



DEVELOPMENT OF SOYBEAN GENOTYPES AS A FUNCTION OF WATER AVAILABILITY AND SOWING SEASONS IN RIO VERDE, STATE OF GOIAS

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ABSTRACT

Soybean crop yield is affected in the absence of favorable conditions for its complete development, and one of the most limiting factors is the water availability throughout the crop cycle. Therefore, the objective of this study was to evaluate the behavior of three soybean genotypes, in two sowing dates, during two harvests, in the city of Rio Verde, Stat of Goiás. Four experiments were carried out in a randomized block design, with four replicates in the 2018/2019 and 2019/2020 harvests. The variables analyzed in the experiment were plant height at maturity, days to maturity, and grain yield. The water balance in the soil considered the water storage of 46.8 mm. It was observed periods with greater water deficiency (53.5 mm) in the 2018/2019 harvest for all genotypes. In short, for genotypes with 100 to 110 days of the cycle, the sowing time that showed to be the most promising to obtain higher yields, was between October 20 and November 20, for genotypes with a cycle of 120 days. This range of adaptation becomes broader, mainly because these genotypes have a longer vegetative period, being, therefore, the period of least water requirement for the crop.

Palavras-chave:

Glycine max (L.) Merrill
Estresse hídrico
Meteorologia

DESENVOLVIMENTO DE GENÓTIPOS DE SOJA EM FUNÇÃO DA DISPONIBILIDADE HÍDRICA E ÉPOCAS DE SEMEADURA NO MUNICÍPIO DE RIO VERDE, GOIAS

RESUMO

A produtividade da cultura da soja é afetada na ausência de condições favoráveis para seu completo desenvolvimento, e um dos fatores mais limitantes é a disponibilidade hídrica ao longo do ciclo da cultura. Neste sentido, objetivou-se avaliar o comportamento de três genótipos de soja, em duas épocas de semeadura, durante duas safras, no município de Rio Verde, Goiás. Foram instalados 4 experimentos em delineamento de blocos casualizados, com 4 repetições, nas safras 2018/2019 e 2019/2020. As variáveis analisadas foram altura de plantas na maturação, dias para maturação e rendimento de grãos. O balanço de água no solo considerou armazenamento de água de 46,8 mm. Evidenciou-se períodos com maior deficiência hídrica (53,5 mm) na safra 2018/2019 para todos os genótipos. Em suma, para genótipos de 100 a 110 dias de ciclo, a época de semeadura que se mostrou mais promissora para obter maiores rendimentos, foi compreendida entre 20 de outubro a 20 de novembro, já para genótipos com ciclo de 120 dias de ciclo, essa faixa de adaptação torna-se mais ampla, principalmente em virtude desses genótipos apresentarem maior período vegetativo, sendo, portanto, o período de menor exigência hídrica da cultura.

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is one of the most important crops in the Brazilian economic scenario, covering around 36.8 million hectares in the 2019/2020 harvest. So far, it has been predicted to establish an average yield of 3,373 kg ha⁻¹. Estimates for the Central-West region point to a rise in the production area of approximately 2.9%, totaling 16,574.4 thousand hectares (CONAB, 2020).

However, higher yields can be achieved when the ideal conditions for crop development are supplied at all phenological stages. Crop yield tends to be restricted by the unfavorable climate, and by factors that directly influence the intensity of meteorological phenomena. The occurrence of dry spells and periods of drought, associated with the evapotranspirative demand and irregular distribution of rainfall are the major factors limiting the achievement of high grain yields (NUNES *et al.*, 2016), leading to a drop in crop yield (SILVA *et al.*, 2020).

The total amount of water requirement of soybean crops may vary according to climatic conditions, soil texture and organic matter content and plant genetics. Depending on the characteristics of each cultivar, the demand for water varies between 450 to 800 mm per crop cycle as long as they are well distributed during this period (EMBRAPA, 2020).

The largest need for water by the soybean crop occurs in two moments, in the germination phase - emergence, when the seed has to absorb 50% of its weight in water, and the water values in the soil cannot exceed 85%, and in the reproductive stage (EMBRAPA, 2020). From the flowering period to the full-grain filling, the need for water can reach 7 to 8 mm day⁻¹, which may vary according to cultivar and region (MOREIRA *et al.*, 2013). According to Souza *et al.* (2016), the highest water consumption occurs when the plant reaches the highest leaf area index.

Evapotranspiration (evaporation + transpiration) is the primary process by which water is lost in agricultural systems to the atmosphere, and it

can affect several biochemical and anatomical processes, limiting crop productivity. Schapardini *et al.* (2019) defined evapotranspiration as a form of energy exchange between the surface and the atmosphere through the direct evaporation of water from the soil, water available in other parts of the system, and water that passes through the plant canopy via transpiration.

Using the data on the maximum crop evapotranspiration (ET_c), precipitation (P), and available soil water capacity (CAD) variables allowed us to carry out the sequential climatological water balance of the crop. The water balance is used to account for water inputs and outputs in agricultural systems and associate them with crop productivity, as well as serving as a tool for agricultural planning (PASSOS *et al.*, 2016).

The knowledge of rainfall volumes and crop water balance is important to manage the crop as it allows to determine the best sowing season for each cultivar in regions different from those that were indicated. Therefore, understanding the factors that influence soybean performance is extremely important for the maximum expression of the genetic potential of the cultivars to occur. Therefore, the objective of this work was to evaluate the behavior of three soybean genotypes, in two sowing seasons, under rainfed cultivation conditions in the municipality of Rio Verde, State of Goiás, during two crops.

MATERIAL AND METHODS

The experiments were carried out in the municipality of Rio Verde, State of Goiás, located at latitude 17°44'35.7" S, longitude 50°57'45.1" W, and altitude of 865 m. The local climate is classified as Aw - tropical hot and humid, according to Köppen's classification, with rainfall distributed from October to April, and an annual average of 1,621 mm. Average temperature was 23.8°C (LOPES SOBRINHO *et al.*, 2020). The soil of the experimental area is classified as Dystrophic Red Latosol (EMBRAPA, 2018).

To study the genotype x environment interaction (GxE), two trials were implemented in the 2018/2019 harvest and two trials in the 2019/2020 harvest, sown at two different seasons. In the 2018/2019 harvest, the first and second seasons were sown on October 12, 2018 (RDE18/19-1) and November 1, 2018 (RDE18/19-2), respectively. The experiments of the 2019/2020 harvest were sown October 22, 2019 (RDE19/20-1) and November 22, 2019 (RDE19/20-2), for the first and second season, respectively.

The tests were made up of three soybean genotypes, which were the commercial cultivars SYN 1163 RR and BMX Desafio RR and the experimental lineage CG14-1996R568IPRO. The experimental design used in all experiments was a randomized block design, with four replications. The experimental unit consisted of four rows of six meters in length, spaced at 0.45 m between lines. At harvest, the two lateral lines and 0.5 m from each end of the plot were disregarded, considering 4.5 m² as a useful area.

The variables analyzed were plant height at maturity (PHM), days to maturity (DTM), and grain yield in kg ha⁻¹ (GY). Data were collected following the scale of development of the culture proposed by Fehr and Caviness (1977).

Meteorological data (air temperature and humidity, wind speed, solar radiation, and precipitation) were obtained from the National Institute of Meteorology (INMET), from the Rio Verde Automatic Weather Station, located at latitude 17°47'07" S, longitude 50°57'53" W and at 775 m of altitude.

To determine the sequential climatological water balance of cultivation, it was used data

from October to March, during the soybean growing season in each year, following the adaptation proposed by Pereira *et al.* (2007), in which there is no need for direct measurements of soil conditions. The fixed value of the available water capacity of 78 mm (clay textured soil) was adopted, taking into account the values of the water availability factor proposed by Doorenbos and Kassam (1979).

The calculation of reference evapotranspiration (ET_o) was performed using the Penman-Monteith method (FAO Standard). Crop evapotranspiration was determined according to Equation 1.

$$ET_c = ET_o \cdot kc \quad (1)$$

In which:

ET_c = maximum crop evapotranspiration (mm day⁻¹);

ET_o = reference evapotranspiration (mm day⁻¹);

kc = crop coefficient.

The values of crop coefficient (kc) were adopted according to the cycle of each cultivar and each development phase (Table 1), adapted from Farias *et al.* (2001).

The data were subjected to individual analysis of variance and later, the homogeneity of residual variances was verified by testing the ratio between the largest and smallest mean square of the residue, treating it as homogeneous when this ratio is less than 7, according to Pimentel -Gomes (1990). Subsequently, the joint analysis of variance was applied, and a significant effect (p<0.05) was verified, followed by the application of the Tukey mean comparison test at 5% probability. All statistical procedures were performed using the SISVAR statistical software (FERREIRA, 2011).

Table 1. Length of phenological stages (days) of soybean genotypes with different cycles and respective crop coefficients (kc)

Crop	Cycle	S-V2	V2-R1	R1-R5/R6	R6-R8
Soybean	100	10	30	30	30
	110	10	35	35	30
	120	15	35	40	30
	kc	0.56	1.21	1.50	0.90

S: sowing; V2: fully developed leaf on the first node above unifoliate; R1: start of the flowering stage; R5: start of the grain filling stage and, R8: complete physiological maturity

RESULTS AND DISCUSSION

A significant effect was found at 1% probability for the environmental (E) and genotype (G) sources of variation for the three studied variables (Table 2). For the GxE interaction, there was a significant effect at 1% probability for the plant height at maturity (PHM) and days to maturity (DTM) variables, and a significant effect at 5% probability for the grain yield (GY) variable. The coefficient of variation is a measure of experimental precision; the smaller it is, the more accurate the data obtained. In this case, the coefficients of variation obtained ranged from 1.46 to 10.26%, being classified as low magnitude for DTM and PHM, and medium magnitude for GY, according to Pimentel-Gomes (2009).

The SYN 1163 RR and CG14-1996R568IPRO genotypes showed higher means for PHM in

RDE18/19-1, with values of 62.8 and 66.8, respectively (Table 3). As for RDE18/19-2, only the CG14-1996R568IPRO lineage had a higher mean than the other genotypes; the same was observed for RDE19/20-1 and RDE19/20-2. Regarding the difference between the genotypes in the environments, the CG14-1996R568IPRO lineage showed the highest mean in RDE19/20-1 and RDE19/20-2, with values of 93.0 and 96.0, respectively.

This differential behavior of the genotype in question is associated with the sowing season that the plant encountered fewer water restrictions, which promoted more favorable environmental conditions for its development.

For RDE18/19-1, the BMX Desafio RR and CG14-1996R568IPRO genotypes showed the smallest plant height at maturity when compared to RDE18/19-2, RDE19/20-1, and RDE19/20-

Table 2. Summary of joint analysis of variance for the variables plant height at maturity (PHM), days to maturity (DTM), grain yield (GY)

SV	DF	Mean squares		
		PHM	DTM	GY
Block/environment	12	43.08 ^{ns}	2.90 ^{ns}	162187.92 ^{ns}
Environments (E)	3	1063.64**	49.25**	1160123.86**
Genotypes (G)	2	1890.58**	1385.40**	2024383.40**
GxE interaction	6	233.89**	52.23**	497418.88*
Residue	24	29.06	2.47	154594.48
CV (%)		7.54	1.46	10.26

*Significant at 5% probability, **significant at 1% probability; ^{ns} not significant by the F test

Table 3. Mean values for the variables plant height at maturity (PHM), days to maturity (DTM), and grain yield (GY), in Rio Verde in the 2018/2019 and 2019/2020 crops in two sowing seasons

Genotypes	RDE18/19-1	RDE18/19-2	RDE19/20-1	RDE19/20-2
	PHM (cm)			
SYN 1163 RR	62.8 abB	61.5 bB	83.3 bA	73.5 bA
BMX Desafio RR	53.3 bB	65.5 bA	72.5 cA	54.3 cB
CG14-1996R568IPRO	66.8 aB	76.3 aB	93.0 aA	96.0 aA
DTM				
SYN 1163 RR	94.5 cB	100.0 cA	96.5 cB	101.5 cA
BMX Desafio RR	110.0 bB	113.8 bA	103.0 bC	107.5 bB
CG14-1996R568IPRO	117.8 aA	118.3 aA	118.3 aA	112.5 aB
GY (kg ha ⁻¹)				
SYN 1163 RR	2870.6 bB	3262.8 bAB	3784.5 aA	3850.0 aA
BMX Desafio RR	3396.7 abB	4402.2 aA	4149.5 aAB	3723.9 aAB
CG14-1996R568IPRO	3947.2 aAB	4643.3 aA	4112.2 aAB	3848.4 aB

Means followed by the same lower-case letter in the columns and upper-case letter in the rows are not different from each other by the test of Tukey ($p < 0.05$)

2, which negatively impacted the grain yield, mainly for the cultivar BMX Desafio RR which was subjected to water deficit during stages R3 to R5, which resulted in lower grain weight and consequently a reduction in grain yield. Gava *et al.* (2016) also observed a reduction in plant height when soybeans are subjected to a water deficit of 50 to 70% between the vegetative periods until the beginning of pod formation. These authors also found a reduction in grain filling when grown under water deficit during the grain-filling period.

The reduction in plant height generally causes a reduction in grain yield, besides being related to the response of the cultivar to photoperiod, temperature, and water availability, in which early sowing may be affected by high temperatures, water restriction, and a photoperiod shorter than the critical photoperiod of cultivar, causing early flowering, consequently reducing size and productivity (EMBRAPA, 2020). For Farias *et al.* (2001), each cultivar has its critical photoperiod, therefore photoperiod sensitivity is a characteristic that varies among cultivars.

The commercial cultivar SYN 1163 RR showed lower performance in the environments of RDE18/19-1 and RDE18/19-2 for the grain yield variable, due to its shorter cycle and greater sensitivity to water restrictions, which were observed in the 2018/2019 harvest.

Cultivar BMX Desafio RR had the highest grain yield mean in RDE18/19-2, but not statistically different from RDE19/20-1 and RDE19/20-2 by the test of Tukey at $\alpha = 0.05$, with means of 4402.2; 4149.5 and 3723.9 kg ha⁻¹, respectively. The CG14-1996R568IPRO lineage showed less variation in grain yield when compared to the other genotypes, with grain yield ranging from 3848.4 to 4643.3 for RDE19/20-2 and RDE18/19-2, respectively, not showing inconsistency in superiority with environmental variation.

In the 2018/2019 harvest, the rainy season became uniform in the first half of October (Figure 1), accumulating volumes above 100 mm. However, smaller volumes were observed during the second 10-day period of December 2018 (20.8 mm) and the first 10-day period of January 2019 (18.8 mm). As for the 2019/2020 harvest, stabilization in the rainy season was delayed for the third 10-day period of October, and there were smaller volumes only for the second 10-day period of January 2020 (10.2 mm).

In both harvests, it was found that the thermal requirement of the crop between 20 and 30°C for the soybean crop was met (TECNOLOGIAS, 2020). For the municipality of Rio Verde, Goiás, the minimum and maximum temperatures ranged from 18.8 to 32.5°C for the 2018/2019 harvest and from 18.6 to 35.4°C for the 2019/2020 harvest.

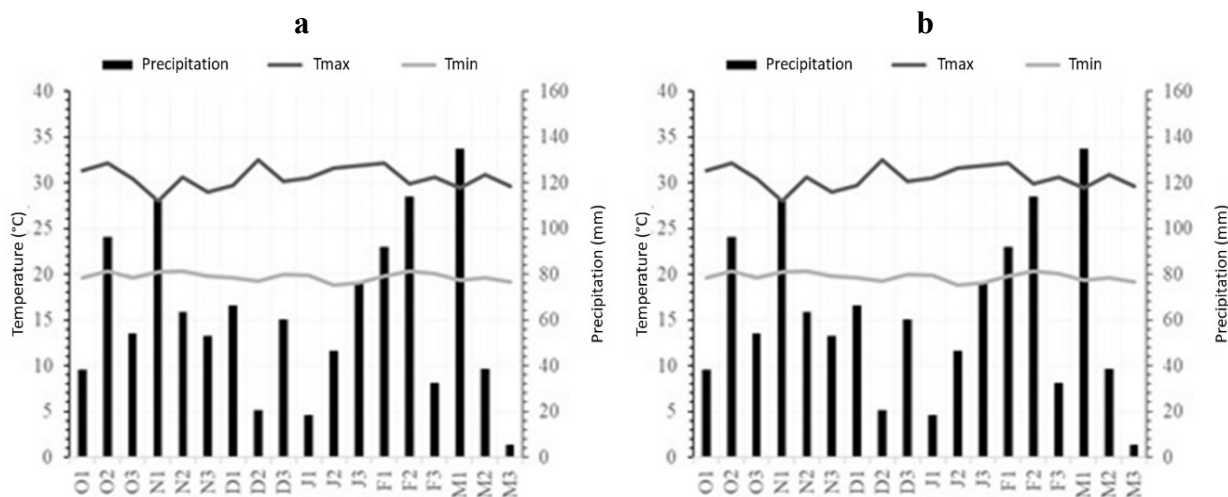


Figure 1. Rainfall, maximum (Tmax), and minimum temperatures (Tmin), observed in 2018/2019 (a) and 2019/2020 (b) harvests in Rio Verde, Goiás. O1, O2, and O3: first, second, and the third ten-day period of October; N1, N2, and N3: first, second, and third ten-day period of November; D1, D2, and D3: first, second, and third ten-day period of December; J1, J2, and J3: first, second and third ten-day period of January; F1, F2, and F3: first, second and third ten-day period of February; M1, M2, and M3: first, second and third ten-day period of March

Cultivar SYN 1163 RR is a genotype adapted to the growing conditions found in the region of Rio Verde, Goiás, with an approximate cycle of 100 days. Grain yield was affected by adverse weather conditions that were manifested in greater intensity in RDE18/19-1 (Figure 2a) and RDE18/19-2 (Figure 2b) but in different phenological phases. For RDE18/19-1, the weather conditions were favorable until the phenological stage R1. From this stage onwards, a period of water deficit began, with greater aggravation at grain filling (R5 and R6), with a water deficit of 53.5 mm, in the second ten-day period of December (Figure 2a).

For the 2018/2019 crop where for RDE18/19-1 (Figure 2a) sowing occurred in the first half of October, a reduction was observed in grain yield, an opposite fact when we observe RDE19/20-1

(Figure 2c) and RDE19 /20-2 (Figure 2d) which were considered late sowing dates for the region of Rio Verde, Goiás. Based on the water balance, periods with greater water deficit occurred during the phenological stages R1 to R6, compromising the productivity of the cultivar. According to Fietz and Rangel (2008), the delay in sowing reduces the risk of occurrence of water deficiencies during the critical period of soybean, which is from the beginning of flowering to the beginning of grain filling, reducing the negative impact on yield.

Cultivar BMX Desafio RR is a genotype adapted to the growing conditions found in the region of Rio Verde, Goiás, with an approximate cycle of 110 days. Water deficit was observed during the pod formation and grain filling stages (R3 to R5), for the RDE18/19-1 environment,

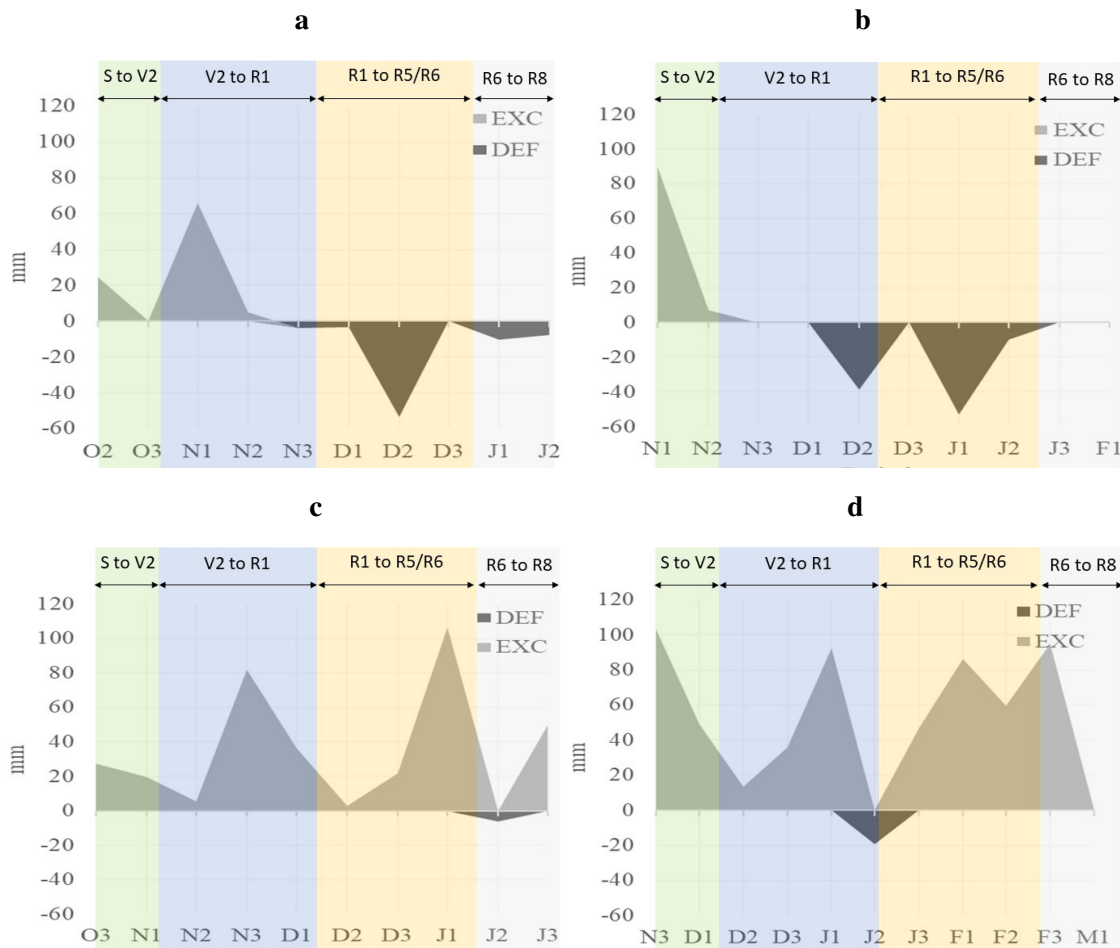


Figure 2. Cultivation water balance extract of two crops for the soybean cultivar SYN 1163 RR in two sowing seasons in Rio Verde, Goiás. a) RDE18/19-1; b) RDE18/19-2; c) RDE19/20-1; d) RDE19/20-2. O2 and O3: second and third ten-day period of October; N1, N2, and N3: first, second and third ten-day of November; D1, D2, and D3: first, second, and third ten-day period of December; J1, J2, and J3: first, second and third ten-day period of January; F1, F2, and F3: first, second and third ten-day period of February; M1: first ten-day period of March

which contributed to the reduction of plant height at maturity, and consequently to reducing the yield (Figure 3a).

The highest soybean yields for all genotypes were obtained in RDE18/19-2 and RDE19/20-1, with sowing dates between the second ten-day period of October and early November. In the 2019/2020 crop, there was better rainfall distribution throughout the crop cycle, and the reduction in the yield of the BMX Desafio RR cultivar in the second sowing season is related to lower adaptive plasticity of the genotype in relation to the sowing season than water shortage.

The water balance extract for the CG14-1996R568IPRO lineage is shown in Figure 4. The lineage has a cycle of approximately 118 days for the region of Rio Verde, Goiás. For the CG14-

1996R568IPRO lineage, periods with greater water deficit were observed during the 2018/2019 crop, which largely compromised the grain yield, especially in RDE18/19-1 (Figure 4a), where water deficit occurred in the grain filling stage. Low soybean yields were obtained by Battisti *et al.* (2018) when the crop went through periods of water deficit. Such reduction reached 48% of the expected yield when the crop is subjected to favorable growing conditions.

Even with evidence of periods with a water deficit in the four evaluated environments, it was found that the response of the CG14-1996R568IPRO lineage was equal to or superior to the response of the other cultivars. This is an indication of the proper plasticity regarding the sowing season and greater rusticity in facing adverse climatic factors, which

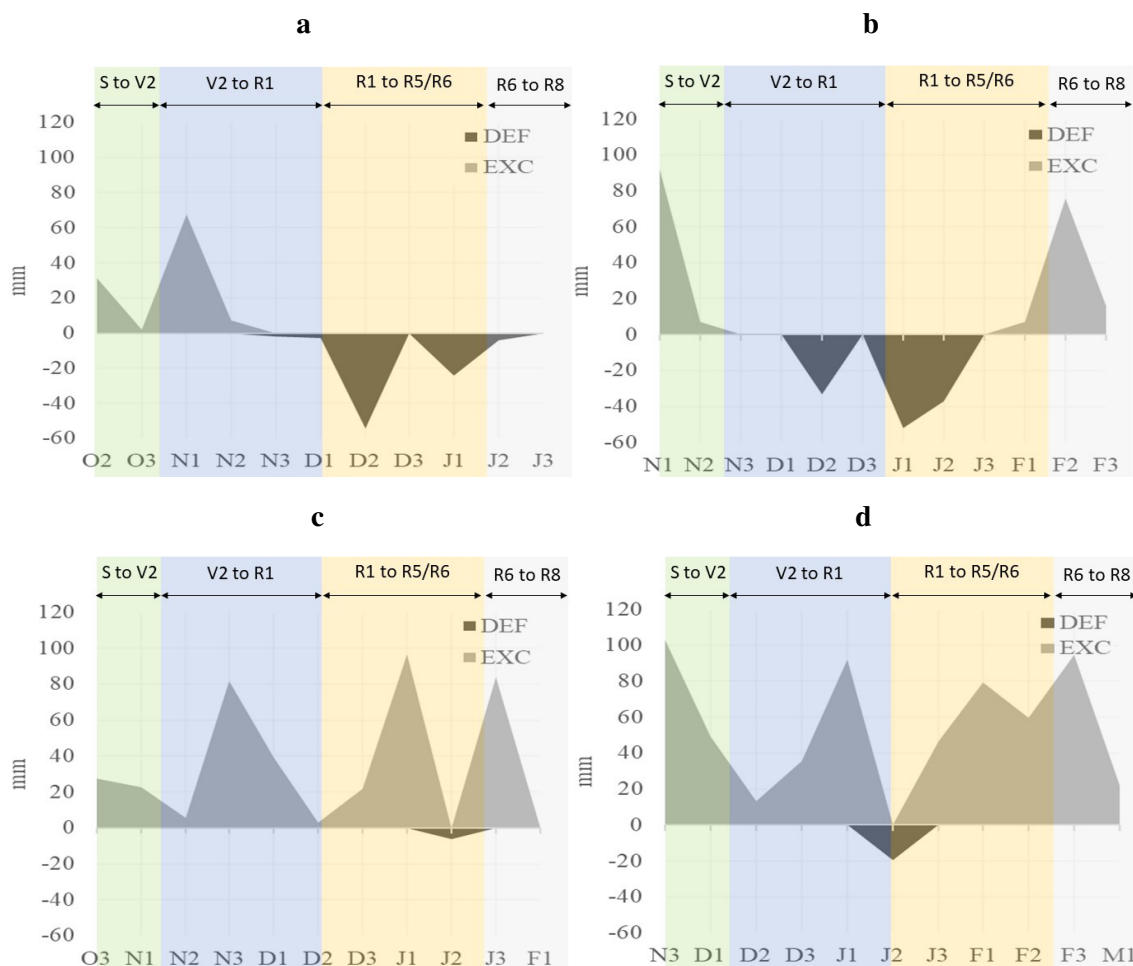


Figure 3. Cultivation water balance extract of two crops for the soybean cultivar BMX Desafio RR in two sowing seasons in Rio Verde, Goiás. a) RDE18/19-1; b) RDE18/19-2; c) RDE19/20-1; d) RDE19/20-2. O2 and O3: second and third ten-day period of October; N1, N2, and N3: first, second, and third ten-day period of November; D1, D2, and D3: first, second, and third ten-day period of December; J1, J2, and J3: first, second and third ten-day period of January; F1, F2, and F3: first, second and third ten-day period of February; M1: first ten-day period of March

can be justified with greater depth and distribution of the root system. The best genotype response was observed in RDE18/19-2 and RDE19/20-1, with means of 4,643.33 and 4,112.20 kg ha⁻¹, respectively. These results are also in agreement with Battisti *et al.* (2018) who demonstrated that soybean yield is influenced by the interaction between genotype, environmental conditions, and management practices, and with Bornhofen *et al.* (2015) who identified that variations in the soybean sowing season directly reflect on the physiological potential of the produced seeds.

Despite the favorable water conditions, a reduction is observed in the cycle of the CG14-1996R568IPRO lineage in RDE19/20-2. It is suggested that this reduction is associated with the late sowing season, with high relative humidity

and high temperatures, which resulted in greater pressure from diseases during the final phase of the cycle, causing early defoliation and consequently a reduction in the cycle. Tavares *et al.* (2013) found, under conditions similar to this work, that water availability is a variable that limits the expression of soybean crop yield potential, regardless of the cycle, cultivar, and sowing season.

The focus on the production of grains without a drop in yields means the use of adapted genotypes, adequate sowing times, in addition to the use of irrigation systems to meet the water demand of the crop in phrases of greater water need. In a work carried out by Silva *et al.* (2020), it was concluded that the use of an irrigation system to supply the water requirement of the soybean crop significantly increases the crop yield. The same authors obtained

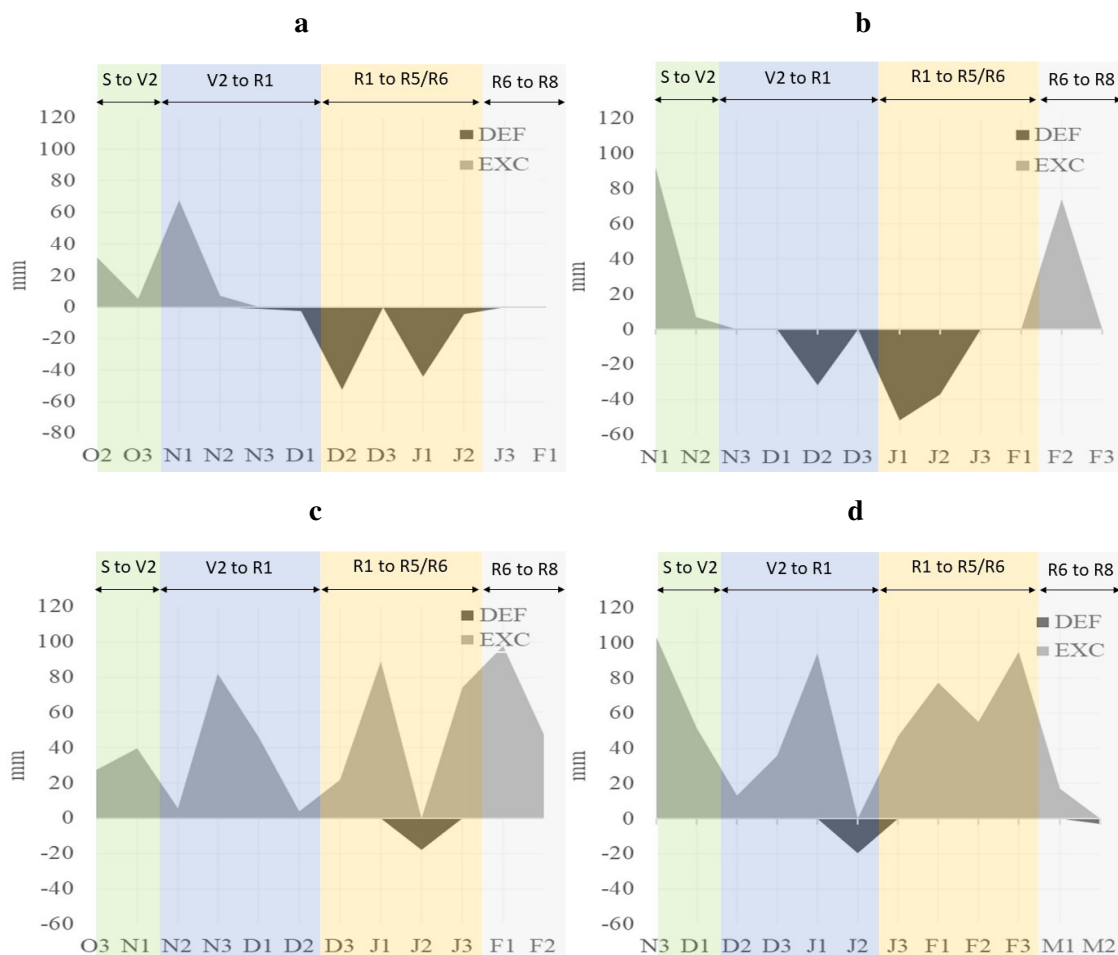


Figure 4. Cultivation water balance extract of two crops analyzed for the CG14-1996R568IPRO lineage in two sowing seasons in Rio Verde, Goiás. a) RDE18/19-1; b) RDE18/19-2; c) RDE19/20-1; d) RDE19/20-2. O2 and O3: second and third ten-day period of October; N1, N2, and N3: first, second and third ten-day of November; D1, D2, and D3: first, second, and third ten-day period of December; J1, J2, and J3: first, second and third ten-day period of January; F1, F2, and F3: first, second and third ten-day period of February; M1: first ten-day period of March

similar results when evaluating different sowing dates of the soybean crop in the municipality of Rio Verde, and concluded that if carried out between October 10th and November 10th, there is no significant difference in the final yield. To extend the soybean crop planting window in the Central-West region, which has approximately six months of drought, Sentelhas *et al.* (2015) suggest, in addition to the sowing season, the use of irrigation systems to seek higher yields and reduce the risks of dry spells. Barros *et al.* (2003), in evaluating soybean sowing seasons in the south of the state of Tocantins, obtained dates similar to those obtained in this work.

CONCLUSIONS

- It can be concluded that for the municipality of Rio Verde, State of Goiás, the different sowing seasons used in the 2018/2019 and 2019/2020 crops did not promote statistically significant differences between soybean yield for soybean genotypes (SYN 1163 RR, BMX Desafio RR, CG14996R568IPRO). However, lower yields were observed on the sowing dates October 12, 2018, and November 22, 2019. These dates are considered extreme dates for the evaluated environments, except for the SYN 1163 RR genotype, which obtained the highest yield when sowed on November 22, 2019.
- In addition, based on the calculated crop water balance, it is recommended for the municipality of Rio Verde to plant between October 20th and November 20th for cultivars with cycles shorter than 110 days (SYN 1163 RR, BMX Desafio RR). For genotypes with an approximate cycle of 120 days (such as CG14996R568IPRO), this adaptation range is wider, ranging from October 10th to November 20th, mainly because these genotypes have a longer vegetative period, in which the daily water requirement is lower.

AUTHORSHIP CONTRIBUTION STATEMENT

SOARES, S.L.: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Resources;

SANTOS, G.O.: Conceptualization, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; SIMON, G.A.: Formal Analysis, Methodology, Resources, Writing – review & editing; ALVARES, R.C.: Supervision, Validation, Visualization, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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