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GRAIN YIELD OF MAIZE GENOTYPES UNDER FULL AND SUBOPTIMAL IRRIGATION

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ABSTRACT – The water stress resulting from irregular water availability is one of the main factors limiting maize (*Zea mays* L.) productivity in the Brazilian Cerrado. This study aimed to evaluate the phenological and yield performance of maize genotypes under different irrigation depths using a line-source system to induce a gradient of water stress. The field experiment was conducted at Embrapa Maize and Sorghum, Sete Lagoas, Minas Gerais, Brazil, from April to October 2024. Eight maize genotypes were evaluated under irrigation depths ranging from 194 to 579 mm in a randomized block design with four replications. Water deficit significantly shortened the phenological cycle, advancing physiological maturity by up to 20 days, whereas full irrigation prolonged the cycle and enhanced grain filling. Average grain yield ranged from 2,100 to 8,900 kg ha^{-1} across the irrigation depths applied throughout the crop cycle. The hybrid 3S 2761 exhibited the highest grain yield, while 1P2216VTPRO2 showed greater earliness under water stress conditions. Increasing irrigation depths promoted gains in harvest index (0.12 to 0.5) and thousand-grain weight, reflecting improved assimilate partitioning. Maximum water productivity was observed within the range of 470 to 500 mm, indicating greater water-use efficiency. These results demonstrate that irrigation management based on optimizing applied water depth is a valid strategy to maximize yield and water-use efficiency in tropical irrigated maize systems.

Keywords: *Zea mays* L., irrigation management, line-source, water stress, water.

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Maize (*Zea mays* L.) is the second most produced crop in Brazil, surpassed only by soybean (Tenher, 2023). The crop plays a fundamental role in national food security and the economy. In addition to its importance for human consumption, maize is the primary energy source in animal feed and supplies the ethanol and bioproducts industries (Produção […], 2025). Brazilian maize production reached a record 139.7 million tons in the 2024/2025 season, representing a 20.9% increase compared with the previous harvest and the highest volume ever recorded in the country. This result was driven mainly by the performance of the second-crop maize("safrinha"), particularly in the states of Mato Grosso, Paraná, Goiás, Minas Gerais, and Mato Grosso do Sul, which remain the leading producers (Conab, 2025).

The Brazilian Cerrado is the main producing region and contributes substantially to second-crop output. However, this biome presents challenging environmental conditions, including inherently low soil fertility and, above all, an unimodal rainfall regime (Prado et al., 2012; Reboita & Ferreira, 2025). Water deficit is among the abiotic stresses that most severely affect maize, especially during the critical period from flowering to grain filling (Oliveira, 2021; Liu et al., 2022b; Vennam et al., 2023). In this context, the use of hybrids adapted to water stress, combined with management practices that enhance water-use efficiency, is essential to ensure yield stability and agricultural sustainability (Bastos et al., 2012; Almeida et al., 2017; Fieldview, 2024).

Such information is essential for guiding breeding programs and supporting technical recommendations for producers. Moreover, studies evaluating hybrid performance across contrasting environments contribute to mitigating climatic risks and enhancing the resilience of production systems to rainfall variability (Kumar et al., 2023; Das et al., 2025). These investigations align with the goals of sustainable agriculture, which seeks to reconcile high productivity with the rational use of natural resources, particularly water. Given this context, this study aimed to evaluate the phenological development and yield performance of maize genotypes cultivated under different irrigation depths.

Material and Methods

The field experiment was conducted at the Experimental Station of Embrapa Maize and Sorghum, Sete Lagoas, Minas Gerais, Brazil (732 m altitude; 19°28′ S, 44°15′08″ W), from April 17 to October 1, 2024. The regional climate is classified as Cwa (humid subtropical with dry winter) according to Köppen (Alvares et al., 2013). Based on the historical series from 1927 to 2013, the mean annual temperature is 21.9 °C and the mean annual precipitation is 1,345 mm, concentrated between October and March (Borges Júnior et al., 2017). The soil is classified as a Latossolo with medium texture (Panoso et al., 2002; Gomide et al., 2006; Santos et al., 2025).

Sowing was carried out mechanically on April 17 under a no-tillage system, with 0.50 m row spacing and a plant population of 75,000 plants ha^{-1} (3.75 plants m^{-1}). Each 4.5 m plot row corresponded to a specific irrigation depth and contained 17 plants. Eight maize genotypes were evaluated: 1P2206 VTPRO2, 1P2216 VTPRO2, 3S2761, 3T2807, 2R2642 VTPRO2, SINTÉTICO 9180 1601, DKB 390PRO, and AG7098 TER. The hybrid NK Feroz VIP3 was sown as a border.

Basal fertilization consisted of 350 kg ha^{-1}

of NPK 08-28-26 + 0.3% B, supplying 28 kg ha^{-1} N, 98 kg ha^{-1} P_2O_5, 91 kg ha^{-1} K_2O, and 1.05 kg ha^{-1} B. Topdressing included: 200 kg ha^{-1} of NPK 20-00-20 at 15 days after sowing (DAS), providing 40 kg ha^{-1} N and 40 kg ha^{-1} K_2O; 200 kg ha^{-1} of ammonium sulfate at 19 DAS, supplying 42 kg ha^{-1} N and 48 kg ha^{-1} S; and 100 kg ha^{-1} of urea at 29 DAS, providing 45 kg ha^{-1} N. A foliar fertilizer (1 L ha^{-1}) containing Mg (1.0%), S (3.4%), B (0.5%), Cu (0.5%), Mn (6.0%), Mo (0.3%), and Zn (3.0%) was applied at 30 DAS.

A conventional sprinkler system equipped with Rain Bird 14070H sprinklers heads was used. Laterals were 18 m apart and sprinkler heads were spaced 12 m. Irrigation depths were measured at each event using 12 catch cans per replication (48 in total). Irrigation scheduling was based on a daily soil water balance computed in an electronic spreadsheet, with irrigation applied when 50% of the available soil water had been depleted (Albuquerque & Andrade, 2001). Meteorological data were obtained from a weather station located 35 m from the experimental area. Four irrigation zones were defined, with average total depths applied (block averages) of 194 mm (L4), 437 mm (L3), 530 mm (L2), and 579 mm (L1).

At 36 DAS, the two outer laterals were removed, leaving only the central line of sprinklers to establish the line-source system. In this configuration, irrigation depths decrease progressively with distance from the central line, enabling the evaluation of maize genotype tolerance to water stress.

The irrigation and precipitation depths recorded throughout the crop cycle are presented in Figure 1. Total accumulated precipitation during the cycle was 26 mm, and the measured irrigation depths were 150.4 mm, 212.3 mm, 252.7 mm, and 256.9 mm.

Female flowering (silking) was assessed twice weekly until the VT stage and three times weekly thereafter, until 50% of the 20 tagged plants exhibited silks at least 2 cm long. Physiological maturity was assessed weekly until the first kernels exhibited a black layer at the base, and subsequently three times per week until at least 50% of the 30 evaluated kernels presented a black layer.

Two ears per plot were evaluated across all treatments. Grain yield was determined from two rows per plot, corresponding to an area of 4.5 m². Plants and ears were counted, and plant height (from the soil surface to the tassel tip) and ear height (from the soil surface to the point of ear insertion) were measured. Six plants were selected for detailed analysis, including determination of the dry mass of 1,000 kernels and the dry mass of plant components (stem, tassel, leaves, husk, cob, straw, and kernels).

A grain sample was collected to determine harvest moisture content, which was used to adjust grain yield to 13% moisture. The harvest index was calculated as the ratio of grain dry mass (GDM) to the total aboveground dry mass, with all components oven-dried at 65 °C to constant weight. Water productivity was calculated as the ratio between grain yield (kg ha^{-1}) and the total volume of water applied (m³ ha^{-1}), according to the methodology of Pereira et al. (2009).

The experiment was conducted using a randomized complete block design with a strip-split-plot arrangement and four replications. Irrigation levels were applied systematically in strips parallel to the irrigation line, while genotypes were randomly distributed in strips perpendicular to that line. Statistical analyses were performed using R software (version 4.3.0) and the ExpDes.pt package. Initially,

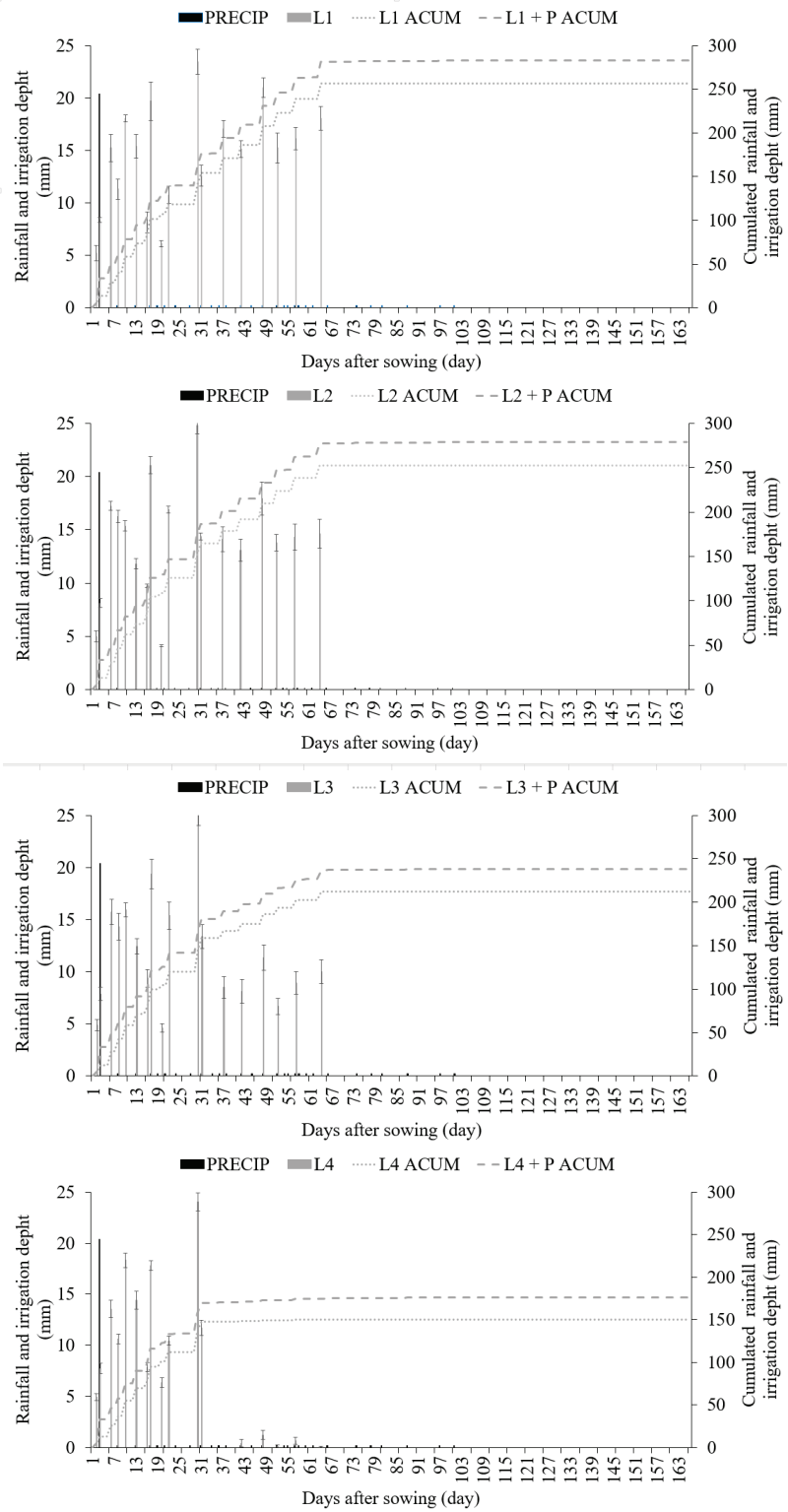


Figure 1. Daily and cumulative irrigation and rainfall depths measured throughout the maize growing cycle for each of the four irrigation treatments. Sete Lagoas, MG, Brazil, 2024.

the data were subjected to analysis of variance (ANOVA).

The analysis followed the model with specific error for each effect: $Yijk = \mu + gi + bj + eij + lk + ekj + glik + eikj$; where: Yijk is the value of the i-th genotype observed in the j-th block of the k-th water depth; μ is the overall mean; gi is the effect of the i-th genotype (i=1, 2, ..., 8); bj is the block effect (j=1, ..., 4); eij is the genotype × block interaction, corresponding to the error for testing the genotype effect; lk is the effect of the k-th water depth (1, ..., 4); ekj is the water depth × block interaction, corresponding to the error for testing the water depth effect; glik is the genotype × water depth interaction effect; and eikj is the genotype × water depth × block interaction, corresponding to the error for testing the genotype × water depth interaction effect.

When the F-test indicated a significant effect ($p < 0.05$) for genotypes or the genotype × irrigation interaction, treatment means were compared using the Scott-Knott test at the 5% probability level.

Polynomial regression analysis was performed for each genotype individually, considering the four irrigation levels as a continuous independent variable. Quadratic models were fitted for all variables. The selection of the best-fit model was based on the coefficient of determination (R^2) and the significance of the regression coefficients ($p < 0.05$). This approach allowed for the identification of genotypes exhibiting quadratic responses to water availability—distinguishing between materials more sensitive or tolerant to water deficit—as well as the estimation of the optimal water application depth for maximum productivity. The regression results are presented in Figures 2 through 5, showing fitted curves and their respective confidence intervals. The SE was calculated as SE = sqrt(MSE/r), where SE is the standard error, MSE is the mean square error (residual mean square), and r is the number of replicates. The LSD was calculated as LSD = qt(0.975, df_res) * sqrt(2*MSE/r), where LSD is the least significant difference, qt is the critical value of the Student's t-distribution, df_res is the residual degrees of freedom, MSE is the mean square error, and r is the number of replicates. The coefficients of variation (CV) for each variable, calculated from the respective residual mean squares, are reported in the figures, indicating good experimental precision and lending reliability to the obtained results.

Results and Discussion

The summary of the analyses of variance for all evaluated traits is presented in Table 1. It is observed that the block effect was significant only for grain yield (GY) and thousand-grain mass (TGM) ($p < 0.05$), indicating variation among experimental blocks for these variables. For the remaining variables, the block effect was not significant ($p > 0.05$), demonstrating that environmental variability among blocks was controlled and did not significantly influence the results. The genotype effect was also observed to be significant ($p < 0.001$) for all evaluated variables (physiological maturity – PM, grain yield – GY, harvest index – HI, thousand-grain mass – TGM, and irrigation water productivity – IWP). This demonstrates the existence of genetic variability among the evaluated materials, indicating that the genotypes exhibited distinct behaviors regarding productivity, harvest index, thousand-grain mass, and irrigation water use efficiency, while also highlighting differences in physiological maturity among them. The effect of irrigation depths on all

Table 1. Summary of the analysis of variance (ANOVA) for physiological maturity (PM), grain yield (GY), harvest index (HI), thousand-grain mass (TGM) and irrigation water productivity (IWP) of maize genotypes under different irrigation levels

SV	DF	QM				
		GY	PM	HI	TGM	IWP
Block	3	2672368**	15.35^{ns}	0.001^{ns}	1142*	0.084^{ns}
Genotype	7	4638146***	69.64***	0.019***	1297***	0.288***
Error a	21	605486	6.97	0.001	216	0.025
Depth	3	292044077***	2735.9***	0.514***	60749***	1.406***
Error b	9	285835	2.39	0.001	211	0.073
Genotype x Depth	21	1446122***	5.85^{ns}	0.002***	606***	0.104***
Erro c	63	522452	4.25	0	119	0.021
CV1 (%)		12.07	1.74	6.04	6.38	12.56
CV2 (%)		8.31	1.02	6.77	6.31	21.39
CV 3(%)		11.23	1.36	5.27	4.73	11.53

MS = mean square. DF = degrees of freedom. CV = coefficient of variation. ns = not significant; * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$ by F-test.

evaluated variables was highly significant ($p<0.001$). This shows that different irrigation depth levels significantly altered the agronomic performance of the evaluated genotypes. Furthermore, we can see that the interaction between irrigation depths and genotypes was significant ($p<0.001$) for all variables, except for PM ($p>0.05$). This means that the response of the genotypes depends on the irrigation level applied, that is, the genotypes did not respond uniformly to different levels of water availability. Therefore, the interpretation of the main effects must be complemented by the breakdown of the interaction, comparing the genotypes within each depth and/or the depths within each genotype, and not by the effects alone. The CVs varied between 1.02 and 6.38% for PM, HI and TGM, considered low, which indicates good experimental precision, and for GY they varied from 8.31 to 12.07%, relatively high, but still acceptable for productivity in field experiments (Pimentel-Gomes, 1985). The coefficients of variation, in general, indicate good experimental precision, providing reliability to the results obtained.

Grain yield was strongly influenced by the applied irrigation depths, showing progressive reductions as water availability decreased (Figure 2). Overall, shifting from the maximum irrigation depth (L1) to L2 resulted in yield losses ranging from 2.0% to 26.4%, depending on the genotype - with the exception of 2R2642VTPRO2, which showed a 3.2% increase. However, the most drastic effect was observed when the irrigation depth was reduced to L3, with losses ranging from 12.1% (3S2761) to 37.9% (AG7098TRE). Under conditions of severe water deficit (L4), losses were even more pronounced, ranging from 64.1% (1P2216VTPRO2) to 86.7%

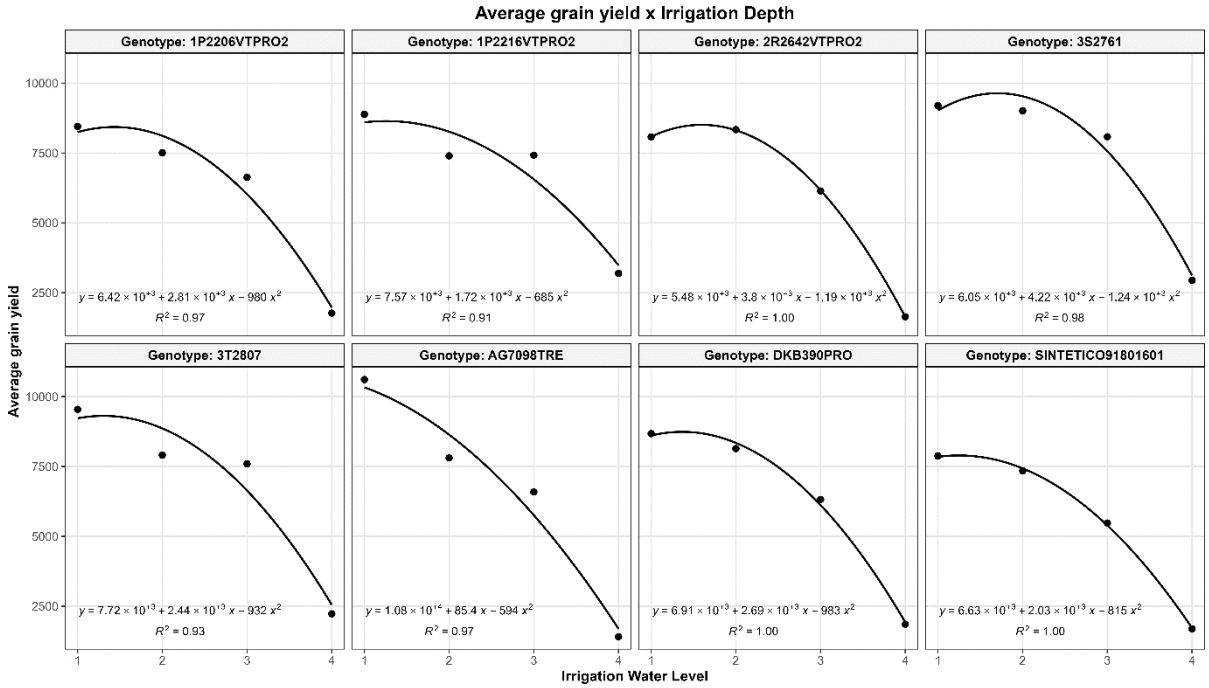


Figure 2. Average grain yield (kg $^{ha-1}$) of different maize genotypes under four irrigation depths, 579 mm (L1), 530 mm (L2), 437 mm (L3) e 194 mm (L4). CV=11,19 %. DMS = 1010,9. Standard Error: 359,96. Sete Lagoas, MG, Brazil, 2024.

(AG7098TRE). These results corroborate the studies by Bergamaschi et al. (2006) and Bastos et al. (2012), which demonstrated that maize is particularly sensitive to reduced water availability, especially when the deficit occurs during reproductive stages such as flowering and grain filling (Liu et al., 2022b; Vennam et al., 2023).

Among the genotypes evaluated, 3S2761 stood out as the most tolerant to reduced irrigation depth, exhibiting the lowest relative losses under all deficit conditions, with reductions of only 2.0% (L2), 12.1% (L3), and 68.0% (L4) compared to the maximum irrigation depth.

This behavior indicates greater efficiency in the use of available water, possibly associated with characteristics such as a deeper root system, greater capacity for osmotic adjustment, and maintenance of leaf area under stress (Peixoto, 2020; Das et al., 2025). The 1P2216VTPRO2 genotype also proved remarkably tolerant, with losses of 16.7% (L2), 16.5% (L3), and 64.15% (L4); this demonstrates that early-maturing materials can escape water stress by completing their reproductive phase over a shorter period, thereby reducing exposure to the deficit (Bergamaschi & Matzenauer, 2009; Alves et al., 2011). Notably, this genotype achieved the highest yield under the most severe stress condition (L4), outperforming all other materials—a result that reinforces its suitability for environments with limited water availability.

In contrast, the AG7098TRE genotype was the most adversely affected by the reduction in irrigation depth, exhibiting the greatest relative losses under virtually all conditions: 26.4% (L2), 37.9% (L3), and 86.7% (L4). This behavior indicates low tolerance to water deficit, possibly associated with its

longer cycle (155 days), which exposes it to stress conditions for a longer period, thereby compromising grain filling (Bergamaschi & Matzenauer, 2009). The SINTÉTICO91801601 genotype also demonstrated high sensitivity, with losses of 6.7% (L2), 30.4% (L3), and 78.5% (L4), reinforcing the low efficiency of this material under water-restricted conditions. Similar results were obtained by Almeida et al. (2017), who observed greater susceptibility to yield reduction under water deficit among late-maturing genotypes.

The 3T2807 and 1P2206VTPRO2 genotypes exhibited intermediate behavior, with losses of 17.2% and 11.11% (L2), 20.4% and 21.5% (L3), and 76.6% and 79.0% (L4), respectively. Although the DKB390PRO genotype performed well at L2 (a loss of only 6.2%), it showed a sharp decline at L3 (27.1%) and L4 (78.6%), indicating that its tolerance to water deficit is limited to moderate stress conditions. The 2R2642VTPRO2 genotype displayed atypical behavior, with a slight increase at L2 (+3.2%) suggesting that the maximum water application level may have been excessive for this material, possibly causing losses due to drainage or nutrient leaching but its productivity dropped drastically at L3 (24.0%) and L4 (79.7%), demonstrating low tolerance to severe deficits.

The analysis of the relative effect of reducing the irrigation depth on the productivity of the genotypes shows that the choice of genetic material is decisive for productive stability in systems with water restrictions. Genotypes such as 3S2761 and 1P2216VTPRO2, which showed the lowest percentage losses, are more suitable for regions at risk of water deficit or for supplementary irrigation systems, in which the applied depth may be limited. Particularly, the 1P2216VTPRO2 genotype was superior under severe stress (L4), suggesting that its precocity (149 days) confers a competitive advantage in an environment with very reduced water availability. On the other hand, more sensitive genotypes, such as AG7098TRE and SINTÉTICO91801601, require full irrigation conditions to express their yield potential, making them suitable only for systems with a guaranteed adequate water supply (Bastos et al., 2012; Camargo et al., 2022). The intermediate performance of genotypes such as 2T2807 and 1P2206VTPRO2 makes them versatile options for systems with moderate water availability. This information is crucial for guiding breeding programs and informing producer decisions regarding hybrid selection based on expected water availability for the growing season—particularly in the Brazilian Cerrado, where rainfall irregularity poses a constant challenge to maize production (Reboita & Ferreira, 2025).

Physiological maturity (PM) of the evaluated genotypes ranged from 149 to 155 DAS (Table 2), indicating significant genetic differences regarding cycle duration. The AG7098TRE hybrid exhibited the longest cycle, whereas 1P2216VTPRO2 and 3S2761 were the earliest-maturing. Although the developer of AG7098TRE specifies a 147-day cycle (Agro Bayer, 2025), the longer cycle observed in this study may be attributed to milder temperatures during the experiment, which delay maize development and prolong grain filling (Bergamaschi & Matzenauer, 2009; Alves et al., 2011).

Reducing the irrigation depth consistently shortened the growth cycle across all genotypes, with physiological maturity occurring up to 20 days earlier under the lowest irrigation level (L4) compared to full irrigation (L1). This behavior represents a drought-

Table 2. Average physiological maturity of different maize genotypes

Genotype	PM (days)
AG7098TRE	155.31 a
3T2807	153.06 b
SINTÉTICO91801601	152.75 b
1P2206VTPRO2	152.12 b
DKB390PRO	151.81 b
2R2642VTPRO2	150.68 c
1P2216VTPRO2	149.12 c
3S2761	149.12 c

PM = Physiological maturity (days). Means followed by the same letter do not differ from each other by the Scott Knott test (P<0.05). CV=1.74 %. DMS = 3,04. Standard Error: 1,08. Sete Lagoas, MG, Brazil, 2024.

escape mechanism, wherein the plant accelerates maturation to complete its cycle before the water deficit worsens (Boyer, 1982; Peixoto, 2020). Since the genotype-by-irrigation interaction was not significant for this variable (Table 1), the reduction in cycle length was proportionally similar across all genotypes, indicating that the response to water deficit—in terms of earliness—is independent of the genetic material.

In contrast, the application of adequate irrigation depths (530 to 579 mm) extended the genotypes' growth cycle up to 161 days, providing a longer grain-filling period. This extension, combined with greater water availability, favored the maintenance of leaf area and photosynthetic activity, resulting in greater assimilate accumulation and, consequently, higher grain yield and thousand-grain mass (Bergamaschi et al., 2004; Liu et al., 2022a).

Considering genetic differences and consistent stress responses, it is concluded that earlier-maturing genotypes - such as 1P2216VTPRO2 and 3S2761 - are better suited for water-limited environments or second-crop systems in the Cerrado, where the cessation of rainfall can compromise grain filling in late-maturing cultivars (Almeida et al., 2017; Reboita & Ferreira, 2025). Conversely, longer-cycle hybrids, such as AG7098TRE, are more appropriate for fully irrigated systems, where the extended grain-filling period can translate into higher yields (Bastos et al., 2012). Thus, although the effect of reduced water application on cycle shortening was uniform across genotypes, the choice of material must take into account its absolute cycle duration and the expected water availability for the growing season.

The harvest index (HI) increased with higher irrigation levels, ranging from 0.12 (L4) to 0.50 (L1) (Figure 3), indicating that greater water availability improved assimilate partitioning to the grains (Liu et al., 2022a).

Reducing the water application depth led to significant drops in the harvest index (HI), with losses varying across genotypes. At the L4 level, reductions ranged from 39.58% (1P2216VTPRO2) to 73.91% (AG7098TRE). Genotypes 1P2216VTPRO2

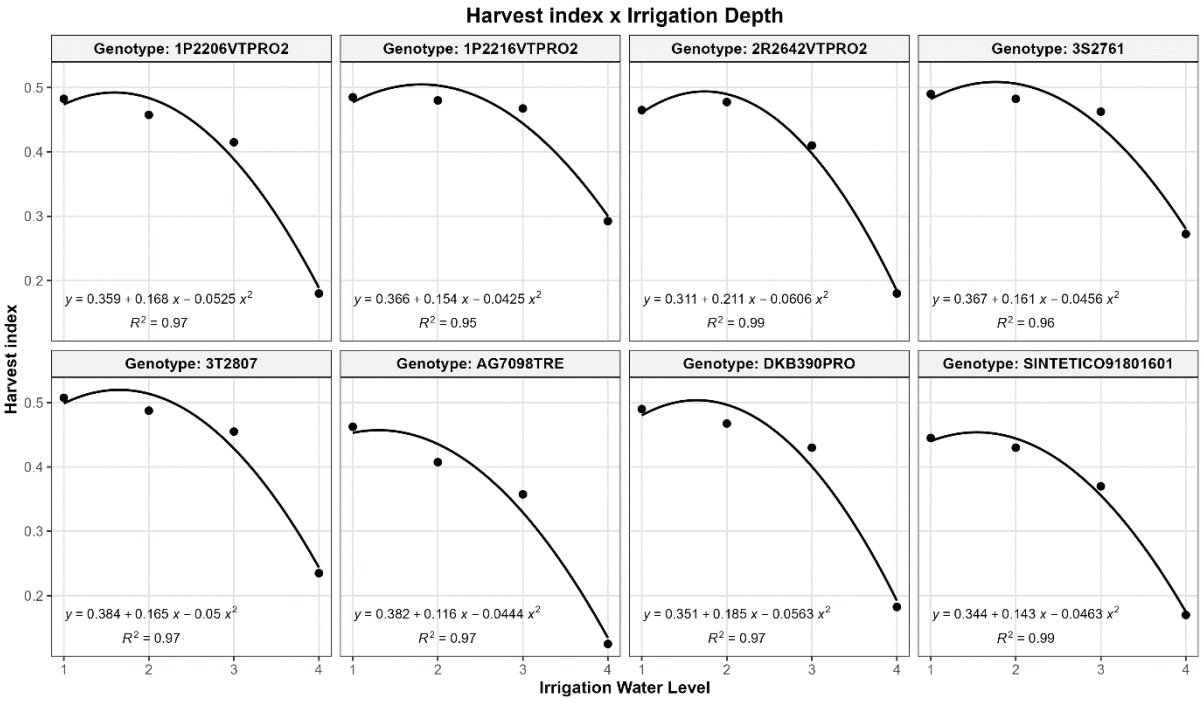


Figure 3. Harvest index of different maize genotypes under four irrigation depths, 579 mm (L1), 530 mm (L2), 437 mm (L3) e 194 mm (L4). CV= 5,61%. DMS = 0,03. Standard Error: 0,01. Sete Lagoas, MG, Brazil, 2024.

and 3S2761 were the least affected, with losses of 39.58% and 44.90%, respectively; this is attributed to their earlier maturity (149 days – Table 2), which concentrates the reproductive phase within a period of lower stress (Bergamaschi & Matzenauer, 2009; Peixoto, 2020). In contrast, AG7098TRE was the most sensitive (73.91% loss) due to its longer cycle (155 days), which extends the duration of exposure to water deficit (Alves et al., 2011; Bastos et al., 2012).

It is concluded that genotypes such as 1P2216VTPRO2 and 3S2761 are more suitable for water-restricted systems, whereas sensitive materials like AG7098TRE require full irrigation to express their potential (Almeida et al., 2017).

Thousand-grain mass (TGM) increased with higher irrigation depths, ranging from approximately 148 g (L4) to 285 g (L1) (Figure 4), confirming that water availability during grain filling is critical for dry matter accumulation (Bergamaschi et al., 2004; Peixoto, 2020).

Irrigation depth reduction led to decreases in TGM, with magnitudes varying among the genotypes. At L4, losses ranged from 21.2% (1P2206VTPRO2) to 43.1% (SINTÉTICO91801601). The genotypes 1P2206VTPRO2 (21.2%), 2R2642VTPRO2 (28.4%), and DKB390PRO (31.8%) were the least affected under severe stress, indicating a greater capacity to maintain grain filling despite water restriction. In contrast, SINTÉTICO91801601 (43.1%) and AG7098TRE (43.0%) were the most sensitive, showing losses exceeding 40% at L4.

Although the 1P2216VTPRO2 genotype exhibited the highest grain mass per ear (TGM) at L1 (285.09 g), it showed a 40.5% loss at L4, indicating that its high yield potential is expressed only under full irrigation. The 3S2761 hybrid showed similar behavior, with a 39.4% loss at L4. Despite being

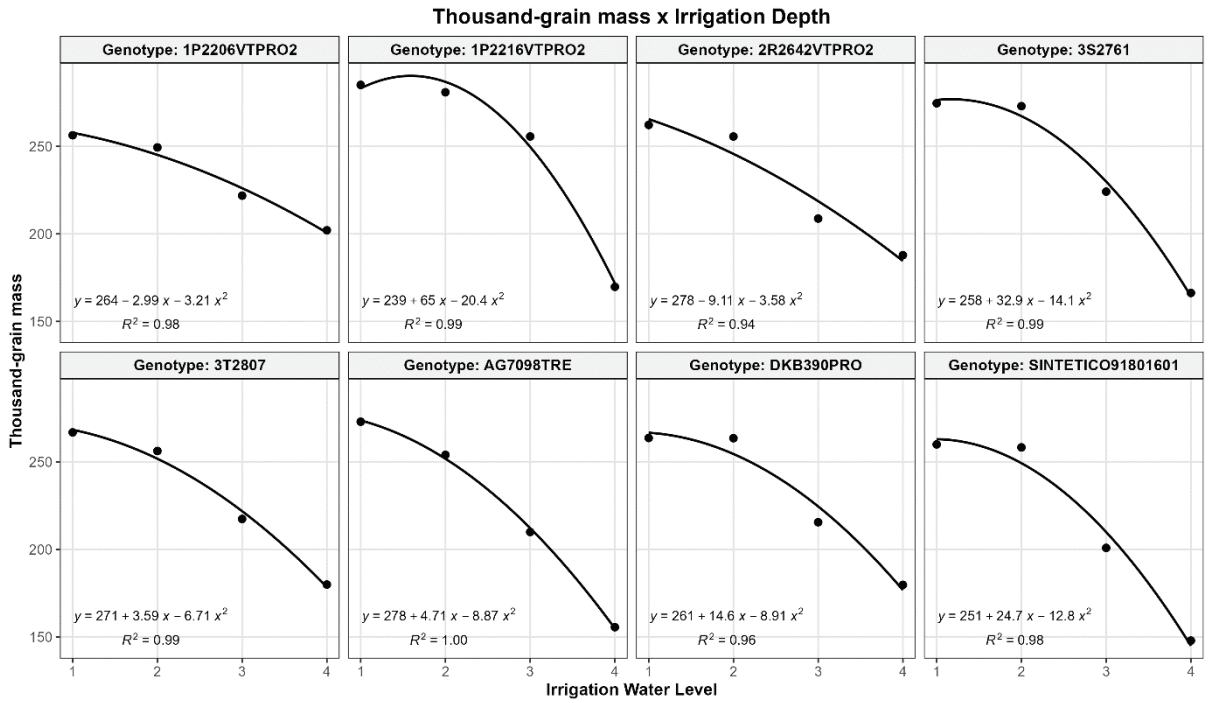


Figure 4. Thousand-grain mass (g) of different maize genotypes under four irrigation depths 579 mm (L1), 530 mm (L2), 437 mm (L3) e 194 mm (L4). CV= 5,31 %. DMS = 17,19. Standard Error: 6,12. Sete Lagoas, MG, Brazil, 2024.

early-maturing (149 days – Table 2), neither genotype maintained the same grain-filling efficiency observed for the HI.

Analysis of the relative effect of water application reduction on thousand-grain mass (TGM) reveals that genotypes such as 1P2206VTPRO2, 2R2642VTPRO2, and DKB390PRO—which exhibited the smallest losses at the L4 level—are better suited for water-restricted systems, as they maintain a higher grain-filling capacity even under water deficit. Conversely, more sensitive genotypes, such as SINTÉTICO91801601 and AG7098TRE, require full irrigation to realize their grain mass potential (Bastos et al., 2012; Almeida et al., 2017).

Irrigation water productivity (IWP) varied among genotypes and applied water depths, with values ranging from 0.46 kg m^{-3} (SINTÉTICO91801601 at L4) to 1.66 kg m^{-3} (3S2761 at L3) (Figure 5). Overall, IWP increased at intermediate water depths and decreased at the extremes of the gradient, indicating the existence of an optimal irrigation range for maximizing water use efficiency (Bergamaschi et al., 2004; Oliveira, 2020).

Reducing the water application level from L1 to L4 resulted in decreases in IWP, with magnitudes varying across genotypes. At L4, losses ranged from -7.3% (1P2216VTPRO2) to 62.3% (SINTÉTICO91801601). Genotype 1P2216VTPRO2 stood out as the most efficient, showing a 7.3% increase in IWP at L4 compared to the maximum water level, indicating a high capacity for grain production even under severe water deficit. The 3S2761 hybrid also showed excellent performance, with a loss of only 4.9% at L4, reinforcing its stress tolerance. In contrast,

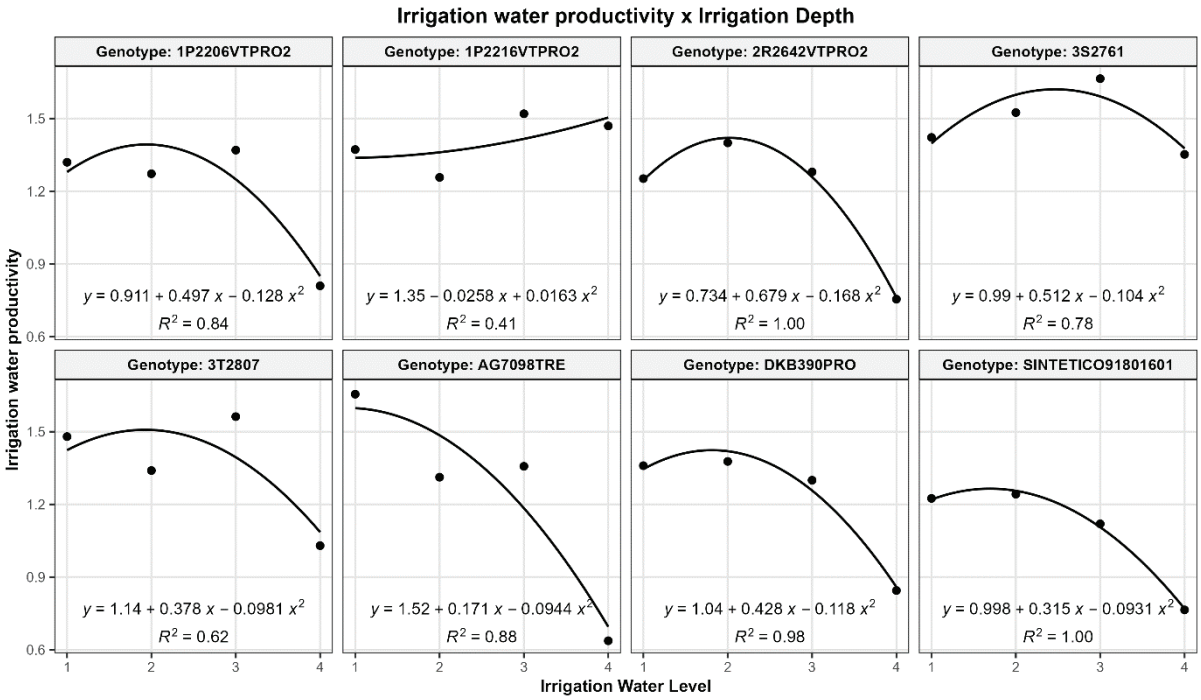


Figure 5. Irrigation water productivity (kg m^{-3}) of different maize genotypes under four irrigation depths, 579 mm (L1), 530 mm (L2), 437 mm (L3) e 194 mm (L4). CV= 13,04 %. DMS = 0,23. Standard Error: 0,08. Sete Lagoas, MG, Brazil, 2024.

the genotypes SINTÉTICO91801601 (62.3%) and AG7098TRE (61.8%) were the most affected by the reduction in water application, with losses exceeding 60% at level L4, indicating low water-use efficiency under severe deficit conditions. The genotypes 1P2206VTPRO2 (38.6%), DKB390PRO (38.2%), and 2R2642VTPRO2 (40.0%) showed intermediate performance, with losses ranging from 38% to 40%.

It is noteworthy that, at irrigation level L3, several genotypes exhibited an increase in IWP compared to the maximum irrigation level: 3S2761 (+16.9%), 1P2216VTPRO2 (+10.9%), 1P2206VTPRO2 (+3.8%), and 2R2642VTPRO2 (+2.4%), indicating that the range from L3 to L2 represents the point of maximum water use efficiency for these materials. This behavior confirms that water productivity does not increase linearly with the applied irrigation depth but reaches a maximum value at intermediate levels, beyond which efficiency declines (Howell, 2001; Wang et al., 2025).

Analysis of the relative effect of reducing water application on IWP reveals that genotypes such as 1P2216VTPRO2 and 3S2761- which maintained or increased their efficiency under stress - are the most suitable for water-restricted systems. Notably, genotype 1P2216VTPRO2 stood out by increasing IWP at level L4 (a 7.3% increase), suggesting that its earliness (149 days – Table 2) confers a competitive advantage in environments with severely limited water availability. In contrast, more sensitive genotypes, such as SINTÉTICO91801601 and AG7098TRE, require full irrigation to achieve their

potential efficiency and are recommended only for systems with a guaranteed water supply (Bastos et al., 2012; Almeida et al., 2017).

Conclusions

Analysis of variance shows that genotypes differed significantly for all evaluated variables, and that irrigation levels also had a significant effect on all of them. For grain yield (GY), harvest index (HI), thousand-grain mass (TGM), and irrigation water productivity (IWP), there was a significant interaction between genotypes and irrigation levels, indicating that the genotypes' response varied according to water supply. The interaction was not significant only for physiological maturity (PM), suggesting that the effect of irrigation on this trait was consistent across genotypes, and indicating that cycle shortening under water deficit represents a general stress-escape mechanism, independent of the genotype.

The evaluated genotypes exhibited distinct responses to water availability. Genotype 1P2216VTPRO2 and 3S2761 demonstrated greater earliness under water-limited conditions.

Increasing irrigation depths promoted substantial gains in grain yield, harvest index, and thousand-grain weight. Irrigation depths of approximately 470 to 500 mm were associated with the highest WP, representing the technical threshold of water-use efficiency under the evaluated conditions. Lower irrigation depths severely reduced yield, whereas higher water volumes did not produce proportional gains, demonstrating that WP does not increase linearly with the applied water depth but reaches a maximum value at intermediate levels. These results show that both genotype selection and irrigation management based on optimizing the applied water depth are valid strategies for maximizing yield in tropical irrigated maize systems, particularly in the Brazilian Cerrado, where rainfall irregularity poses a constant challenge to production.

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