PRODUCTIVE POTENTIAL OF SECOND GROWING SEASON OF MAIZE IN DIFFERENT SOWING TIMES SUBJECTED TO SUPPLEMENTARY IRRIGATION

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Revista Brasileira de Milho e Sorgo, v.17, n.3, p. 408-419, 2018

ABSTRACT - Understanding effects of climate variability over agricultural systems may support decisions to improve yield and environmental sustainability. Maize production systems in second season have a significant participation in Brazilian economy, and its yield depends of sowing times and soil water content. This work aimed to study maize yield in four sowing dates and supplementary irrigation in the second growing season in Brazil. The field experiment was developed in the 2015/2016 agricultural year in a completely randomized blocks design. Sowing dates were 01/27/2017, 02/09/2016, 02/25/2016 and 03/11/2016, and two irrigation conditions were adopted: the first without irrigation and the second with a supplementary irrigation of over 130% of the reference evapotranspiration (ET_0). Yield performance indicated that the best result was obtained for the 01/27/2017 sowing date. The effects of supplementary irrigation affected the yield for the dates 02/25/2016 and 03/11/2016.
Keywords: water balance, productivity, irrigation effect, *Zea mays L.*

POTENCIAL PRODUTIVO DO MILHO PARA ÉPOCAS DE SEMEADURA EM SEGUNDA SAFRA SUBMETIDO À IRRIGAÇÃO SUPLEMENTAR

RESUMO – O estudo dos efeitos da variabilidade climática na agricultura pode auxiliar nas tomadas de decisão para a melhoria contínua da produtividade e sustentabilidade ambiental. O milho de segunda safra no Brasil tem participação significativa na economia, e sua produtividade está vinculada, entre outros fatores, à pontualidade da semeadura e ao teor de água no solo. O objetivo deste estudo foi avaliar o efeito das épocas de semeadura em segunda safra no desempenho agronômico da cultura do milho em Tangará da Serra-MT, evidenciando a irrigação suplementar para semeaduras antecipadas, indicando a melhor época. O experimento foi realizado no ano agrícola de 2015/2016 com a cultivar de ciclo precoce AG 7088, em quatro épocas de semeadura (27/01/2016; 09/02/2016; 25/02/2016 e 11/03/2016), sob irrigação suplementar a 130% da evapotranspiração de referência (ET_0) e sem irrigação, em delineamento experimental de blocos ao acaso com quatro repetições e parcelas de área útil de 7,2 m². Foram avaliadas as características agronômicas para determinar o desempenho produtivo da cultura, em relação às épocas de semeadura em sistema irrigado e não irrigado. A semeadura realizada em 27/01 apresentou os melhores resultados de produtividade. A irrigação suplementar promoveu efeito sobre a produtividade nas épocas com restrição de chuvas (25/02/2016 e 11/03/2016).
Palavras-chave: balanço hídrico, produtividade, efeito da irrigação, *Zea mays* L.

The maize production system has a significant participation in the Brazilian economy. It is an important commodity for export and feedstock for animal and human food production (Silva et al., 2013). Most of the maize produced is cultivated in a second season, after the soybean crop, with a total area around 9.5 million hectares and a total production of 76.2 million tons (Acompanhamento da Safra Brasileira [de] Grãos, 2016). Mato Grosso state is the main producer in Brazil, with a total maize production area in second season of around 3.57 million hectares (Acompanhamento da Safra Brasileira [de] Grãos, 2016).

Comparing the agricultural seasons 2014/2015 and 2015/2016 in the Mato Grosso state, the cultivated area increased by 4.80%. However, total production decreased 8.50% (Acompanhamento da Safra Brasileira [de] Grãos, 2016). Usually, maize yield losses are caused by environmental behavior influences, especially by rainfall shortage after the sowing process in January and February (Serpa et al., 2012; Bergamaschi & Matzenauer, 2014).

Regarding maize development, two characters are more sensitive to the lack of water: the number of rows per cob (V5 up to V10 stages), and number of grains per row (VT up to R2 stages), directly affecting maize yield (Bergamaschi et al., 2006; Brito et al., 2013). For the flowering stage, a period of two days with water restrictions may decrease the yield by 20.0%; between four and eight days, it may decrease up to 50.0% (Magalhães & Durães, 2008). Thus, strategies to choose an appropriate sowing date and complementary irrigation may provide better conditions for maize development and, consequently, may minimize yield losses (Amudha & Balasubramani, 2011; Serpa et al., 2012; Silva et al., 2012).

Soil water storage, rainfall and evapotranspiration may be different in each region, and they are necessary to determine maize sowing dates and irrigation demands, thus requiring new studies for specific situations (Pereira et al., 2002; Bergamaschi & Matzenauer, 2014). Therefore, this work aimed to study the yield of maize cultivated in second season in Brazil in four sowing dates, with and without supplementary irrigation.

Material and Methods

The field experiment was developed in the Tangará da Serra municipality, Mato Grosso state, Brazil (14°39’S, 57°25’W, 440 m a.s.l.). The local climate is Tropical wet and dry (Aw), according to the Köppen classification system, with average annual temperature, rainfall and relative humidity of 24.4 °C, 1,830.0 mm and 70-80%, respectively. There are two specific periods in that region, rainy between October and March and dry between April and September (Dallacort et al., 2011).

The local area is flat to gently undulating, with a clayey soil (0.689 g of clay per g of soil). Soil classification is dystrophic Red Latosol (Emygdio &Teixeira, 2006). Samples of soil were collected and, after pH and fertility analysis (Table 1), improved according to recommendation rules by Coelho (2007). The basic fertilization consisted of 45 kg ha^{-1} K_2O and 95 kg ha^{-1} P_2O_5 applied to the sowing line. Total N applied was 314 kg ha^{-1}, divided into three applications: a) one at sowing and two cover applications; b) when the crop was at the V4 stage; and, c) at the V8 stage of development.

Meteorological data were collected by an automatic station installed near the experimental field. The devices were a datalogger (model CR1000), air temperature and relative moisture sensor (model CS215), barometer sensor (model

Table 1. Chemical analysis of soil samples (layer 0 to 0.20 m) from the experimental field.

Sample	pH	P	K	Ca+Mg	Ca	Mg	Al	H	H+Al	S	CTC	V	M.O
	H_2O	mg dm^{-3}				cmolc dm^{-3}					cmolc dm^{-3}	%	g dm^3
1	5.90	3.60	51.00	3.71	2.30	1.41	0.00	4.50	4.50	3.80	8.30	46.00	35.00
2	5.90	1.80	58.00	3.27	2.02	1.25	0.00	4.25	4.25	3.40	7.70	44.60	38.00
3	6.00	2.50	71.00	4.32	2.61	1.71	0.00	4.50	4.50	4.50	9.00	50.00	43.00
4	6.20	2.50	81.00	3.10	2.01	1.09	0.00	4.00	4.00	3.30	7.30	45.30	30.00

CS106), pyranometer (model CMP3), anemometer (model 03002-R.M) and pluviometer (model CS700), all of them by Campbell Scientific Inc. The leaf moisture content was measured by a sensor model 237-L (Campbell Scientific Inc.). The collected data was recorded and processed at the Laboratory of Agrometeorology of the Agro-environmental Study, Research and Development Center (CEPEDA).

The field experiment was developed in the 2015/2016 agricultural year. The factorial design was completely randomized blocks with four replicates. The factor one was maize sowing dates and the factor two was supplementary irrigation. After the soybean harvest, the sowing dates were 01/27/2017 (D1), 02/09/2016 (D2), 02/25/2016 (D3) and 03/11/2016 (D4). The maize hybrid used was AG 7088 (Agroceres), with a crop population of 60,000 plants per hectare, and spacing at planting of 0.45 m between rows. Two irrigation levels were adopted, one of them without irrigation, and the other with supplementary irrigation.

The daily irrigation water needed for maize was determined by the Penman-Monteith's method (Allen et al., 1998), assuming a depth of 130% of the reference evapotranspiration. Data from the local meteorological station were used to calculate irrigation depth, adopting as the initial day the sowing date (Eq. 1), where D is the irrigation depth (mm d^{-1}), ETo is the reference evapotranspiration (mm d^{-1}) and CP is the accumulated rainfall (mm d^{-1}).

$$D = (1.3 \text{ x } ETo) - CP \tag{1}$$

A sprinkler irrigation system (12 x 12 m) was assembled with A232 ECO devices (Fabrimar® brand), at 300 kPa pressure, and the Christiansen Uniformity Coefficient was equal to 0.87 (Figure 1).

There were six cultivated rows (spacing 0.45 m) for each plot. The plot dimensions were 2.7 (width) per 12 m (length). Along its perimeter, an extra board was placed to exclude some possible effects from irrigation factor. Besides, border strips were allocated, totaling an experimental area of 1,036.8 m^2. The whole plant protection process against pests and diseases was performed. Details about dates, rates and application method are available in Barbieri (2017).

Aiming a full maize development, specific harvest dates for the sowing dates D1, D2, D3 and D4 were assigned as follows: 05/23/2016, 06/10/2016, 06/18/2016 and 07/05/2016, respectively. Plants from the two central rows from each plot were collected for evaluation of maize agronomic characteristics. Plant height, stem diameter, number of rows per ear, number of grains per row, number of grains per cob, mass of grains per plant, mass of 1,000 grains, and yield were measured. After manual threshing, the grains were subjected to forced air circulation for 48 h at 55 ºC, and

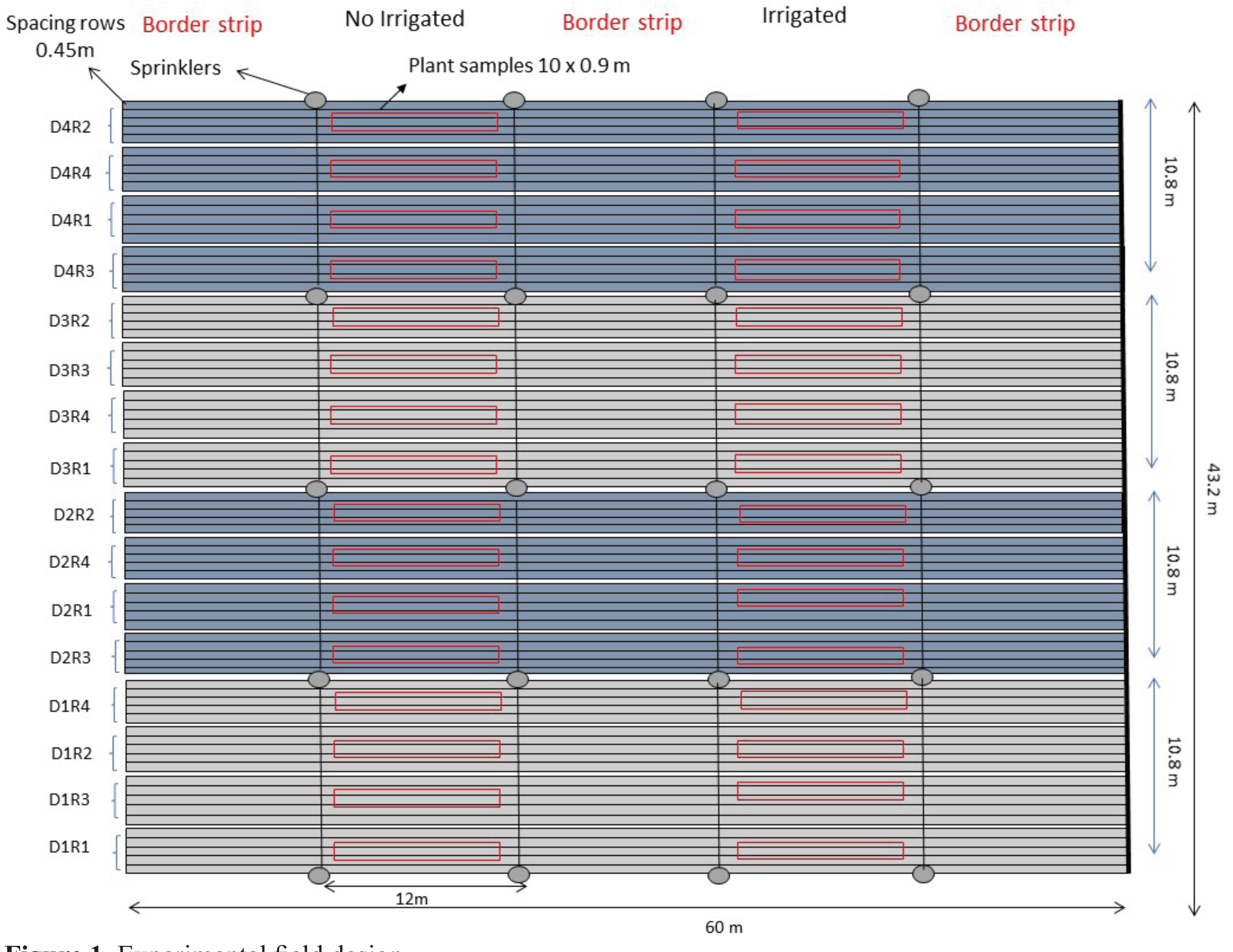

Figure 1. Experimental field design

the grain moisture was corrected to 12%. Degree-days for physiological maturity were calculated from plant emergence by Equations 2 and 3, where GD is degree-days (°C), Tmax is the maximum air temperature (°C), Tmin is the minimum air temperature (°C), Tb is the plant basal temperature lower than 10 °C, and Tm is the plant basal temperature higher than 30 °C.

$$GD = \sum_{i=1}^{N}\left[\frac{(\mathrm{Tm}+\mathrm{Tb})}{2} - \mathrm{Tb}\right] \; (\text{if Tmax} > Tm \text{ and } Tb > Tmin) \quad (2)$$

$$GD = \sum_{i=1}^{N}\left[\frac{(\mathrm{Tmax}+\mathrm{Tb})}{2} - \mathrm{Tb}\right] \; (\text{if Tm} > Tmax \text{ and } Tb > Tmin) \quad (3)$$

The analysis of variance (ANOVA) was applied to determine the effects of the factors on the measured variables. For significant cases ($p<0.05$), a Tukey test was conducted to compare factor levels. Calculations procedures were carried out using the ASSISTAT 7.7 (Silva & Azevedo, 2016) software.

Results and Discussion

According to meteorological data for the third ten-day period (beginning of sowing), the accumulate rainfall was 111.0 mm; following, at the fourth and fifth ten-day period, the accumulate rainfall decreased to 43.0 and 48.0 mm, respectively (Figure 2). Thus, there is a lack of rainfall for the last two periods, and supplementary irrigation was demanded.

The maize crop production cycle demands approximately 650.0 mm of water for an early variety (Bergamaschi et al., 2004). The total rainfall for the sowing dates D1, D2, D3, and D4 was 552.5, 407.7, 324.4 and 164.6 mm, thus demanding supplementary irrigation of 210.0, 348.0, 448.0, and 558.0 mm, respectively. The maize water balance estimative for Sorriso-MT (around 370 km away) is 808 mm according to the Penman-Montheith reference evapotranspiration method (Sobenko et al., 2016). Thus, for maize crop in second season there is a need of supplementary irrigation for a normal maize development. Otherwise, it may decrease maize yield, particularly at the eighth period of ten days (Farinelli et al., 2003).

Besides rainfall, maize yield potential demands a specific thermal energy level (growing degree-days). For an early variety, the value is between 831.0 and 890 °C degree-days (Fancelli & Dourado Neto, 2000; Stewart et al., 2003; Storck et al., 2009). For the sowing dates D1, D2, D3 and D4, GDD (growing degree-days) values were 1,934.0, 1,886.0, 1,764.0, and 1,663.0 °C, respectively.

These values are similar to those found by Dourado Neto et al. (2003), with GDD values between 1,700 and 1,800 °C for an early maize variety, and the base temperature was 10 °C. Regarding only the GDD values found, for all sowing dates evaluated, there is no impediment for a full early variety maize development.

Comparing maize phenology stages among sowing dates, there is a smooth variation under supplementary irrigation conditions. However, by comparing supplementary irrigation conditions with no supplementary irrigation, specifically for D3 and D4, the difference of maize phenology stages increases (Figure 3).

Regarding only absence of supplementary irrigation for the sowing dates D1 and D2, the water content available in soil from rainfalls is enough for a normal crop development. The opposite situation happened for the sowing dates D3 and D4, where the maize phenology stage R7 decreased at 19 and 24 days, respectively, in relation to sowing with irrigation.

For this region, the sowing dates D3 and D4 are critical months to maize sowing, since rainfall levels decrease on June and July (Dallacort et al., 2011). According to Wagner et al. (2013), water deficit may reduce the maize crop cycle, especially at the reproductive stage, decreasing maize yield. Thus, confirming the results found by Dallacort et al. (2011), the delay in maize sowing increases the risks to obtain a low maize yield.

Sequential water balance results, for no additional irrigation, showed an accumulated water deficit of 128.0 and 181.0 mm for the sowing dates D1 and D2, respectively (Figure 3). For those sowing dates, the rainfall shortage reached the R4-R7 stages for both sowing dates, and it did not affect yield. For the sowing dates D3 and D4, the accumulated water deficits were 193.0 and 234.0 mm, respectively, and reached the maize reproductive phenology stage. This may decrease the number of grains per row and, therefore, yield (Bergamaschi & Matzenauer, 2014). Thus, sequential water balance and irrigation are tools to assist sowing dates planning (Fenner et al., 2014).

Note that the water balance behavior for the region is optimum to provide conditions for early maize variety cultivation. Results similar to those obtained by Nied et al. (2005) showed that the early maize variety is feasible to late sowing, decreasing losses risks by rainfall shortage.

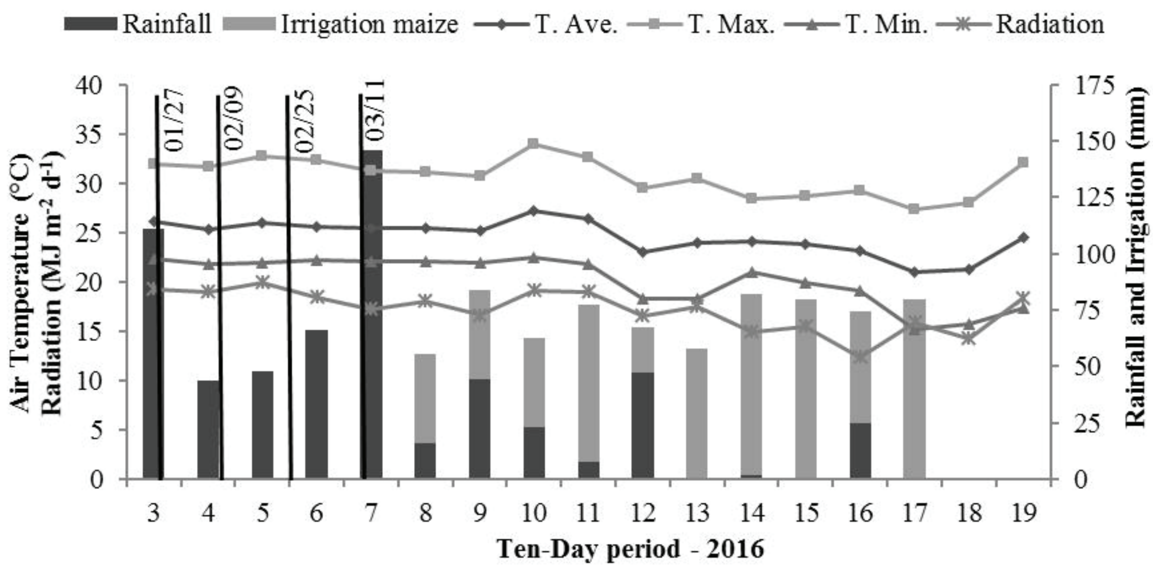

Figure 2. Ten-day period with measured rainfall; irrigation; average (T. Ave.), maximum (T. Max.) and minimum (T. Min.) air temperatures; and solar radiation throughout the experimental period, Tangará da Serra–MT.

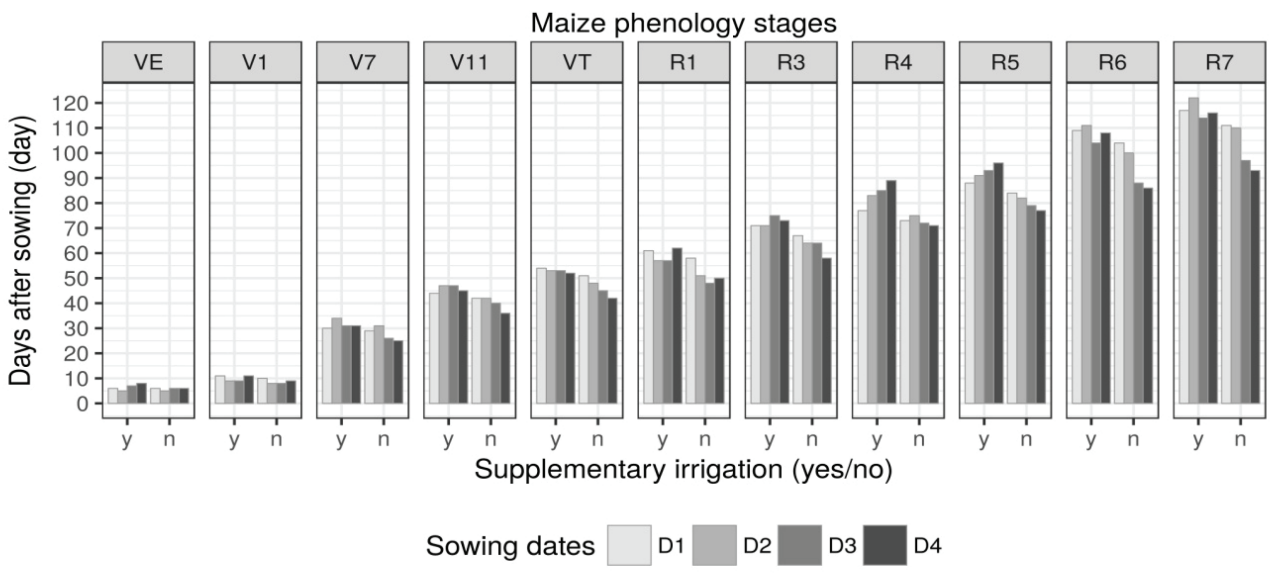

Figure 3. Maize phenology stages in DAS (days after sowing) for sowing dates, Tangará da Serra-MT.

The analysis of variance indicated an interaction between irrigation and sowing dates (Table 2). There was a statistically significant effect of irrigation levels and sowing dates on plant height, stem diameter, number of rows per ear, number of grains per row, mass of 1,000 grains and yield.

By analyzing the irrigation's effects, the maize agronomic characteristics plant height, stem diameter, number of rows per ear and number of grains per row were harmed at the sowing dates D2 or D4 (Table 3).

The critical period was the sowing date D2, between the fourth and the fifth ten-day period (Figure 1). Short mini-droughts ("Indian summer") happened, causing inhibition of plant growing, especially over the initial development without irrigation. Results from the sowing date D3 were equal or greater than the sowing date D2. This was because of water availability from rainfalls between the sixth and seventh ten-day period, which accumulated 200 mm water depth. About the sowing date D4, there was a negative water balance from the 31st day (Figure 4), which affected the crop.

An overall view show that the later the sowing date, the greater the tendency to decrease the growing and development of plant, especially without irrigation. This was because other climate variables (temperature, relative air humidity, degree-days) may change along the year, compromising the plant development. Köpp et al. (2015) observed similar results for the maize initial development stage.

By comparing the sowing dates D1 and D3, there is no significant difference for number of grains per row. If we do not consider the short mini-droughts ("Indian summers") affecting the sowing date D2, we would have not found a significant difference between three of the four sowing dates. Thus, the critical period to start the maize farming was the sowing date D4. In that period, water shortage may affect the formation and fecundation of potential ovules at the V14 and R1 stages, respectively (Ritchie et al., 2003). A consequence from the low number of grains per row is a decreasing yield (Table 4).

The reduction in the number of grains per ear at D1 and D2 for the irrigated environment occurred due to the high frequency of rainfalls during the fertilization phase associated with irrigation, which consequently caused a loss of pollen by reducing the fertilization of the female flower. Irrigation was performed in the morning, and rainfall occurred in the afternoon. Silva et al. (2010) pointed out that the greatest effect of this deficit is reflected in the formation of the grain, not in the number of grains, since the process of filling the grains depends on water availability.

Along the sowing dates, the number of grains per cob decreased. For the sowing date D2, there was an extra decrease because of the short mini-droughts ("Indian summers"). On another hand, on the sowing date D2, the mass of 1,000 grains was greater than all other sowing dates. The low fecundation on the sowing date D2 reduced the number of grains per row. It provided more free space and energy available to the development of grains, resulting in more mass per grain (Ritchie et al., 2003).

A product from the number of grains per row and mass of 1,000 grains, the greater yield was obtained for the sowing date D1, followed by D2, D3 and D4. Note that for the sowing date D2, although a less relevant maize agronomic characteristic (Table 3), the ratio between mass of 1,000 grains and number of grains per cob was greater than D3 and D4, providing a higher yield. Therefore, postponing the sowing dates provides a tendency to decrease the

Table 2. Mean square values obtained by analysis of variance (ANOVA), results and coefficient of variation for plant height (HP), stem diameter (SD), number of rows per ear (NR), number of grains per row (NKR), number of grains per ear (NGC), mass of 1,000 grains (MTG) and yield (YD) in relation to the interaction between irrigation levels and sowing dates.

SV	DF	HP	SD	NR	NGR	NGC	MTG	YD
Block	3	0.013	0.006	0.641	0.324	325.708	250.742	102455.610
Irrig (I)	1	0.006	0.188	6.771	11.437	15,110.274	147,466.265	9,200,096.590
Ep (E)	3	0.321	1.172	3.091	119.687	271,998.192	117,269.566	33,120,861.741
I*E	3	0.036	0.186	7.176	15.471	61,902.736	27,181.173	8,719,937.126
Res.	23	0.002	0.006	0.698	2.227	552.968	149.604	67,244.186
F value		19.47**	31.77**	10.27**	6.94**	111.94**	181.69**	129.67**
CV (%)		2.13	3.27	4.91	4.61	5.16	3.07	4.87

ns No significant; * Significant at 5% probability by Tukey-test; ** Significant at 1% probability by Tukey-test

Table 3. Averages for plant height (HP), stem diameter (SD), number of rows per ear (NR) and number of grains per row (NKR) under irrigation and no irrigation systems at four sowing dates.

	D1	D2	D3	D4
Plant height(m)				
No Irrigation	2.19 aA	1.90 aC	2.04 bB	1.93 bC
With Irrigation	2.12 bA	1.88 aC	2.08 aAB	2.04 aB
msd for column = 0.035		msd for row = 0.046		
Stem diameter(cm)				
No Irrigation	2.63 aA	1.92 bD	2.42 aB	2.21 bC
With Irrigation	2.59 aA	2.25 aC	2.39 aB	2.30 aC
msd for column = 0.100		msd for row = 0.091		
Number of row per ear				
No Irrigation	17.26 aA	15.53 bB	17.10 aA	17.10 aA
With Irrigation	17.53 aAB	17.63 aA	17.30 aAB	16.66 aB
msd for column = 0.680		msd for row = 0.899		
Number of grains per row				
No Irrigation	34.33 aA	29.28 bB	34.95 aA	29.58 bB
With Irrigation	33.52 aA	31.25 aB	34.36 aA	31.77 aB
msd for column = 1.215		msd for row = 1.605		

Means followed by different lower case letters in the same column and upper case in the same row are different (Significant at 5% probability by Tukey-test).

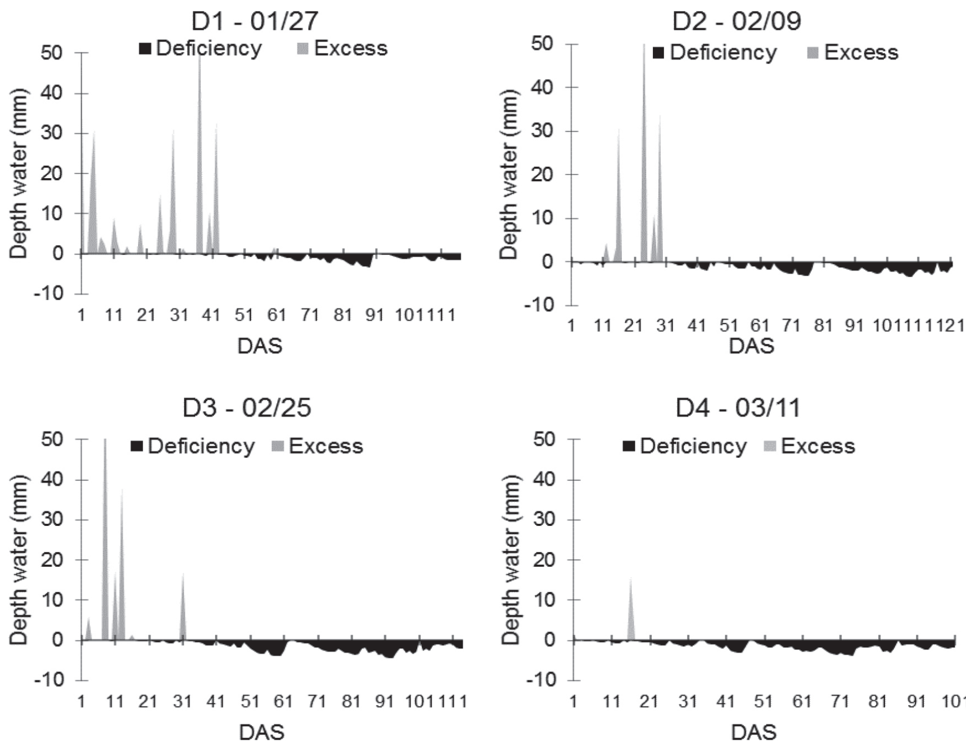

Figure 4. Sequential water balance for DAS (days after sowing) in an experimental field, Tangará da Serra-MT.

Table 4. Averages for number of grains per cob, mass of 1,000 grains and yield with or without irrigation, and four sowing dates (D1 – 01/27; D2 – 02/09; D3 – 02/25 and D4 – 03/11).

Number of grains per cob

	D1	D2	D3	D4
No Irrigation	662.86 aA	435.33 aC	466.26 bB	308.67 bD
With Irrigation	528.93 bA	354.50 bD	488.40 aB	400.92 aC
msd for column = 19.157		msd for row = 25.299		

Mass of 1,000 grains (g)

	D1	D2	D3	D4
No Irrigation	370.43 bB	412.25bA	318.66 bD	333.39 bC
With Irrigation	399.04 aC	580.20 aA	343.24 aD	425.79 aB
msd for column = 9.964		msd for row = 13.159		

Yield (kg ha^{-1})

	D1	D2	D3	D4
No Irrigation	6,309.50 bA	5,272.53 bB	4,440.61 bC	3,103.11 bD
With Irrigation	7,237.81 aA	6,159.22 aB	4,966.67 aC	5,095.24 aC
msd for column = 211.261		msd for row = 278.991		

Means followed by different lower case letters in the same column and upper case in the same row are different (Significant at 5% probability by Tukey-test).

yield, because of the lower water balance and possible stresses.

As occurred with supplementary irrigation, the yield was lower in the sowing dates D3 and D4 than in the sowing dates D1 and D2. This was a consequence of temperature decrease along the period. It may decrease the photosynthetic process of the crop, and consequently, affect the yield (Nied et al., 2005; Wagner et al., 2013; Bergamaschi & Matzenauer, 2014; Pinotti et al., 2014; Bao et al., 2015).

In an irrigated system, productivity was higher in all seasons, taking into account the water requirement of the crop during the grain filling phase, which is the period with the greatest water demand of the crop. According to Bergamaschi and Matzenauer (2014), at this stage the crop requires approximately 300 mm of water. In many cases, growers using irrigation in the maize crop discontinue irrigation at the R5 phase, causing a water deficit in plants and the loss of water from the grains to the plant before physiological maturity.

The maize sensibility to water shortage in a second season, especially in the reproductive stage, is clear. Thus, an irrigation system, such as a supplementary source of water, is helpful and may increase yield. These results are similar to those found by Bergamaschi et al. (2004, 2006) and Wagner et al. (2013).

Conclusions

In this study, greater maize yields of 7,237.81 kg ha^{-1} were found for the sowing date D1 (01/27).

At the sowing date D2 (02/09), there was water deficit during the initial period. It decreased the number of grains per cob. Despite the increase in mass of 1,000 grains, yield was affected.

The effects of supplementary irrigation were positive for all sowing dates (D1, D2, D3 and D4), and increased maize yield by 12.8, 14.4, 10.6 and 39.9%, respectively.

Supplementary irrigation management may avoid losses in maize yield by water stress during dry periods. It may supply the water needs of the crop, especially during critical stages, avoiding reductions in maize yield by up to 2,000 kg ha^{-1}.

Irrigation ensures that early sowing results in high yields with less volume of water per irrigation.

Acknowledgements

The authors would like to thank CAPES for the Master's Degree grant to the first author, and APROSOJA for the financial support.

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