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EFFECT OF WATER SUPPLY AND SOWING DATES ON CORN YIELD OF HYBRIDS GROWN DURING OFFSEASON

Denise N. Fabris[1], Eder P. Gomes[1], Cesar J. da Silva[2], Danilton L. Flumignan[2], Kamila de A. M. Mello[1*], Arthur C. Sanches[1]

[1*]Corresponding author. Universidade Federal da Grande Dourados/Dourados - MS, Brasil.
E-mail: kamilamonaco@ufgd.edu.br | ORCID ID: https://orcid.org/0000-0002-6118-2640

KEYWORDS

Zea mays L., irrigation, genotype, offseason, yield.

ABSTRACT

This study aimed to evaluate the effect of water supply and sowing time on yield and yield components of two corn hybrids grown during offseason in the region of Dourados-MS, Brazil. The experimental design was randomized blocks in sub-divided plots, with four replications. In the main plot, two sowing dates were defined (2013 crop year: February 27 and March 27; and 2014 crop year: March 18 and April 5). In subplots, irrigation management systems were defined (irrigated and rainfed). Hybrids AS 1555 and AS 1590 were grown in the sub-plots. The parameters evaluated were plant height, ear insertion height, stem diameter, ear length and diameter, 100-grain weight, and grain yield. Regardless of irrigation and hybrid used, sowing time significantly affected corn yield, which responded to climate changes throughout crop cycle. Water supply increased corn yield, with the highest value being of 9338 kg ha^{-1} (156 bags ha^{-1}) and obtained when irrigated AS 1555 hybrid was sown on February 27, 2013.

INTRODUCTION

Technological evolution in corn production during the last decade, second crop (off-season), has been responsible for a 45% increase in Brazilian crop yield, with current national average productivity of 5700 kg ha^{-1} (Ferreira & Capitani, 2017). Corn is grown in all Brazilian regions in intercropping, rotation, succession, and integration systems, with yield expectations for the next decade between 121.4 and 182.7 million tons (Gasques et al., 2018; Contini et al., 2019).

However, offseason corn yields have gradually increased but discontinuously, which is due to droughts or frosts that occurred in some years (Nascimento et al., 2018; Comas et al., 2019). As offseason corn cultivation is predominant in Brazil and late sowing is common due to delays in sowing and/or soybean harvest, a strategy to face long temperature restriction periods is the use of super-early hybrids with low thermal demand (Silva et al., 2014; Ceccon, 2018).

The Midwest of Brazil accounts for 40% of national corn production, with the state of Mato Grosso do Sul being the second-largest producer, especially the region of Grande Dourados, where it is grown mostly under rainfed conditions (Almeida et al., 2017). However, droughts in this region during sowing or ear formation have caused high corn yield losses in corn grown in offseason, making water supply suitable and advisable to reach its productive potential (Oliveira et al., 2012; Ben et al., 2016; Comas et al., 2019 e Silva et al., 2019).

According to Zucareli et al. (2013). Li & Sun (2016), and Zhang et al. (2019), water stress can interfere with corn growth, development, and physiological processes, which can reduce biomass and hence grain yield. However, in case of extremely late sowing, at the limit or after climatic zoning (Costa et al., 2017; Passos et al., 2018; Simão et al., 2018), irrigation may not be able to mitigate the negative effect of low thermal sum on yield.

Corn crops may also be extremely affected by adverse changes in temperature, that is, sudden and continuous reductions, with very low and sequential temperatures can be extremely harmful to corn sowing,

[1] Universidade Federal da Grande Dourados/Dourados - MS, Brasil.
[2] Empresa Brasileira de Pesquisa Agropecuária, Embrapa Agropecuária Oeste/Dourados - MS, Brasil.

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development, and harvest in offseason, impacting much more than rainfall (Nascimento et al., 2018).

Considering the hypothesis that irrigation can attenuate late sowing of offseason corn (second crop), partially compensating for a low thermal sum, our goal was to evaluate the effects of water supply and sowing times on production components and yield of two corn hybrids grown in the offseason in region of Dourados-MS, Brazil.

MATERIAL AND METHODS

The experiment was carried out in the experimental irrigation unit of the College of Agricultural Sciences, Federal University of Grande Dourados, in the city of Dourados, which is located in the southern Mato Grosso do Sul State. It lies at the geographic coordinates: 22° 11' 45” S, 54° 55' 18” W, and 446-m altitude, in the second harvest of the crop years of 2013 and 2014.

According to the Köppen climate classification, the region has a Cwa-type climate, which stands for humid mesothermal, with hot summers and dry winters (Fietz et al., 2017). The temperature during the coldest month is below 18°C and in the hottest month above 22°C. Average annual rainfall ranges from 1,250 mm to 1,500 mm.

The soil in the region is classified as a dystrophic Red Latosol, very clayey, of high depth, very porous, and permeable (EMBRAPA, 2018). Table 1 shows the main soil chemical properties within the 0.00-0.20 m depth layer.

TABLE 1. Soil chemical analysis of experimental area in a depth layer of 0.00 - 0.20 m.

Crop year	pH	P	K	Ca	Mg	H+Al	Al	CEC	BS
	$CaCl_2$	$mg.dm^{-3}$	$cmol_c.dm^{-3}$						(%)
2013	4.79	12.64	0.48	4.31	1.64	6.72	0.23	13.15	48.00
2014	5.13	14.32	0.67	5.18	2.13	5.58	0.05	13.57	58.89

H+Al - potential acidity, SB - sum of bases, CEC - cation exchange capacity, BS% - base saturation. Source: Laboratory of Soil Analysis of the EMBRAPA Agropecuária Oeste.

Meteorological data of the experimental period were acquired from the automatic agrometeorological station of EMBRAPA Agropecuária Oeste located in the municipality (Table 2).

TABLE 2. Accumulated data for rainfall (mm), degrees days, global radiation (MJ m^{-2} day^{-1}), irrigation depth (mm), number of rain events (nº), and photoperiod average (h day^{-1}) in the stages/ periods of the crop years 2013 (February 27 [02/27] and March 27 [03/27]) and 2014 (March 18 [03/18] and April 5 [04/05]).

Crop year of 2013													
Stage	Period	Rainfall		Degrees Day		Global Radiation		Photoperiod		Irrigation Depth		n° of events	
		02/27	03/27	02/27	03/27	02/27	03/27	02/27	03/27	02/27	03/27	02/27	03/27
Initial	0-15	79	134	266	199	400	212	12.31	11.69	55	0	3	0
Growth	16-50	430	84	441	383	571	592	11.76	11.19	104	219	5	9
Reproduction	51-100	84	214	555	492	724	528	10.97	10.7	270	182	11	11
Final	101-130*	165	27	181	207	178	359	10.65	10.81	32	216	2	8
Total		758	459	1443	1281	1873	1691	11.42	11.1	461	617	21	28
Crop year of 2014													
Stage	Period	Rainfall		Degrees Day		Global Radiation		Photoperiod		Irrigation Depth		n° of events	
		03/18	04/05	03/18	04/05	03/18	04/05	03/18	04/05	03/18	04/05	03/18	04/05
Initial	0-15	34	52	218	194	264	189	11.89	11.50	21	0	1	0
Growth	16-50	114	132	433	368	498	472	11.37	11.04	16	50	1	4
Reproduction	51-100	103	81	488	458	629	594	10.76	10.68	156	169	5	7
Final	101-130*	72	75	208	371	297	518	10.73	11.03	29	190	1	10
Total		323	340	1347	1392	1688	1773	11.19	11.06	222	409	8	21

*final stage varies according to sowing time.

The experimental design used was randomized blocks, arranged in sub-divided plots, with four replications per treatment. In the main plots, sowing dates were defined, which were February 27 and March 27 for the 2013 crop year and March 18 and April 05 for the 2014 crop year. Sowing date should have been the same in both crop years, but due to rains at the end of February and beginning of March in 2014, sowing date was delayed that year. In the subplots, irrigation management systems were assigned, which were (I) irrigated and (NI) non-irrigated. In the sub-subplots, two high-tech transgenic hybrids of rapid grain moisture loss were evaluated, namely: a simple hybrid with an early cycle, with a thermal requirement of 820 degrees days (GD), recommended for main and second-season sowings, and with an average resistance to lodging (AS 1555) and a triple hybrid with an extremely early cycle, with a thermal requirement of 800 GD, recommended for the second season and with high resistance to lodging (AS 1590).

Sub-subplot dimensions were 5 x 4.5 m (22.5 m^2), with five sowing rows spaced 0.90 m apart and plants spaced 0.17 m apart. The three central lines were considered as useful area of each sub-subplot, discarding 1 m from each end, obtaining 8.1 m^2 of useful area (3 m x 2.7 m), considering the remainder as borders. The sub-subplots were 0.90 m apart from each other.

Irrigation consisted of five dripper lines per plot, installed between plant rows. It was managed using tensiometers installed at 0.20-m depth. Soil water tension readings were performed on Mondays, Wednesdays, and Fridays, with a fixed irrigation shift.

Irrigation depth (ID) was determined as the difference between volumetric moisture at field capacity (ϴcc) and current volumetric moisture (ϴa), multiplied by effective root depth (Z), equal to 400 mm.

The values of ϴa were estimated using the soil water retention curve, adjusted by the Van Genuchten equation (1980):

$$\theta a = 0.200 + \left[\frac{(0.589 - 0.200)}{[1+(0.5485\ \sigma_a)^{19.322}]^{0.026}}\right];\ (R^2 = 0.99 \text{ and } P < 0.01) \quad (1)$$

Where:

Θ_a = current volumetric moisture ($cm^3\ cm^{-3}$),

σ_a = current soil water tension (kPa).

Irrigation time (IT) in each event was obtained as the ratio between irrigated depth (ID) and application intensity (AI). The latter was determined on site, obtaining a value of 6.1 mm h^{-1}.

At female flowering, ten plants per sub-subplot were determined, with the aid of a graduated ruler, for plant height (PH) and ear insertion height (EIH), measuring the distance between soil level and insertion point of the flag leaf and, subsequently, that between soil level and insertion of the first ear. Then, stem diameter (SD) was determined near the ground level using a digital caliper.

Biometric production data were obtained after manually harvesting 40 ears from the useful area of each plot, randomly separating 10 ears. Ear length (EL) and diameter (ED) were measured with the aid of a digital caliper, and average for each plot was subsequently calculated.

Grain yield (GY) and 100-grain weight (100-GW) were obtained from 40 ears collected. After weighing grain mass and 100-GW, grain moisture was determined, which was corrected to 13%. Then, total grain mass was multiplied by the final stand, obtaining grain yield in kg ha^{-1}. The data obtained were subjected to analysis of variance, and means compared by the Tukey's test at 5% probability, using the SISVAR statistical software (Ferreira, 2019).

The increment was used to compare the evaluated variables of irrigated plants with rainfed ones using the following formula:

$$Inc = \left(\frac{Pir * 100}{Prf}\right) - 100 \quad (2)$$

Where:

Inc = Increase observed in the variables from irrigated plants to rainfed ones, in percentage (%);

Pir = Mean of the analyzed variable in irrigated plants,

Prf = Mean of the variable analyzed in rainfed plants.

RESULTS AND DISCUSSION

Table 3 shows the averages of plant height (PH), ear insertion height (EIH), and stem diameter (SD) in corn plants sown on February 27 (Feb/27) and March 27 (27/Mar) for the 2013 crop year, and on March 18 (Mar 18) and April 5 (Apr 05) for the 2014 crop year, and their respective increments compared to the control.

As for PH in the 2013 crop year, significant differences between irrigated and rainfed plants were observed in March sowing only for the hybrid A1555. The plants had an average height of 170.88 cm, which corresponds to a 17% increase compared to rainfed plants. It was also observed that PH of the hybrids were higher in irrigated plants in the first crop year, with the highest PH found for the hybrid A1555 (198.50 cm), which represents an increase of 5.3% in relation to the same hybrid grown in rainfed conditions. According to Aydinsakir et al. (2013) and Li & Sun (2016), water stress can interfere with growth, development, and physiological processes of corn plants, which can reduce biomass and, consequently, grain yields.

In the 2014 crop year, significant differences in PH were observed between irrigated and rainfed plants only for the AS1590 hybrid in the first season. The irrigated plants had a height of 183.88 cm, which corresponds to an increase of 13.33% in relation to rainfed plants. Almeida et al. (2017) studied crop yield and water-use efficiency in corn grown under different water management strategies and observed that plant height, dry matter and ear mass were also higher for irrigated crops.

Hybrid heights were higher in the first season, with the highest being found in the hybrid AS1555 (184.69 cm) and a small increase compared to rainfed plants (2.5%). The greatest height expressed is still smaller than the potential height of the hybrid, which can vary from 210 to 230 cm. According to Souza & Barbosa (2015), high irradiation levels and air temperatures accentuate plant transpiration, while hot nights increase plant respiration, increasing consumption of photoassimilates consumed with respiration, which may impair plant growth. Similar results were observed by Alves et al. (2013) and Zucareli et al. (2013) who evaluated the performance of corn genotypes with low thermal sum and observed variations of up to 22% in plant height depending on water deficit time.

Still, Almeida et al. (2017), when studying corn yield and water-use efficiency under different water management systems, observed that plant height, dry matter, and ear mass are also higher in irrigated crops. This is consistent with Comas et al. (2019), who recommended, in situations of severe water deficit, irrigation during the end of vegetative stage to mitigate the effects of water scarcity on crop production.

Regarding ear insertion height in the 2013 crop year (Table 3), statistically significant differences were observed only in the offseason. The hybrid A1555 showed the highest ear insertion height when irrigated, representing a 26.59% increase compared to the same hybrid under rainfed conditions. When comparing sowing times, statistical differences were observed only in the hybrids grown under rainfed conditions, with those sown in February having the highest ear insertion heights, with emphasis on hybrid

A1555 (85.88 cm). Silva et al. (2012) assessed the influence of irrigation on the corn hybrid AG 5020, with an early cycle, sown in February, in the state of São Paulo, observed a 35% increase in ear insertion height, which was higher than those of the present study.

In the 2014 crop year, no statistical differences were observed for ear insertion height between hybrids grown in rainfed and irrigated conditions. Statistical differences were observed only for sowing times, with plants sown in March having the highest heights. The hybrid AS1590 showed the highest average ear insertion height (80.31 cm) in irrigated plants, which provided an increase of 12.32% when compared to the same hybrid grown in rainfed conditions. This more pronounced effect evidences the interference of climatic factors with plant development since the April sowing was outside the agricultural zoning of climatic risk for the region of Dourados-MS, Brazil.

According to Simão et al. (2018), the lower plant and ear insertion heights in the second sowing of 2013 may be due to the beginning of the dry period when the crop was at vegetative stage. This result is because water deficiency at this phase reduces corn growth rate.

When comparing water supply systems, average stem diameters in the 2013 crop year (Table 3) were statistical different only in the offseason, in which irrigated plants sown in March had the highest average (2.30 cm) in the hybrid AS1590. When irrigated, this hybrid had an increase of 33.72% in stem diameter when compared to rainfed conditions. However, the hybrid AS 1555 (2.27 cm) was showed the greatest increase (37%) when irrigated compared rainfed (1.66 cm). Such results are superior to those of Silva et al. (2012), Hernándes et al. (2009), and Schlichting et al. (2014), who observed increases of 22%, 15%, and 11%, respectively. When comparing sowing dates, no statistical differences were observed. In the 2014 crop year, when comparing plants grown in an irrigated or rainfed system, statistical differences were observed only for the hybrid AS1555 sown in March, in which irrigation increased average diameter (1.96 cm) by 10.11% compared to rainfed conditions. Still, when comparing sowing dates, the hybrids sown in March had the highest average stem diameters, in which the hybrid AS1590 reached the highest average (2.01 cm) and an increase of 5.24% compared to rainfed system. Therefore, the greater the stem diameter, the greater the probability of benefiting crop agronomic characteristics, as stems are structures of reserve, storage, and translocation of photo-assimilates to grains, thus increasing corn yield (Soratto et al., 2010).

Irrigation had a more pronounced effect in the offseason of the 2013 crop year (Table 3). This effect is due to low rainfall at crop growth phase (Table 2), influencing plant development. Therefore, nine irrigation events were necessary, corresponding to a total irrigation depth of 219 mm in the period (Table 2). According to Zhang et al. (2019), irrigation is decisive during the growth phase, mitigating crop water scarcity, thus maintaining corn production sustainability (Comas et al., 2019).

TABLE 3. Averages of plant height, ear insertion height, and stem diameter in the seasons of February 27 (02/27) and March 27 (03/27) for the 2013 crop year, and in the seasons of March 18 (03/18) and April 5 (04/05) for the 2014 crop year.

	Crop year of 2013				Crop year of 2014			
	Plant height (cm)							
System	02/27		03/27		03/18		04/05	
	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555
Irrigated	187.50 a A 1	198.50 a A 1	155.38 a A 2	170.88 a A 2	183.88 a A 1*	184.69 a A 1*	140.00 a A 2	144.69 a A 2
Rainfed	181.13 a A 1*	188.50 a A 1*	136.25 a A 2	146.00 b A 2	162.25 b B 1*	180.25 a A 1*	136.25 a A 2	143.81 a A 2
Inc. (%)	3.53	5.31	14.01	17.05	13.31	2.44	2.71	0.63
	CV %	System 9.12	Season 6.88	Hybrid 5.06	CV %	System 10.43	Season 9.63	Hybrid 9.48
	Ear insertion height (cm)							
System	02/27		03/27		03/18		04/05	
	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555
Irrigated	85.38 a A 1	79.38 a A 1	78.88 a A 1	85.13 a A 1	80.31 a A 1*	77.25 a A 1*	54.44 a A 2	52.88 a A 2
Rainfed	81.25 a A 1*	85.88 a A 1*	62.50 b A 2	67.25 b A 2	71.50 a A 1*	73.69 a A 1*	52.75 a A 2	53.81 a A 2
Inc. (%)	5.04	-7.57	26.24	26.45	12.31	4.88	3.03	-1.67
	CV %	System 9.11	Season 10.98	Hybrid 6.38	CV %	System 20.19	Season 19.19	Hybrid 13.97
	Stem diameter (cm)							
System	02/27		03/27		03/18		04/05	
	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555
Irrigated	2.04 a A 1	2.15 a A 1	2.30 a* A 1	2.27 a* A 1	2.01 a A 1	1.96 a* A 1*	1.85 a A 2	1.76 a A 2
Rainfed	1.99 a A 1	1.97 a A 1	1.72 b A 1	1.66 b A 1	1.91 a A 1	1.78 b A 1	1.79 a A 2	1.77 a A 1
Inc. (%)	2.51	9.14	33.72	36.75	5.25	10.11	3.35	-0.56
	CV %	System 10.44	Season 11.21	Hybrid 10.39	CV %	System 5.60	Season 7.44	Hybrid 7.24

Averages followed by the same lowercase letter in the column and uppercase in the row. The number compares sowing date averages for each hybrid in the system in each growing season. Means followed by the same letter or number do not differ from each other, according to Tukey's test at 5%, * P < 1%.

Table 4 shows the averages for ear length, ear diameter, and 100-grain mass of maize plants. Ear length was influenced by irrigation in the offseason of the 2013 crop year for both hybrids. When irrigated, the hybrid AS1590 reached the highest average ear length (13.87 cm), representing a 20.40% increase when compared to rainfed conditions. This result corroborates those of Hernándes et al. (2009), in a study on sweet corn yield under different water tensions sown in April in Mexico. These authors observed an increase of 21% in ear length when plants were under greater irrigation depths (493.6 mm).

When comparing hybrids, those sown in February had greater average ear length than those sown in March, and the irrigated AS1590 hybrid had ears with the longest average length (17.36 cm), with an increase of 5.08% compared to rainfed plants. Nascimento et al. (2011) studied yield of corn genotypes in response to sowing times in February and obtained the shortest ear lengths, therefore, sowing time is an important factor for this trait.

In the 2014 crop year, no statistical differences were observed when comparing irrigated and rainfed systems. Corn plants sown in March showed greater average ear lengths, with the AS1590 hybrid standing out with 14.73-cm ears in the irrigated system, which corresponds to an increase of 7.60% compared to rainfed conditions.

In both crop years, the first sowing dates showed higher average ear lengths, regardless of irrigation and hybrid studied. Average increases were of 23 and 15% for 2013 and 2014 crop years, respectively, when comparing the first with second sowing dates (Table 4). Such results are lower than those observed by Nascimento et al. (2011), who obtained a 35% decrease in average ear length.

TABLE 4. Average of ear length and ear diameter in the seasons of February 27 (02/27) and March 27 (03/27) for the 2013 crop year, and in the seasons of March 18 (03/18) and April 5 (04/5) for the 2014 crop year.

	Crop year of 2013				Crop year of 2014			
	Ear length (cm)							
System	02/27		03/27		03/18		04/05	
	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555
Irrigated	17.36 a A 1*	16.21 a A 1*	13.87 a A 2	13.40 a A 2	14.73 a A 1*	14.67 a A 1*	12.37 a A 2	12.06 a A 2
Rainfed	16.52 a A 1*	14.99 a A 1*	11.52 b A 2	11.11 b A 2	13.69 a A 1	13.61 a A 1*	12.15 a A 2	11.27 a A 2
Inc. (%)	5.08	8.14	20.40	20.61	7.60	7.79	1.80	7.01
	CV %	System	Season	Hybrid	CV %	System	Season	Hybrid
		6.68	9.92	3.21		7.98	9.08	6.07
	Ear diameter (cm)							
System	02/27		03/27		03/18		04/05	
	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555
Irrigated	4.71 a A 1*	4.86 a* A 1*	4.22 a A 2	4.19 a A 2	4.53 a A 1	4.61 a A 1	4.19 a A 1	4.28 a A 1
Rainfed	4.44 b A 1*	4.42 b A 1*	3.94 b A 2	4.04 a A 2	4.40 a A 1	4.53 a A 1*	4.13 a A 1	3.81 b A 2
Inc. (%)	6.08	9.95	7.11	3.71	2.95	1.77	1.45	12.34
	CV %	System	Season	Hybrid	CV %	System	Season	Hybrid
		3.22	3.45	1.93		10.37	9.49	9.12
	100-grain mass (g)							
System	02/27		03/27		03/18		04/05	
	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555	AS 1590	AS 1555
Irrigated	28.01 a* A 1*	29.24 a* A 1*	20.13 a A 2	20.84 a A 2	26.37 a A 1*	26.46 a A 1	21.07 a B 2	23.66 a A 2
Rainfed	23.72 b A 1*	24.02 b A 1*	19.53 a A 2	20.42 a A 2	24.18 b A 1*	24.92 a A 1*	19.10 a A 2	20.77 b A 2
Inc. (%)	18.09	21.73	3.07	2.06	9.06	6.18	10.31	13.91
	CV %	System	Season	Hybrid	CV %	System	Season	Hybrid
		4.37	3.34	5.92		9.50	7.56	4.93

Averages followed by the same lowercase letter in the column and uppercase in the row. The number compares sowing date averages for each hybrid in the system in each growing season. Means followed by the same letter or number do not differ from each other, according to Tukey's test at 5%, * P < 1%.

In the 2013 crop year, average ear diameters differed significantly in February sowing between irrigated and rainfed plants, in both hybrids. The highest increment (9.95%) was seen for the hybrid AS 1555 (4.86 cm) comparing irrigated and rainfed conditions. In sowing in March of the same year, irrigation provided a significant difference in average ear diameter, only for the hybrid AS 1590 (4.22 cm), corresponding to an increase of 7.11% over the rainfed conditions (Table 4).

In the 2014 crop year, a statistical difference was observed between water supply systems only for the hybrid AS 1555, in which the average ear diameter was 4.28 cm, with an increase of 12.34%, from irrigated to rainfed plants (Table 4). Higher values were observed by Hernándes et al. (2009), in a study on yield of sweet corn under different water and tensions sown in April in Mexico, in which the authors obtained an average ear diameter of 5.54 cm, with an increase of 35% compared to the highest tension depth (80Kpa).

Regarding sowing times, in both crop years, plants sown in the first season (February in 2013 and March in 2014) had the highest average ear diameters. The hybrid AS 1555 stood out with the highest average ear diameters when irrigated, with diameters of 4.86 cm in 2013 and 4.61 cm in

2014, representing increments of 9.95% and 1.77% from irrigated to rainfed in the 2013 and 2014 crop years, respectively.

Such results are close to those of Nascimento et al. (2011), who studied three corn genotypes in four sowing dates. The authors observed an average ear diameter of 4.58 cm with sowing in October and 3.81 cm in February, regardless of the genotype. Passos et al. (2018) studied agronomic and economic performance of sixteen corn genotypes in offseason (second crop), sown in April, in the state of Rondônia, considered the observed ear diameters to be low, in which the highest averages were for the varieties BRS Caimbé (4, 84 cm) and BRS 4103 (4.78 cm), with diameters varying by 64%, from 4.84 cm in the BRS Caimbé variety to a minimum of 2.95 cm in the popcorn variety IAC 125.

When comparing irrigated and rainfed systems, statistical differences were observed only in the first season of 2013. The hybrid AS 1555 grown in an irrigated system had the highest average 100-grain mass (29.24 g), with an increment of 21.73% from rainfed conditions. Almeida et al. (2017) also observed a lower number of grains in rainfed ears. After all, low water availability is correlated with reduced ear sizes and poor grain formation per ear, resulting in low crop productivity (Hernández et al., 2009; Silva et al., 2012; Comas et al., 2019).

When comparing sowing times, plants sown in the first season had the highest 100-grain mass in the 2013 crop year. The same trend was observed in the 2014 crop year; however, a statistical difference was observed in the hybrid AS 1590 although the hybrid AS1550 irrigated showed the highest 100-grain mass (26.46 g), with an increase of 6.18% from rainfed conditions. Similar results were reported by Nascimento et al. (2011), in a study with three corn genotypes in four sowing times in São Paulo State, which obtained a decrease of 49% for 1000-grain mass average, when comparing August (358.6 g) and February (240.8 g) sowing dates.

Figure 1 shows the average corn grain production. In both crop years, grain production differed significantly between irrigated and rainfed systems, except for the hybrid AS 1590 (3197 kg ha^{-1}), sown in April 2014, which was also the lowest yield obtained in the irrigated system (53 bags ha^{-1}). However, in the 2013 crop year, the hybrid AS 1555 showed the highest yield (9338 kg ha^{-1}) when sown in February (156 bags ha^{-1}), corresponding to an increase of 44% from rainfed conditions (Figure 1). Such values are higher than those obtained by Almeida et al. (2017) in a study in the same region (Dourados/MS), evaluating water management strategies on corn yield in the 2013/2014 crop year. These authors obtained an average yield of 8955 kg ha^{-1} (149 bags ha^{-1}) when irrigated.

In both crop years, grain yields showed differences between sowing seasons regardless of water supply system and hybrid used. In the 2013 crop year, the hybrid AS 1555 reached the largest increment (137%) when irrigated when comparing sowing in February (9338 kg ha^{-1}) and March (3931 kg ha^{-1}). Ours are consistent with the values obtained by Garcia et al. (2018), who assessed grain yield of different soybean and corn cultivars in succession, sown at different sowing times in the city of Dourados-MS. These authors found an average yield of 8141 kg ha^{-1}(136 bags ha^{-1}) for the crop years of 2013, 2014, and 2015 at sowing in mid-February. Likewise, Almeida et al. (2016) observed, in the city of Ponta Porã-MS, yields in a commercial irrigated area of about 8500 kg ha^{-1} (142 bags ha $^{-1}$).

The interaction among irrigation system, sowing time, and corn hybrid showed that irrigation reduces sowing time effects on yield, requiring greater attention to the second crop (offseason). It is because periods of greater thermal and water inputs increase yield and prove to favor sowing anticipation (Zucareli et al., 2013).

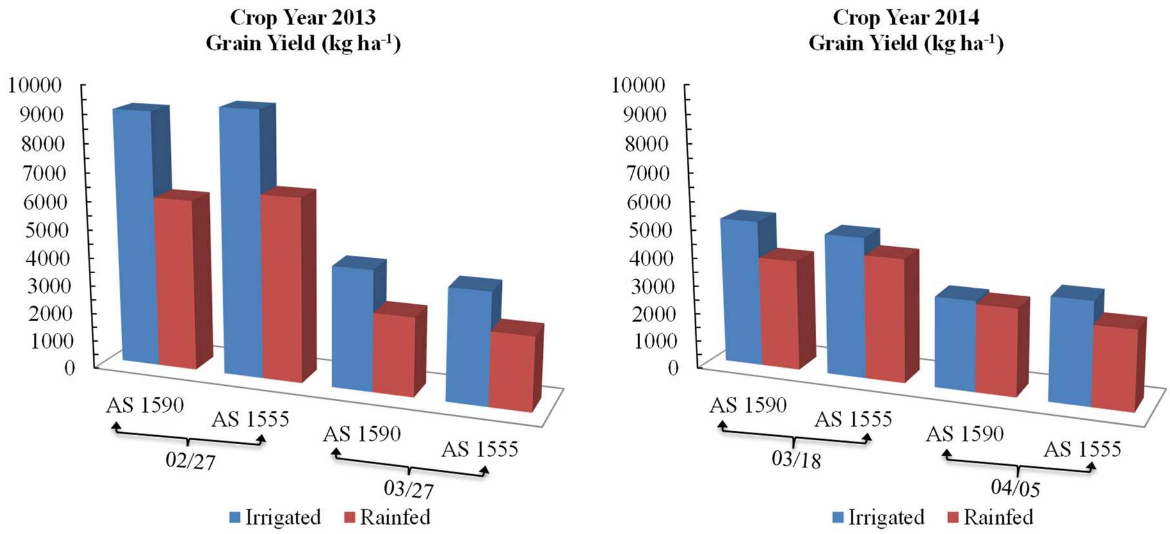

FIGURE 1. Average results for grain yield (kg ha^{-1}) for the 2013 and 2014 crop years in Dourados/MS, 2016. Means followed by the same lowercase letter compare irrigation systems and uppercase compare hybrids (AS 1590 and AS 1555), in each crop year. The number compares sowing date averages for each hybrid in the system in each growing season. Means followed by the same letter or number do not differ from each other, according to Tukey's test at 5%, * P < 1%.

When comparing sowing dates (02/27, 03/18, 03/27, and 04/5), regardless of the crop year, corn yield reduced linearly (Figure 2). Corn plants show good growth and development when environmental conditions meet their demands. Among the climatic elements that stand out the most are solar radiation, air temperature, and rainfall; these provide suitable water availability and photosynthetic rate since corn cultivation in offseason has a peculiar and distinct performance from that in the first cultivation (Bergamaschi & Matzenauer, 2014; Comunello et. al., 2018; Silva et al., 2019).

We observed an average variation of 126 kg ha^{-1} day^{-1} (Figure 2), which is 5% higher than that obtained by Shioga & Gerage (2010) when studied corn sowing times in offseason in Paraná State. These authors noted a linear effect on corn grain yield, with an average reduction of 120 kg ha^{-1} day^{-1}. Nascimento et al. (2011) also noted a decrease in corn yield as the sowing date delays, obtaining a 199% variation when comparing the highest yield, in October (5961 kg ha^{-1}), with the lowest, in February (1992 kg ha^{-1}).

After the deadline for offseason sowing (Figure 2), irrigation was unable to ensure a good productivity. It was due to the low radiation supply at that time, which, in turn, influenced temperatures as winter approached, decreasing thermal supply in May, June, and July. Such reduction lengthened the crop cycle (Table 2) and thus affected flowering and grain filling (Shioga & Gerage, 2010; Silva et al., 2019). At these stages, plants use net radiation better, therefore, these periods are the most critical for corn as the expressive reduction of this factor limits photosynthetic activities and translocation of carbohydrates from leaves and stem to grains, decreasing grain yield potential in late sowings (Nascimento et al., 2011; Rodrigues et al., 2011; Bergamaschi & Matzenauer, 2014).

Furthermore, a hybrid can be grown by estimating its number of degree days and meteorological variations, associated with plant phenological stage. The degree-days needed to complete a crop cycle were higher in both 2013 and 2014 crop years (Table 2), especially in later sowing periods, due to the low daily average temperatures in May and June, and accumulation of degrees days that induced male flowering, leading to a longer cycle (Rodrigues et al., 2011; Bergamaschi & Matzenauer, 2014). Such cycle elongation may have affected crop yield and its morphological traits.

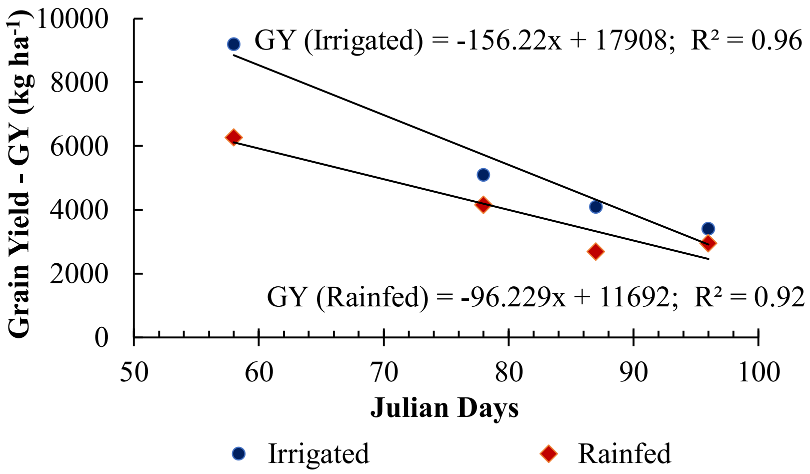

FIGURE 2. Grain yield (kg ha^{-1}) in the sowing time depicted in the Julian days (Feb 27: 58th day; Mar 18: 78th day; Mar 27: 87th day; and Apr 05: 96th day) in the city of Dourados – MS, Brazil.

CONCLUSIONS

Water supply provides an increase in corn yield. Dates from the third ten-day of February to the second ten-day of March are the most suitable for sowing corn hybrid AS 1590 (super-early) and AS 1555 (early) in the region of Dourados-MS, Brazil, due to yields obtained and gradual yield reductions on subsequent dates, as photoperiod, temperature, and radiation accumulation reduce, especially during flowering and grain filling stages.

Hybrids AS 1590 (super-early) and AS 1555 (early) do not differ from each other for most of the evaluated variables. However, the highest yield (9338 kg ha^{-1}) , which is equivalent to 156 bags ha^{-1}, was obtained in the sowing on February 27, 2013, for the hybrid AS 1555 grown under irrigated conditions.

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