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Performance of soybean cultivars under drought stress and sowing seasons in Brazilian Savannah

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ABSTRACT

Objective: Evaluate the performance of two soybean cultivars submitted to water deficit in two sowing seasons (July 10, 2019, and October 27, 2020), in Tocantinense Savannah, Brazil.

Methodology: The experiments were carried out in a greenhouse, in pots. The experimental design used in each experiment was completely randomized in a 4×2 factorial scheme with four replications, represented by four irrigation management systems (water deficit in the flowering, grain filling and maturation stages, and without water deficit) and two cultivars (TMG132RR™ and TMG1288RR™). The means were grouped by the Scott-Knott test at 5% significance. The characteristics evaluated were: number of seeds per plant, mass of one hundred seeds in grams, number of pods per plant, plant height and grain yield per hectare (GY) in kilograms.

Results: In the two seasons, the water deficit during grain filling affected the number of pods and seeds per plant, the 100 seeds mass, and the grain yield of both cultivars.

Implications: The water availability and sowing seasons are environmental factors with the greatest impact on cropping. Therefore, understanding how cultivars behave in adverse environmental situations is of great importance to management programs.

Conclusions: The cultivar TMG132RR™ was less sensitive to water deficit, whereas the cultivar TMG1288RR™ was more productive under adequate conditions of temperature and water availability.

Keywords: Available water; environmental stress; [*Glycine max* (L.) Merrill]; irrigation.

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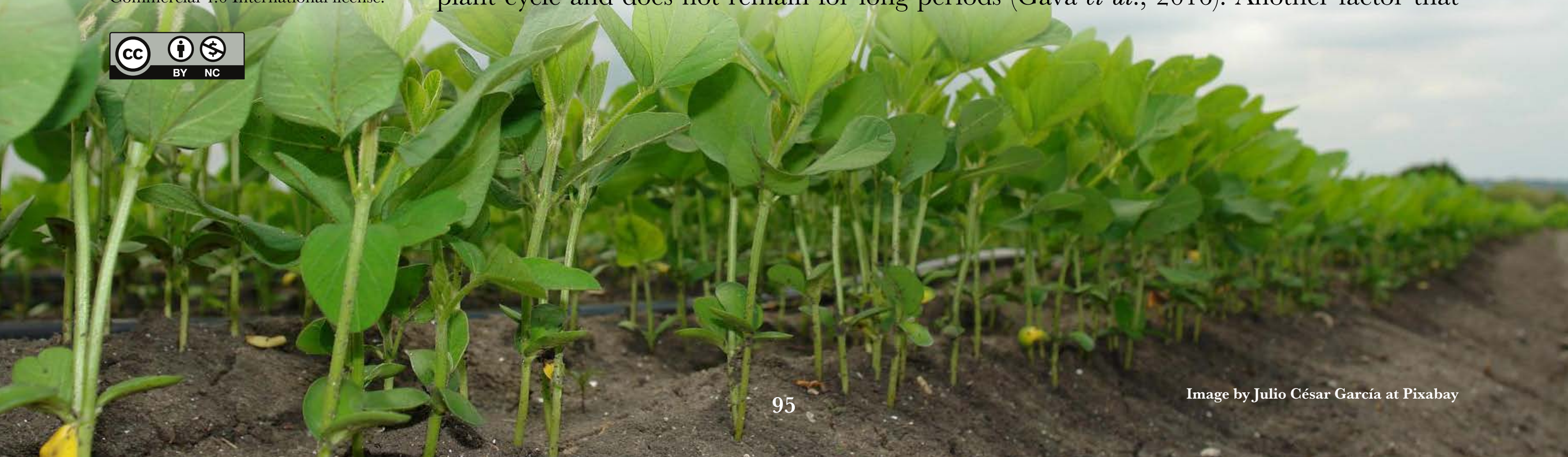
INTRODUCTION

Water availability and sowing seasons are environmental factors considered to have a major impact on crop yield. Soybeans [*Glycine max* (L.) Merrill] are considered to be tolerant to water deficit, as long as this condition does not occur in critical stages of the plant cycle and does not remain for long periods (Gava *et al.*, 2016). Another factor that



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adds up to the effects of drought is temperature, since plants subjected to the same water depth but at different temperatures generally present different physiological responses.

At high temperatures, Pípolo (2002) observed changes in nitrogen availability for grains in soybean plants and, consequently, variations in protein content, producing seeds with low commercial value.

When the water deficit occurs during flowering and beginning of pod formation, the effects are reflected on the abortion of flowers, and, later, on the size and chemical composition of the grains (Mundstock; Thomas, 2005).

Another important aspect related to the response to drought is the crop plasticity. Soybean has high plasticity, *i.e.* the ability to adapt to environmental and management conditions through changes in its morphology and yield components (Komatsu *et al.*, 2010). However, it is important to consider that different cultivar can respond differently to these environmental variations.

For this reason, understanding how cultivars behave in adverse environmental situations is of great importance to management programs, aiming to minimize losses in unusual situations.

Thus, the present study aimed to evaluate the performance of two soybean cultivars, submitted to water deficit, in different reproductive stages and sowing seasons, in the state of Tocantins, Brazil.

MATERIAL AND METHODS

Location and Characterization of Experimental Area

Two experiments were carried out in a greenhouse, on the campus of the Federal University of Tocantins, municipality of Palmas, Brazil the first being installed on July 10, 2019, and the second on October 27, 2019.

According to the Köppen climate classification, the climate in this region is a humid tropical type with a well-defined dry season (Aw) in winter. The average annual potential evapotranspiration is 1500 mm, with average annual temperature and precipitation of 27.5 °C and 1600 mm, respectively (INMET, 2015). The climatic data were collected from a mobile experimental station installed near the greenhouse (Figure 1).

The soil in the experimental area is red yellow dystrophic oxisol with textural class loam sandy (sand-82%; clay-13%; silt-5%), pH-4.9; organic matter 6 g.dm^{-3}. The average value of soil density was 1.55 g cm^{-3}. Fertilization was carried out based on the recommendation for soybean cropping (EMBRAPA, 1999).

Conduction of Experiments

The experimental design in each experiment was completely randomized with four repetitions for treatment. The treatments were arranged in a 4×2 factorial scheme, represented by four irrigation systems (WDF> water deficit in flowering R1-R3, WDG> water deficit in grain filling R4-R5.5, WDM> water deficit in maturation R6-R7, and NI> normal irrigation/control) and two cultivars (TMG132RR™ and TMG1288RR™, both of medium cycle and determined growth habit).

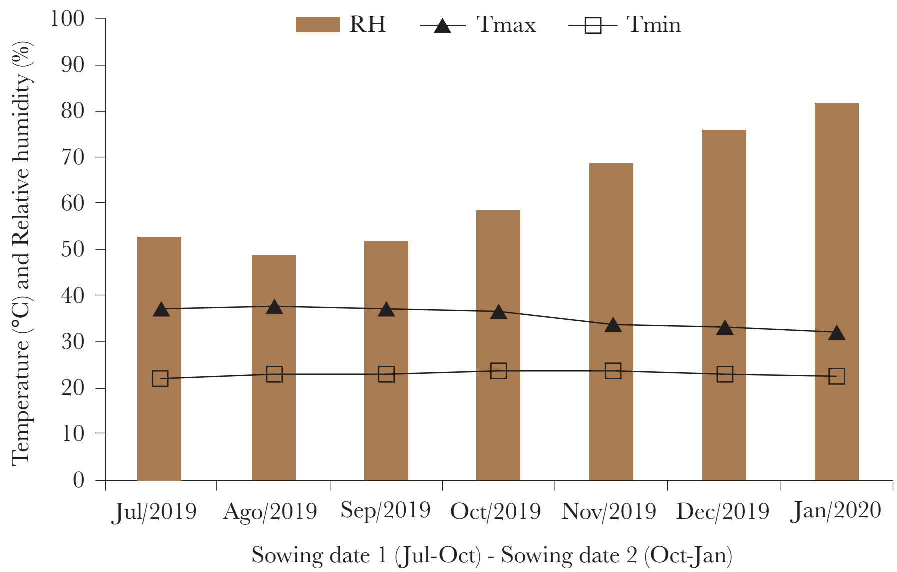

Figure 1. Climatic data (maximum, minimum, and relative humidity) of the experimental area at the Federal University of Tocantins, in the municipality of Palmas, Brazil, obtained during the experiment conduction (from July 2019 to January 2020).

The experimental plot was represented by polyethylene pots, with a volumetric capacity of eight liters. The seeds were sown manually. After emergence, the plants were thinned to leave two plants per pot.

The water balance was carried out through the physical–hydraulic characteristics of the soil (field capacity – FC and permanent wilting point - PWP), determined *in situ*. The available soil water was calculated by the difference between field capacity and permanent wilt point. Irrigation management was performed with an adaptation of the methodology proposed by Sinclair and Ludlow (1986). For WDF, WDG and WDM, a variation of up to 30% of the water available in the soil was maintained. For NI, the volume always remained close to 70% of the water available in the soil.

Evaluated characteristics

The agronomic characteristics evaluated were: number of seeds per plant (NSP), mass of one hundred seeds (M100) in grams, number of pods per plant (NPP), plant height (PH) in centimeters, and grain yield per hectare (GY) in kilograms.

Statistical Analysis

The treatments were subjected to individual analysis of variance, and then to joint analysis (Cruz; Regazzi, 2004). The means were grouped by the Scott-Knott (1974) test at 5% significance. The statistical program SISVAR version (5.0) was used.

RESULTS AND DISCUSSION

The summary of the joint analysis of variance for the characteristics number of seeds per plant (NSP), mass of one hundred seeds (M100) in grams, number of pods per plant

(NPP), plant height (PH) in centimeters, and grain yield in kilograms per hectare (GY) is shown in Table 1.

For all characteristics, significant effects were detected for IM and S, demonstrating the importance of water supply management and planting period.

There was a significant difference for all characteristics for the interaction S×IM. As for the interaction S×C, a significant effect was only detected in two characteristics, revealing the similar behavior of cultivars in the two analyzed periods, and differing from the other characteristics.

The interaction IM×C resulted in a significant effect on the NSP, NPP, and GY. As for the triple interaction S×IM×C, only NSP showed no statistical difference between treatments. In this case, this interaction reflects the differential behavior of the cultivars according to the sowing seasons and irrigation management.

Comparison of means

In the S×MI interaction (Table 2), the number of seeds per plant NSP, for all irrigation managements, was higher in the second season (S2) compared to the first season (S1), probably due to the occurrence of milder temperatures recorded throughout the cycle in S2 (Figure 1).

Among the irrigation managements, in the two studied sowing seasons, the highest number of NSP occurred during maturation (WDM) and normal irrigation (NI). At maturation, the occurrence of water deficit did not result in losses in NSP, as at this stage the plants were at the beginning of physiological maturation and the pods were already full, that is with the grains already occupying the entire cavity of the pods. Conversely, lower NSP values were observed in flowering (WDF) and grain filling (WDG), as a result of the harmful effect of water deficit in these stages, corroborating the results reported by Palharini (2016).

Table 1. Analysis of variance related to the characteristics: number of seeds per plant (NSP), mass of one hundred seeds (M100), number of pods per plant (NPP), plant height (PH) and grain yield (GY) of two soybean cultivars.

Source of Variation	GL	NSP	M100 (g)	NPP	PH (cm)	GY (kg)
RE(S)	6	37.01^{ns}	0.96^{ns}	8.86^{ns}	12.83^{ns}	32518.72^{ns}
S	1	27340.62^{**}	93.05^{*}	561.09^{*}	5003.79^{*}	34063169.54^{*}
IM	3	5910.94^{**}	35.27^{*}	576.41^{*}	90.00^{*}	6849649.17^{*}
C	1	252.81^{ns}	32.56^{*}	718.91^{*}	546.97^{*}	306824.45^{ns}
S×IM	3	2708.54^{**}	12.88^{*}	191.38^{*}	41.67^{*}	2786878.26^{*}
S×C	1	556.96^{*}	5.92^{ns}	659.84^{*}	52.38^{ns}	25816.49^{ns}
IM×C	3	523.50^{**}	1.27^{ns}	314.26^{*}	36.99^{ns}	818495.60^{*}
S×IM×C	3	305.12^{ns}	5.54^{*}	172.68^{*}	50.60^{*}	1110791.62^{*}
Error	42	128.85	1.68	18.13	15.54	164751.97
CV%		11.96	9.93	13.77	9.23	12.82

Note: * Significant at 5% probability by the F–test; ns–Not significant. RE: repetition; S: sowing seasons; IM: irrigation management; C: cultivar; CV%: coefficient of variation.

Table 2. Analysis of the interaction S×IM and of the interaction IM×C for the number of seeds per plant (NSP), in Palmas, Tocantins, Brazil.

IM	Number of seeds per plant (NSP)			
	Sowing Seasons		Cultivars	
	S1	S2	TMG 132RR™	TMG 1288RR™
WDF	33.21bB	49.62aA	50.77cA	32.06bB
WDG	20.43bB	41.93bA	33.12dA	29.25bA
WDM	39.37aB	97.81aA	60.00bA	69.18aA
NI	41.62aB	102.62aA	73.37aA	70.87aA

Means followed by the same lowercase letter, in each column, and uppercase (between the two sowing season; between the two cultivars), in the row, belong to the same statistical group, at 5% significance by the Scott–Knott test. * WDF: water deficit in the flowering stage; WDG: water deficit in the grain–filling stage; WDM: water deficit in the maturation stage; NI: normal irrigation (no water deficit); S1: first sowing season (July 10, 2019); S2: second sowing season (October 27, 2019).

Lima *et al.* (2009) argue that in adverse conditions such as water restriction, the plant will preferably form few seeds in the fixed pods since the biological objective is to guarantee reproduction. The water deficit during flowering (WDF) reduced the number of seeds per plant in cultivar TMG1288RR™ (32.06) compared to cultivar TMG132RR™ (50.77) (Table 2).

Normally, water deficit during flowering causes flower abortion and prevents anthesis (Casagrande, 2001), due to the decrease in photo-assimilated compound translocation from leaves to flowers (Kramer; Boyer, 1995), making seed formation unfeasible. This observed difference may indicate different response mechanisms to water deficit between the cultivars evaluated in this study.

According to Beever (2000), drought tolerance is a polygenic characteristic that is difficult to identify. A specific physiological response to water deficit represents combinations of molecular events that are triggered by the perception of stress (Bray, 1993). Understanding how these events interact with each other is important for identifying drought-tolerant cultivars and enabling breeding programs for this purpose.

The results of the triple S×IM×C interaction for plant height (PH) and number of pods per plant (NPP) characteristics are shown in Table 3.

For plant height (PH), there were no differences between the irrigation management, in the two evaluated sowing seasons, for TMG132RR™, showing stability for this characteristic, even in unfavorable environmental conditions. Conversely, for the cultivar TMG1288RR™, irrigation management effects were observed in each of the sowing seasons. The PH reduction observed for TMG1288RR™ submitted to water deficit in S1 may have occurred in response to the environmental stress imposed during the grain-filling (Figure 1). As for S2, also for TMG1288RR™, possibly the genetic factor was decisive, since there was no water deficit in NI, and, during WDM, plants had already reached the maximum height.

The sowing season did not influence the NPP of the cultivar TMG132RR™ (Table 3). Conversely, for TMG1288RR™, was observed greater NPP in S2 during WDM and

Table 3. Analysis of the S×IM×C, for the plant height (PH) and number of pods per plant (NPP), in Palmas, Tocantins, Brazil.

MI	Plant height (cm)				Number of pods per plant (NPP)			
	TMG132RR™		TMG1288RR™		TMG132RR™		TMG1288RR™	
	S1	S2	S1	S2	S1	S2	S1	S2
WDF	48.97aA1	34.00aB1	48.62bA1	37.37aB1	19.00aA1	17.37aA1	13.37bA1	14.25bA1
WDG	45.25aA2	28.50aB1	54.12bA1	31.62bB1	8.12bA1	8.12bA1	12.37bA1	12.87bA1
WDM	51.00aA1	27.50aB2	52.87bA1	40.87aB1	13.37bA1	13.00bA2	17.37aB1	42.00aA1
NI	52.87aA1	30.12aB2	58.62aA1	40.92aB1	18.75aA1	18.75aA2	17.39aB1	40.62aA1

1=Comparison between irrigation managements: means followed by the same lowercase letter in the column, for the same sowing seasons and cultivar, belong to the same statistical group, at 5% significance by the Scott–Knott test. 2=Comparison between sowing seasons: means followed by the same upper case letter in the row, for the same cultivar and irrigation management, belong to the same statistical group, at 5% significance by the Scott–Knott test. 3=Comparison between cultivars: means followed by the same number, for the same sowing season and irrigation management, belong to the same statistical group, at 5% significance by the Scott-Knott test. * WDF: water deficit in the flowering stage; WDG: water deficit in the grain-filling stage; WDM: water deficit in the maturation stage; NI: normal irrigation (no water deficit); S1: first sowing season (July 10, 2019); S2: second sowing season (October 27, 2019).

NI, since at this time the temperature and humidity conditions were more favorable (Figure 1). This indicates that under more favorable environmental conditions, the cultivar TMG1288RR™ had a better response to NPP.

Comparing the irrigation managements within each cultivar, the cultivar TMG132RR™ showed a reduction of NPP during WDG and WDM. For TMG1288RR™, the lowest NPP values occurred in WDF and WDG (Table 3).

According to Gava *et al.* (2015), the reproductive phase is more sensitive to water stress, which reinforces the results found in the study for this characteristic.

As for the cultivars within each season and irrigation management, the cultivar TMG1288RR™ showed higher NPP in S2 for WDM and NI (Table 3).

This response can often be related to the crop plasticity, which can vary among cultivars (Ludwing *et al.*, 2011), a fact that may have resulted in differences between the cultivars TMG132RR™ and TMG1288RR™. It is important to note that although the largest size of cultivar TMG1288RR™ occurred in S1, compared to S2, the largest number of pods per plant (NPP) occurred in S2 in comparison to S1, for the WDM and NI management systems.

Normally, larger plants have greater water demand, compromising the formation of pods and the grain-filling (Farias *et al.*, 2007). In a study conducted by Balbinott Júnior *et al.* (2018), the authors observed that the number of pods per plant was the variable that most contributed to explaining the phenotypic plasticity in soybean plants.

As for the mass of 100 seeds (M100) (Table 4), for the cultivar TMG132RR™, the water deficit in S1 provided a reduction in all treatments, differing only from normal irrigation. In S2, only WDF differed from the others, resulting in a higher average. For TMG1288RR™, the management that promoted the lowest M100 values was WDM, in S1, and WDM and WDG, in S2.

The comparative study between sowing seasons, in each cultivar and irrigation management system, revealed a reduction in M100 only in WDF, for cultivar TMG132RR™ and in WDF, WDM, and NI for cultivar TMG1288RR™ (Table 4).

Table 4. Analysis of the interaction S×IM×C, for the characteristic mass of 100 seeds (M100) and grain yield (GY), in Palmas, Tocantins, Brazil.

IM	Mass of 100 seeds (g)				Grain yield (kg)			
	TMG132RR™		TMG1288RR™		TMG132RR™		TMG1288RR™	
	S1	S2	S1	S2	S1	S2	S1	S2
WDF	6.38bB1	11.10aA1	8.64aB1	12.82aA1	691.46bB1	2240.19bA1	801.38bB1	1292.79bA2
WDG	6.33bA1	7.32bA1	7.69aA1	7.59cA1	316.78cB1	1097.26cA1	564.94cB1	785.29cA2
WDM	6.21bA1	7.87bA1	5.68bB1	10.57bA1	544.17bB1	2168.72bA2	554.46cB1	3301.84aA1
NI	9.33aA1	9.18bA2	9.62aB1	12.63aA1	1168.98aB1	2890.92aA2	1193.86aB1	3731.76aA1

1=Comparison between irrigation managements: means followed by the same lowercase letter in the column, for the same sowing season and cultivar, belong to the same statistical group, at 5% significance by the Scott–Knott test. 2=Comparison between sowing seasons: means followed by the same upper case letter in the row, for the same cultivar and irrigation management, belong to the same statistical group, at 5% significance by the Scott-Knott test. 3=Comparison between cultivars: means followed by the same number, for the same sowing season and irrigation management, belong to the same statistical group, at 5% significance by the Scott-Knott test. * WDF: water deficit in the flowering stage; WDG: water deficit in the grain–filling stage; WDM: water deficit in the maturation stage; NI: normal irrigation (no water deficit); S1: first sowing season (July 10, 2019); S2: second sowing season (October 27, 2019).

For grain yield, in both cultivars, and in S1 and S2, the management that most compromised yield (GY) was the water deficit during grain-filling (WDG) (Table 4), which also reduced NSP (Table 2), NPP (Table 3), and M100 (Table 4).

The drought stress during grain filling also affected the mass of 100 seeds (M100). According to Albrecht (2008), water restriction can accelerate maturation and reduce the period of reserve accumulation, resulting in grains of stressed plants that not show the normal pattern of development.

Grain yield is a direct function of components such as NPP, PH, NSP, and M100, and depends on a balance between photosynthesis and translocation of its products. Under environmental stress conditions, the plant tries to compensate for cellular damage by adjusting metabolic pathways to ensure reproduction. These mechanisms may vary according to the genotype, stress intensity, and phase in which they occur.

For GY, among the cultivars, no differences were detected in the first sowing season. In the second sowing season, there were different responses of the cultivars in relation to the irrigation managements, as the cultivar TMG132RR™ presented higher grain yield mean in WDF and WDG, while the cultivar TMG1288RR™ was more productive in WDM and WDG.

Considering that the reproductive phase presents more water demand and is most sensitive to water variations, mainly in flowering and grain–filling, it can be inferred that the cultivar TMG132RR™ was less sensitive to drought stress. In contrast, under more favorable conditions, with wide water availability (NI) and milder temperatures (S2), the cultivar TMG1288RR™ was the most productive.

CONCLUSION

The drought stress influenced the agronomic characteristics, cultivars, and sowing seasons. The cultivar TMG132RR™ was less sensitive to drought stress. Under favorable conditions of temperature and water availability, the cultivar TMG1288RR™ was more productive.

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