lateral lines of 36 m. The sprinklers used had different nozzles in each lateral line to obtain the different irrigation depths.

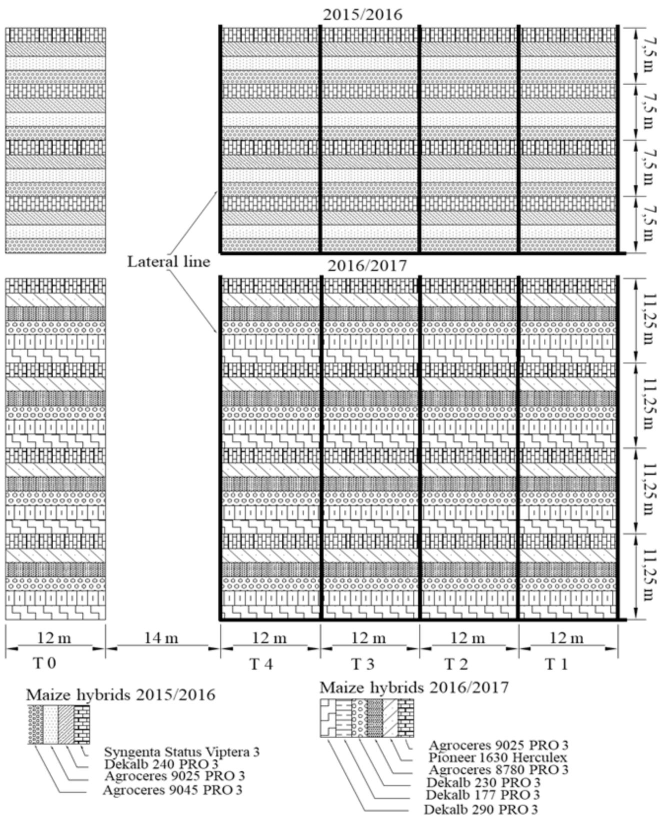


Figure 1. Area with distribution of the experimental units (EU) with treatments and blocks in the 2015/2016 and 2016/2017 crop seasons

Irrigation management was carried out by estimating crop evapotranspiration (ETc), and a seven-day fixed irrigation interval was used, calculated using the reference evapotranspiration (ETo) according to the Penman-Monteith/FAO method (Allen et al., 1998), and the crop coefficient (Kc) according to Doorenbos & Kassam (1994). The same Kc value was used for all maize hybrids, since there is no a specific Kc for each hybrid and they have similar cycles.

The ETo was calculated based on climatic data from an automatic weather station at 100 m from the experimental area. Effective precipitation (EP) was considered to calculate the irrigation depths, according to the methodology proposed by Millar (1978). The field capacity (FC) converted to the storage depth was 250 mm, and the permanent wilting point (PWP) was 108 mm, considering a 0 to 60 cm soil layer. The soil water depletion factor (SWD) used was 50%; water deficit was characterized by soil moistures below this value (Doorenbos & Kassam, 1994).

Total EP was 799 mm in crop season I, requiring application of 169 mm of water in the treatment of 100% ETc. Total EP was 683 mm in crop season II, requiring application of 134 mm in the treatment of 100% ETc. A total of six irrigations were performed in both crop seasons. Effective precipitation, surface runoff, field capacity, permanent wilting point, soil water depletion and soil water balance of each treatment in the evaluated crop seasons are shown in Figure 2.

The maize hybrids were harvested at 135 days after emergence in both crop seasons. Twenty plants were randomly collected in each EU (evaluation area) to evaluate number of plants per square meter (NPSM), number of ears per plant (NEP), number of grains per ear (NGE), 100-grain weight (100GW; g of dry grains) and grain yield (GY; kg ha^{-1} at 13% moisture at wet basis). GY was calculated using Eq. 1:

$$GY = NPSM \times NEP \times NGE \times 100GW \times 0.0115 \qquad (1)$$

where 0.0115 is the grain moisture correction to 13% and the productivity conversion from g m^{-2} to kg ha^{-1}.

WUE (kg m^{-3}) was calculated by the ratio between grain yield and total volume of water supplied per hectare.

The data were subjected to analysis of variance; significant means for the irrigation depth factor were subjected to regression analysis; and significant means for the maize hybrid factor were subjected to Tukey's test ($p < 0.05$).

Results and Discussion

The maize hybrids and irrigation depths presented isolated effects on the treatments, but there was no significant interaction for the analyzed variables. However, the number of grains per ear (NGE), 100-grain weight (100GW), grain yield (GY) and water use efficiency (WUE) of the plants were different between maize hybrids and within irrigation depths.

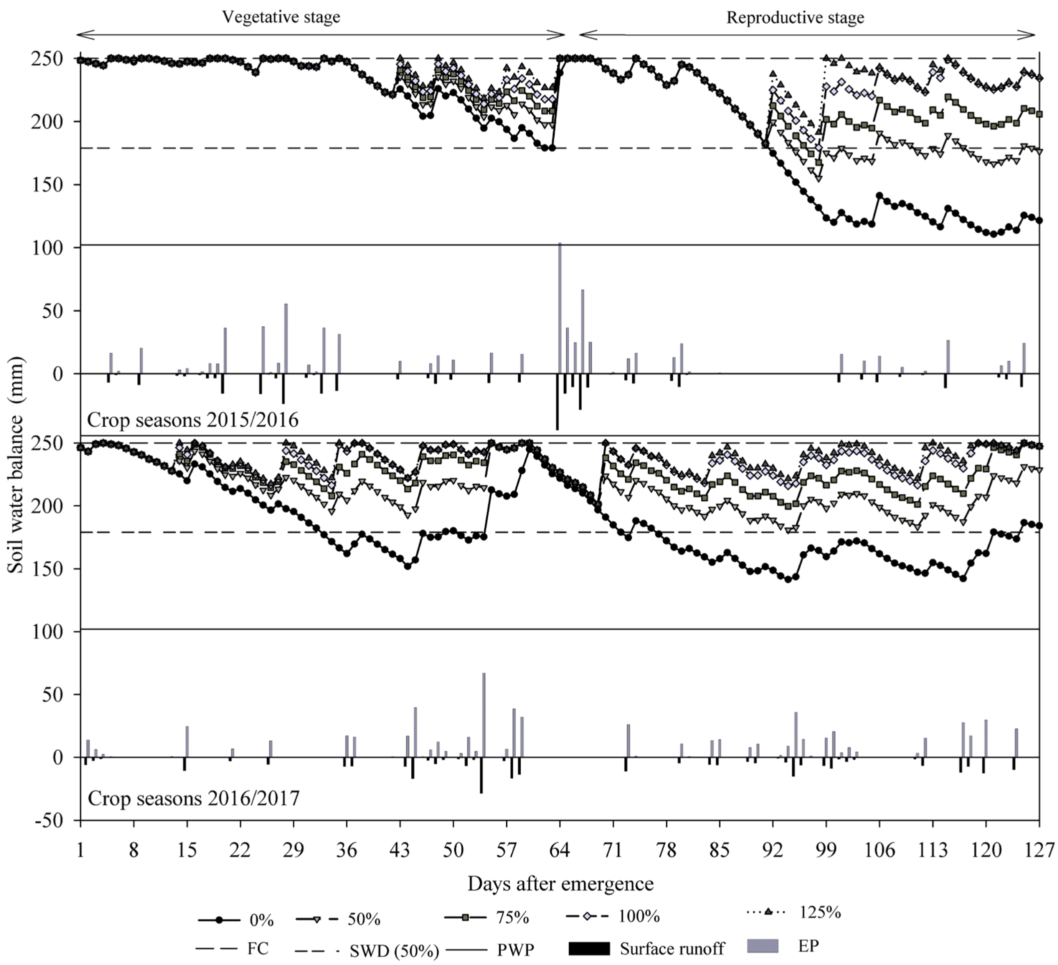


Figure 2. Effective precipitation (EP), surface runoff, field capacity (FC), permanent wilting point (PWP), soil water depletion (SWD) and soil water balance for each treatment in the 2015/2016 and 2016/2017 crop seasons

The means of number of ears per plant (NEP), NGE, 100GW, GY and WUE in both crop seasons the maize hybrids are shown in Table 1.

No statistically significant difference was found between the treatments (maize hybrids and irrigation depths) for NEP, with an overall mean of 1.0 ear plant^{-1}. This result is related to the genotypic characteristics of the evaluated maize hybrids, which usually do not produce more than 1 ear plant^{-1}. The water deficit that occurred during the experiment was not sufficient to show the effect of the irrigation depth factor on NEP.

The production components NGE, 100GW, GY, and WUE presented significant differences among the evaluated maize hybrids, possibly due to their genetic variability and the expression of the factors as a function of the plant potential in the growing environment conditions.

The AG 9025 and DKB 240 hybrids presented the highest NGE (crop season I), 21.5% higher than that with the lowest NGE (Status). P 1630 and DKB 290 presented the highest NGE (crop season II), 28.1% higher, on average, than that with the lowest NGE (AG 9025). AG 9025 presented the highest 100GW in both crop seasons, being on average 36.1% higher than those with the lowest 100GW (DKB 240 and Status) in crop season I, and 32.2% higher than that with the lowest (P 1630) in crop season II.

The AG 9025 maize hybrid had the highest GY (16,281.3 kg ha^{-1}), 48.3% higher than that of the Status, which had the lowest GY (10,975.9 kg ha^{-1}) in crop season I. AG 9025 showed 30.3% and 19.9% higher GY than AG 9045 and DKB 240, respectively, in crop season I. AG 9025 had the highest GY in crop season II (14,293.4 kg ha^{-1}), followed by DKB 290 (13,996.7 kg ha^{-1}) and P 1630 (13,609.1 kg ha^{-1}), presenting no statistically significant differences. On average, the GY of these maize hybrids was 32.3% higher than that of the DKB 177, which had the lowest GY in crop season II.

Differences in GY among hybrids are due to the genotype × environment interaction and crop conditions (Araújo et al., 2016). Therefore, the genetic potential, adaptation of these high grain yield hybrids to the region and conditions of the study site are factors that affected their productive performances. These results denote the high productive potential of these maize hybrids and the possibility of increasing productivity in the edaphoclimatic conditions of the studied region.

The WUE of the maize hybrids followed the same trend of the GY; AG 9025 had the highest WUE in crop season I (1.70 kg m^3); and AG 9025 (1.84 kg m^3), DKB 290 (1.81 kg m^3) and P 1630 (1.75 kg m^3) presented the highest WUE in crop season II. Thus, the use of maize hybrids with high productive performances is important to obtain a high WUE.

The effect of the irrigation depths presented statistical significance for NGE in crop season I (2015/2016), and for 100GW, GY and WUE in crop seasons I and II (2016/2017).

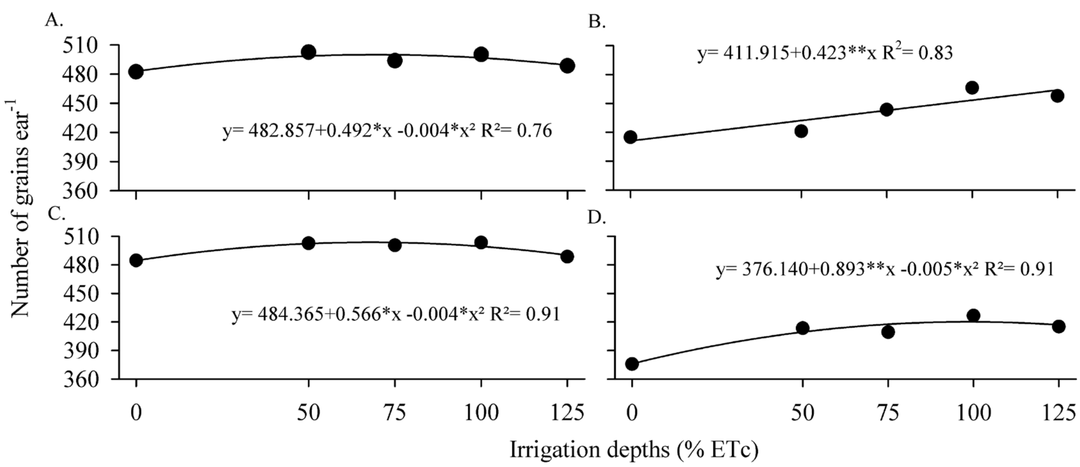
The treatments with irrigation increased the NGE in crop season I (Figure 3). This denotes that the occurrence of water deficit periods from 90 days after emergence (DAE) affected

Table 1. Number of ears per plant (NEP), number of grains per ear (NGE), 100-grain weight (100GW), grain yield (GY) and water use efficiency (WUE) of maize hybrids in the 2015/2016 and 2016/2017 crop seasons

Variable	Maize hybrids - 2015/2016 crop season				
	Status	AG 9045	AG 9025	DKB 240	CV (%)
NEP	1.00 a	1.00 a	1.00 a	1.00 a	0.0
NGE	408.00 c	440.60 b	493.40 a	495.80 a	8.2
100GW (g)	25.90 c	29.40 b	36.00 a	27.00 c	4.2
GY (kg ha^{-1})	10975.90 d	12494.10 c	16281.30 a	13577.90 b	6.1
WUE (kg m^{-3})	1.26 c	1.36 bc	1.70 a	1.47 b	11.8

Variable	Maize hybrids - 2016/2017 crop season						
	P 1630	DK B290	DK B177	AG 8780	DKB 230	AG 9025	CV (%)
NEP	1.00 a	1.00 a	1.00 a	1.00 a	1.00 a	1.00 a	0.0
NGE	543.40 a	529.00 a	486.80 b	468.90 b	466.60 b	418.60 c	7.3
100GW (g)	25.80 de	27.70 c	24.90 f	26.90 cd	31.40 b	34.10 a	5.7
GY (kg ha^{-1})	13609.10 ab	13996.70 ab	10557.60 c	13156.00 b	13194.80 b	14293.40 a	8.5
WUE (kg m^{-3})	1.75 ab	1.81 ab	1.36 c	1.70 b	1.69 b	1.84 a	8.9

Means followed by the same letters in the rows are not significant by the Tukey's test at p ≤ 0.05; CV - Coefficient of variation



**,* Significant at p ≤ 0.01 and p ≤ 0.05 probability levels, respectively by F test

Figure 3. Number of grains per ear (NGE) of maize hybrids — AG 9025 (A), AG 9045 (B), DKB 240 (C) and Status (D) as a function of irrigation depths in the 2015/2016 crop season (I)

the grain filling in the ear tip and, thus, the NGE of plants in treatments with lower irrigation depths, since soil water contents remained above critical limits in all treatments before this period (Figure 2). No significant differences were found between irrigation depths in crop season II, because no significant water deficit occurred during critical periods (mainly in the pollination stage) for NGE.

Souza et al. (2016) also found increased NGE in irrigated plants, with quadratic responses as a function of the irrigation depths, denoting the importance of water supply in critical periods for NGE, which directly affects GY.

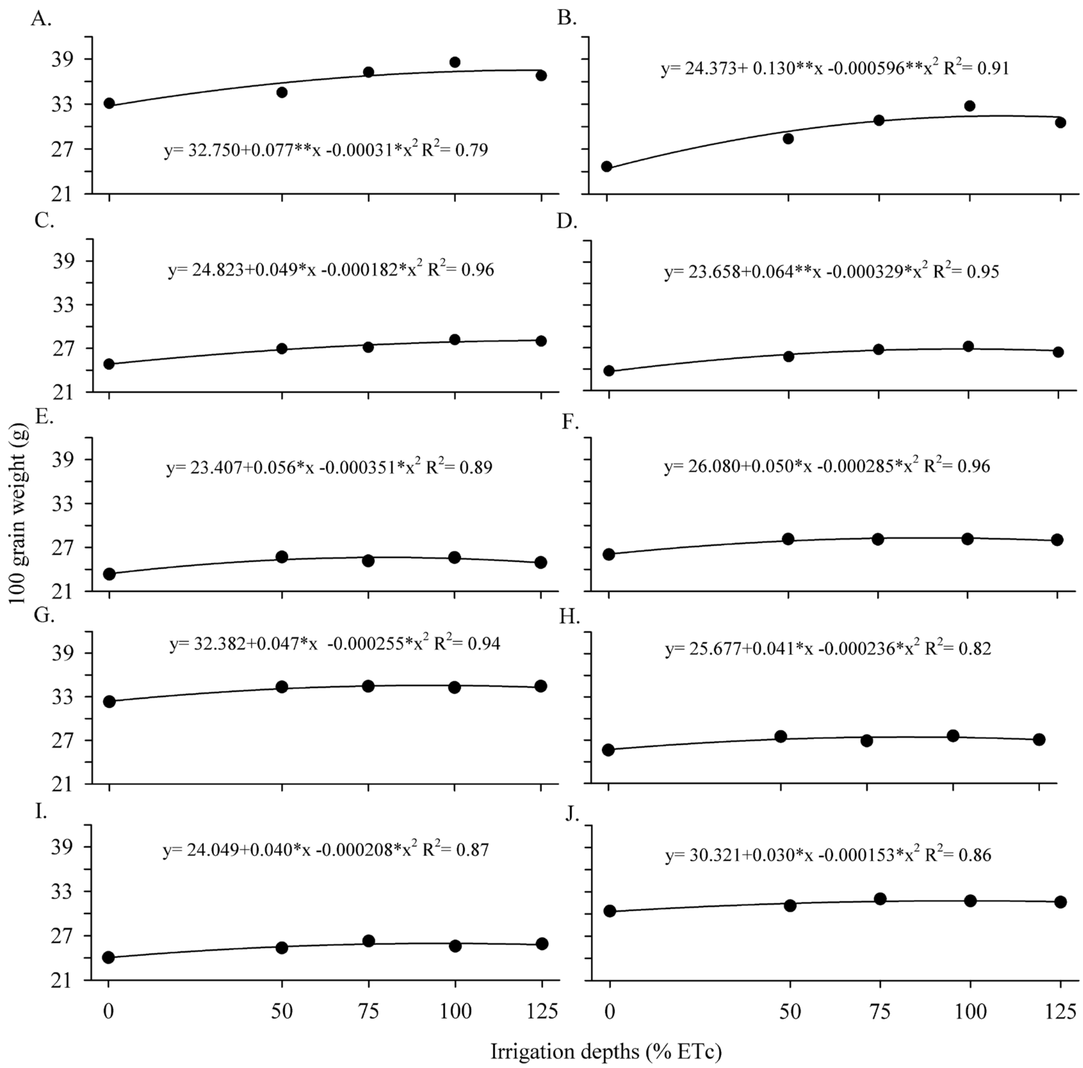
The irrigation depths affected positively 100GW (Figure 4). The treatment T0 resulted in significant water deficit in the reproductive stage of the maize hybrids, when the 100GW is defined. Soil moistures in T0 were below the critical level from the 90 DAE in crop season I (Figure 2), extending until the end of the maize crop cycles. Although soil moisture remained below the critical level from 78 DAE in crop season II, the water deficit was less significant than that one in the crop season I.

The 100GW of all hybrids fitted to the quadratic regression model, with maximum technical efficiency (MTE) varying between irrigation depths of 97% ETc (Status) and 125% ETc (DKB 240) in crop season I. The MTE in crop season II varied between irrigation depths of 80% ETc and 97% ETc. AG 9025 had the highest 100GW in crop season I (37.52 g) and II (34.5 g) in the irrigation depth of MTE.

Similarly, Liu et al. (2017) evaluated irrigation depths of 20% ETc to 120% ETc compared to 100% ETc and found a gradual decrease in 100GW with these irrigation depths, reaching decrease of up to 27% with the irrigation depth of 20% ETc, and 3.1% when using the irrigation depth of 120% ETc, which was attributed to excess of water.

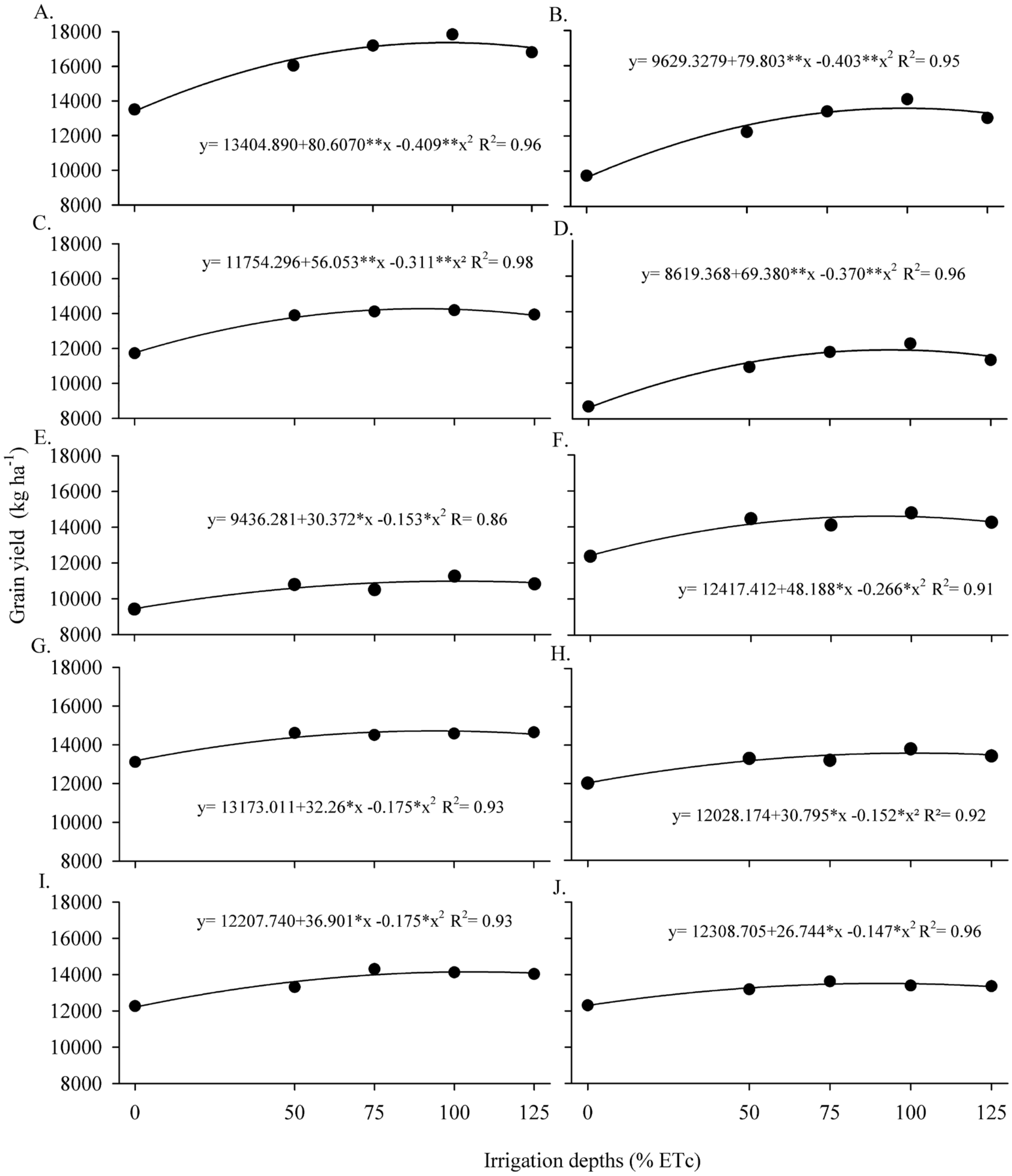
The grain yield (GY) was increased by irrigation depths (Figure 5), reaching a maximum value between the irrigation depths of 90.1% ETc and 105.4% ETc (depending on the maize hybrid), and decreasing with increasing irrigation depth to 125% ETc. This result was due to the water deficit in lower irrigation depths, which reduced the productive potential of the evaluated maize hybrids, and the excess water in the highest irrigation depth (125% ETc), which may have affected the soil aeration, compromising the plant development.

Like in this study, Kresović et al. (2016) observed a quadratic fit for GY as a function of irrigation depths with identification of the MTE.



**,* Significant at $p \leq 0.01$ and $p \leq 0.05$ probability levels, respectively by F test

Figure 4. 100-grain weight (100GW) of maize hybrids as a function of irrigation depth in crop season 2015/2016: AG 9025 (A), AG 9045 (B), DKB 240 (C), Status (D) and crop season 2016/2017: AG 177 (E), DKB 290 (F), AG 9025 (G), AG 8780 (H), P 1630 (I), and DKB 230 (J)



**,* Significant at $p \leq 0.01$ and $p \leq 0.05$ probability levels, respectively by F test

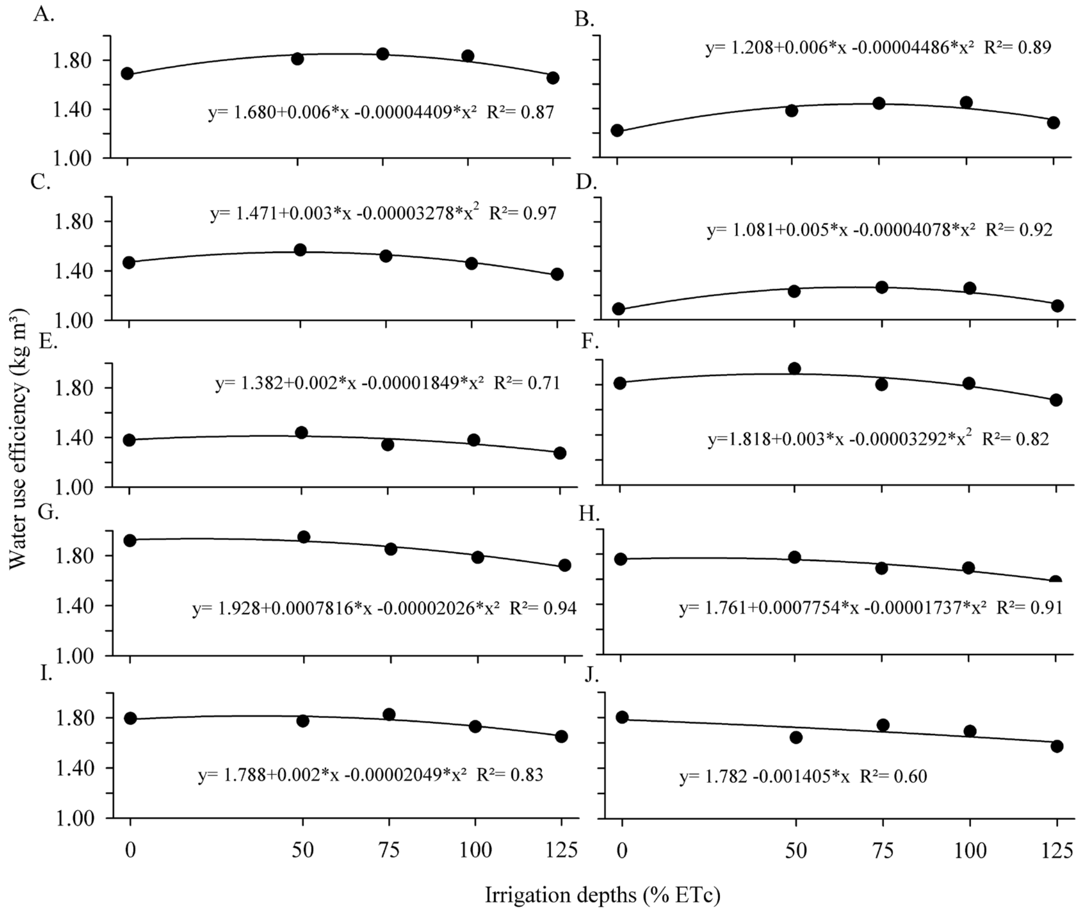
Figure 5. Grain yield (GY) of maize hybrids as a function of irrigation depth in crop season 2015/2016: AG 9025 (A), AG 9045 (B), DKB 240 (C), Status (D) and crop season 2016/2017: AG 177 (E), DKB 290 (F), AG 9025 (G), AG 8780 (H), P 1630 (I) and DKB 230 (J)

Table 2 shows the MTE and the increase in GY due to irrigation in each maize hybrid, with increases between 21.5% (DKB 240) and 41% (AG 9045) in crop season I, and 9.9% (DKB 230) and 17.6% (DKB 290) in crop season II, when compared to T0. These results are probably due to the different tolerance of the hybrids to water deficit and their responses to irrigation (Sousa et al., 2015).

Kaman et al. (2011) found similar results in maize genotypes subjected to full and deficit irrigations, with different GY depending on the irrigation management and genotypes, and the highest GY in treatments without water deficit. This is due to the genetic characteristics of each genotype, which may present different water use efficiencies (Sangoi et al., 2006).

Table 2. Irrigation depths with maximum technical efficiency (%ETc MTE); grain yield with the irrigation depth of MTE (GY MTE); and percentage of increase in GY with the MTE in relation to the treatment without irrigation (%GY MTE), in maize hybrids grown in the 2015/2016 and 2016/2017 crop seasons

	Maize hybrids - 2015/2016 crop season				Maize hybrids - 2016/2017 crop season					
	AG 9025	DKB 240	AG 9045	Status	AG 9025	DKB 290	AG 8780	P 1630	DKB 230	DKB 177
%ETc MTE	98.3	90.1	99.0	93.6	92.2	90.6	101.3	105.4	91.0	99.3
GY MTE	17368.7	14279.2	13578.1	11868.4	14659.7	14599.8	13587.9	14153.0	13525.1	10943.6
%GY MTE	29.6	21.5	41.0	37.7	11.3	17.6	13.0	15.9	9.9	16.0



**,* Significant at p ≤ 0.01 and p ≤ 0.05 probability levels, respectively by F test

Figure 6. Water use efficiency (WUE) of maize hybrids as a function of irrigation depth in crop season 2015/2016: AG 9025 (A), AG 9045 (B), DKB 240 (C), Status (D) and crop season 2016/2017: AG 177 (E), DKB 290 (F), AG 9025 (G), AG 8780 (H), P 1630 (I) and DKB 230 (J)

The irrigation depths used in the present study affected the WUE (Figure 6).

The irrigation depth of MTE of the maize hybrids ranged from 45.7% ETc (DKB 240) to 68.0% ETc (AG 9025) in the crop season I, and from 0% ETc (DKB 230) to 45.5% ETc (DKB 290) in crop season II. The different WUE of the crop seasons was probably due to the higher water deficit in crop season I. The water volumes applied through irrigation in crop season I generated a greater amplitude of productivity when considering the irrigated treatments and T0, as well as for WUE.

Similarly, Zhang et al. (2017) found decreases in WUE with increasing irrigation depths, and the highest WUE (2.61 and 2.93 kg m^{-3} in a two-year experiment) under the irrigation depth of 70% ETc; and Liu et al. (2017) evaluated irrigation depths of 20 to 120% ETc and found the highest WUE when using the irrigation depth of 60% ETc.

According to Magalhães et al. (2009), maize hybrids that present greater WUE have characteristics of tolerance to water deficit. However, genotypes that present high WUE under water deficit and sufficient water conditions are desirable, since it results in greater grain yields (Sousa et al., 2015).

Conclusions

1. The irrigation depth of maximum technical efficiency for grain yield was different among the evaluated maize hybrids, ranging from 90.1 to 105.4% of the crop evapotranspiration (ETc).

2. The irrigation depths of maximum technical efficiency increased grain yield in 9.9 to 41%.

3. The irrigation depth of maximum technical efficiency of the maize hybrids for water use efficiency ranged from 0% ETc to 68% ETc, depending on the maize hybrid.

4. The AG 9025, DKB 290 and P 1630 maize hybrids presented the best productive performance, with grain yields of 16,281.3 kg ha^{-1} (AG 9025) in the 2015/2016 crop season, and 14,293.4 kg ha^{-1} (AG 9025), 13,996.7 kg ha^{-1} (DKB 290) and 13,609.1 kg ha^{-1} (P 1630) in the 2016/2017 crop season.

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