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COMPONENTES DE PRODUÇÃO DE SOJA NO TABULEIRO COSTEIRO DE ALAGOAS EM CULTIVOS DE SEQUEIRO E IRRIGADO

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1 RESUMO

Objetivou-se comparar os componentes de produção de cultivares de soja sob irrigação suplementar e em sequeiro. O delineamento experimental foi em blocos casualizados com cinco repetições e seis cultivares de soja (M 6210, M 6410, BMX-Potência, AS 3730, M 8349 e BRS-9383). Foram analisadas: altura de inserção da primeira vagem (AIPV, cm), número de vagens por planta (NVP, Unid.), massa de mil grãos (MMG, g), índice de colheita (IC), produtividade de água (PA, kg m^{-3}) e rendimento de grãos (RG, kg ha^{-1}). Nos cultivos irrigados, os componentes de produção variaram: AIPV de 13 a 19 cm; NVP de 43 a 118 Unid.; MMG de 147 a 207 g; IC de 17 a 45; PA de 0,80 a 1,28 kg m^{-3} e RG de 3.871 a 6.198 kg ha^{-1}. Enquanto em sequeiro, a AIPV variou de 5,85 a 16,80 cm; o NVP de 28 a 72 Unid.; a MMG de 83 a 176 g; a PA de 0,55 a 0,86 kg m^{-3} e o RG de 2.328 a 3.600 kg ha^{-1}. Somente o IC foi maior nos cultivos em sequeiro, variando de 16,80 a 52. Verifica-se, portanto, que o desempenho dessas seis cultivares de soja foi maior sob regime de irrigação.

Palavras-chave: genótipos, grãos, *Glycine max*., irrigação.

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PRODUCTION COMPONENTS OF SOYBEAN IN THE COASTAL TABLELANDS OF ALAGOAS IN RAINFED AND IRRIGATED CROPS

2 ABSTRACT

The objective was to compare the production components of soybean cultivars under supplemental irrigation and rainfed conditions. The experimental design was randomized blocks with five replications and six soybean cultivars (M 6210, M 6410, BMX-Potência, AS 3730, M 8349, and BRS-9383). The height of the first pod insertion (HFPI, cm), number of pods per plant (NPP, Units), thousand grain mass (TGM, g), harvest index (HI), water

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productivity (WP, kg m^{-3}), and grain yield (GY, kg ha^{-1}) were analyzed. In irrigated crops, the production components varied HFPI from 13 to 19 cm; NPP from 43 to 118 units; TGM from 147 to 207 g; HI from 17 to 45; WP from 0.80 to 1.28 kg m^{-3}, and GY from 3,871 to 6,198 kg ha^{-1}. While in rainfed conditions, the HFPI ranged from 5.85 to 16.80 cm; NPP from 28 to 72 units; TGM from 83 to 176 g; WP from 0.55 to 0.86 kg m^{-3}, and GY from 2,328 to 3,600 kg ha^{-1}. Only the HI was higher in rainfed crops, ranging from 16.80 to 52. It can be seen; therefore, that the performance of these six soybean cultivars was higher under irrigation.

Keywords: genotypes, grains, *Glycine max*., irrigation.

3 INTRODUCTION

Soybeans [*Glycine max* (L.) Merrill] constitute the main *commodity* of Brazilian agribusiness. With approximately 39.20 million hectares cultivated, the annual production of this oilseed for the 2020/2021 harvest was 138.15 million tons (t), with an average productivity of 3,525 kg ha $^{-1}$ (CONAB, 2022). In Alagoas, soybean farming has gained ground in relation to other crops, resulting in a production of 5,500 t, with a cultivated area of approximately 2,200 hectares and an average productivity of 2,500 kg ha $^{-1}$ (CONAB, 2019).

The coastal tablelands of Alagoas are part of the SEALBA region (Sergipe, Alagoas, and northeastern Bahia), which represents a new agricultural frontier for grain cultivation in Northeast Brazil (NEB). However, because it is not a traditional soybean-growing region, the SEALBA region still has lower production rates than other producing regions in NEB (SANTIAGO *et al*., 2019; PROCÓPIO *et al*., 2018).

Soybean cultivation has emerged as an important alternative for crop diversification and is primarily used to replace areas previously cultivated with sugarcane. However, knowledge about its water management and the best cultivars for the soil and climate conditions of Alagoas still needs to be elucidated, which is a limiting factor for increasing its productivity in the region and influencing the expansion of cultivated areas (SANTIAGO *et al*., 2019; CRUZ *et al*., 2009).

Farmers in the coastal tablelands region of Alagoas grow grains in rainfed conditions at the beginning of the rainy season, between May and September, during a harvest that occurs in the autumn–winter seasons, which differentiates them from other producing regions (PROCÓPIO *et al*., 2018; LYRA *et al*., 2014; SOUZA *et al*., 2004).

According to Souza *et al*. (2004), the coastal Tablelands region of Alagoas has an average annual rainfall of 1,800 mm, with 70% of the rainfall concentrated between April and August, whereas 30% falls between October and February. Although the annual rainfall index is relatively high, there is a possibility of dry spells, especially during the region's rainy season. Owing to this seasonality, the water needs of crops may not be met by rainfall, making supplemental irrigation necessary (CARVALHO *et al*., 2013; LYRA *et al*., 2010).

Water availability is a crucial resource for agricultural production, which explains the varying productivity levels among soybean-producing regions in Brazil. In this context, the role of irrigation stands out, as it is a key practice for improving agricultural productivity, especially during seasons with low precipitation. Weather conditions during the soybean growth phase are the main causes of variability in production between harvests and regions, with water deficits accounting for an average of 46% of crop productivity (PROCÓPIO *et al.*, 2018; BATTISTI *et al.*, 2018; SENTELHAS *et al.*, 2015).

Research on competing soybean cultivars is important for providing materials adapted to the climate and soil environmental characteristics of a specific location, which can ensure good agronomic performance for soybean farmers. Given the above, the objective of this study was to compare the production components of six soybean cultivars under supplemental irrigation and dryland conditions over two years of cultivation in the coastal tablelands region of Alagoas.

4 MATERIALS AND METHODS

4.1 Characterization of the experimental area

The soil of the experimental area was classified as Cohesive Yellow Latosol, with a medium/clayey texture, and its physical–chemical characteristics are presented in Table 1. Notably, chemical analysis of the soil was used as a basis for fertilization.

Table 1. Physical and chemical characteristics of the soil in the experimental area located in Rio Largo, Alagoas.

Physical Characteristics					
VIB	Volumetric Density	Total porosity	θ_{CC}	θ_{PMP}	Average slope
($mm\ h^{-1}$)	($Mg\ m^{-3}$)	-------------------- $m^3\ m^{-3}$ ----------------			(%)
52	1.52	0.423	0.244	0.148	≤2

Chemical Characteristics									
Prof. m	pH H_2O	P	K	In the	Here	Mg	Al	H + Al	²CTC t
		-------- mg dm^{-3} ------			--------------- cmol dm^{-3} ---------------				
0 - 0.20	5.5	3	20	10	1.89	1.23	0.09	4.66	3.3
0.2 - 0.40	6.1	4	25	10	2.5	1.89	0	3.12	4.49

Prof. m	CTC_T $cmol.dm^{-3}$	MO $g\ kg^{-1}$	SB	m	Her e	Mg	K	In the
			----------------------------------- % -----------------------					
0 - 0.20	7.87	26.3	41	3	24	15.6	0.6	0.5
0.2 - 0.40	7.61	29	59	0	32.9	24.8	0.8	0.5

VIB – basic infiltration rate, Θ_{CC} – field capacity, Θ_{PMP} – permanent wilting point, Prof. – depth, pH – hydrogen potential, P – phosphorus, K – potassium, Na – sodium, Ca – calcium, Mg – magnesium, Al – aluminum, H+Al – hydrogen plus aluminum, CTCt – effective cation exchange capacity, CTCT – total cation exchange capacity, MO – organic matter, SB – sum of bases, m – aluminum saturation.

Source: Authors (2022).

The field experiments were conducted over two years of cultivation in an area of 0.12 ha. The first experiment received supplementary irrigation and was carried out during the region's dry season, from 11/14/2018 to 04/03/19 (140 days), whereas the second experiment was cultivated under rainfed conditions and was conducted in the rainy season, from 06/20/19 to 10/28/2019 (130 days).

Soil preparation was carried out with two harrowings, after which the furrows were opened for fertilization. Base fertilization followed the recommendations of the Agronomic Institute of Pernambuco-IPA (2008) for soybean crops. 80 and 60 k ha $^{-1}$ simple superphosphate (18% P_2O_5) were applied. and potassium chloride (60% K_2O), respectively.

For planting, industrially treated seeds (TSIs) inoculated with *Bradyrhizobium were used. japonicum* for biological nitrogen fixation (BNF). Sowing was performed manually, with a spacing between rows of 0.50 m, and the plant population was varied according to the cultivar and germination test (BRASIL, 2009).

For weed control, flumioxazine (500 g/L) was used preemergence, and glyphosate N-(phosphonomethyl) glycine (370 g/L) and glyphosate (445 g/L) were used postemergence. Pest control was carried out through the application of the insecticides imidacloprid (700 g/kg) and lambda-cyhalothrin (50 g/L). Preventive control of fungal diseases was carried out by applying the fungicides tebuconazole (200 g/L) and trifloxystrobin (100 g/L) at the V3 and R1 stages, respectively (AGROFIT, 2019).

4.2 Design and treatments

The experimental design used was randomized blocks, with five replicates and six treatments, with the treatments consisting of soybean cultivars with high production potential that present different growth habits and maturity groups (Table 2).

Table 2. Name, growth habit, cycle and maturity group of soybean cultivars used in the work in Rio Largo, AL.

Cultivate	Growth Habit	Cycle	Maturation group
M 6210 IPRO (*)	Undetermined	Precocious	6.2
M 6410 IPRO	Undetermined	Precocious	6.4
BMX-POWER RR	Undetermined	Semiprecocious	6.7
AS 3730 IPRO	Undetermined	Super precocious	7.3
M 8349 IPRO	Determined	Intermediary	8.3
BRS 9383 IPRO	Determined	Late	9.3

(*) M - Monsoy; BRS - National Soybean Research Center (Embrapa Soja); BMX- Brasmax (GDM seeds); AS-Agroeste seeds.
Source: Authors (2022).

The dimensions of the experimental area were 35.0 m long by 33.0 m wide, totaling 1,155 m^2. In each block, six plots composed of 10 lines measuring 5.0 m long (25.0 m^2) were established.

4.3 Meteorological data and irrigation management

The reference evapotranspiration (ET_0) during the experimental period was calculated via the Penmann–Monteith method, parameterized in the FAO-56 bulletin (ALLEN *et al*., 1998), Equation (1). The meteorological data were collected from an automatic meteorological station (Micrologger – CR 1000, Campbell Scientific, Logan, Utah).

$$ET_0 = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{900}{Tmed+273} U\,(e_s - e_a)}{\Delta + \gamma(1 + 0{,}34U_2)} \quad (1)$$

where ET_0: Reference evapotranspiration (mm day^{-1}); Rn: Daily net radiation (MJ m^{-2} day^{-1}); G: Total daily soil heat flux (MJ m^{-2} day^{-1}); T: Mean daily air temperature (°C); U_2: Mean daily wind speed at a height of 2 m (ms$^{-1)}$; es: Mean daily vapor saturation pressure (kPa); ea: Current mean daily vapor pressure (kPa); (eas-ea): mean daily vapor saturation deficit (kPa); Δ: slope of the vapor pressure versus temperature curve (kPa °C^{-1}); and γ: psychrometric coefficient (kPa °C^{-1}).

Supplemental irrigation in the first experiment was performed via the sprinkler method with Agropolo NY-25 sprinklers, with a nominal diameter of 3.0 × 0.0 mm and a red nozzle spaced 12.0 × 12.0 m apart, with a service pressure of 30 mca, an average flow rate of 0.50 m³ h^{-1} and an application intensity of 3.6 mm h^{-1}. The irrigation depths applied throughout the experiment were recorded via water meter readings (Table 3), and irrigation management was based on crop evapotranspiration (ETc), Equation 2.

$$ET_c = ET_0 K_c \quad (2)$$

where: *ETc*: Crop evapotranspiration (mm day^{-1}); ET_0: Reference evapotranspiration (mm day^{-1}); and K_c: Crop coefficient in each development phase. The values considered were 1.0, 1.2 and 0.50 for the initial, vegetative and final phases, respectively, according to the FAO-56 bulletin (ALLEN *et al*., 1998).

Table 3. Soybean cultivars and total water in the irrigated experiment (irrigation + precipitation) and in the experiment in dryland (rainfall) in Rio Largo, Alagoas.

Cultivars	**IRRIGATED**	**DRYNESS**
	(mm)	
M 6210	601.0	515.0
M 6410	617.0	530.0
BMX-Power	650.0	531.0
AS 3730	617.0	530.0
M 8349	650.0	537.0
BRS-9383	720.0	547.0

Source: Authors (2022).

4.4 Soil moisture measurements

Soil water storage (ARM, mm) was monitored from the water balance using the method of Thorntwaite and Mather (1955), adapted by Lyra *et al.* (2010) for agricultural crops. For this purpose, the soil water capacity (CAD, mm) was calculated for each crop stage according to Equation 3, which was developed as a function of the effective depth of the root system (z, m), which varies from 0.1 to 0.4 m between emergence and senescence (FEHR; CAVINESS, 1977). The values of soil moisture on a wet basis at field capacity and the permanent wilting point (θ, m^3 m^{-3}) were determined via the soil water retention curve.

$$CAD = 1.000(\theta_{cc} - \theta_{pmp})z \quad (3)$$

where *CAD* is the soil water capacity (mm); θcc is the field capacity, which is equal to 0.244 m^3 m^{-3}; and θ_{pmp} is the permanent wilting point, which is equal to 0.148 m^3 m^{-3}.

The readily available water (AFD, mm) was calculated according to Equation (4), which uses a water availability factor equal to 0.60 (BERNARDO *et al*., 2019).

$$AFD = CADf \quad (4)$$

where AFD: Readily available water (mm); CAD: Soil water capacity (mm); and *f*: Crop water availability.

4.5 Data collection for production components

Harvesting was carried out when the plants reached the physiological maturity stage (R8), that is, when they presented high grain dry matter, close to 13% moisture. The following production components were evaluated: first pod insertion height (AIPV, cm), number of pods per plant (NVP, Unit), thousand grain weight (MMG, g), plant dry matter (MSP, sum of the dry mass of leaves, branches and pods, kg ha $^{-1}$), harvest index (CI), water productivity (PA, kg m^{-3}) and grain yield (RG, kg ha^{-1}).

The AIPV and NVP were evaluated in 10 plants per plot, which were randomly chosen. The first variable was measured by the distance between the root collar and the first pod, whereas the second was calculated by counting it in the plants. The MMG (g) was obtained by weighing 100 grains, with eight replicates, and multiplying the average by 10 (BRASIL, 2009).

The ratio between the RG (kg ha^{-1}) and the MSP (kg ha $^{-1}$) determines the IC, according to Equation 5.

$$IC = \frac{\mathrm{RG}}{\mathrm{MSP}} \quad (5)$$

where IC is the harvest index; RG is the grain yield (kg ha^{-1}); and MSP is the plant dry matter, which is the sum of the dry masses of leaves, branches and pods (kg ha^{-1}).

The BP (kg m^{-3}) was estimated according to Equation (6):

$$PA = \frac{RG}{10ETc} \quad (6)$$

where PA is the water productivity (kg m $^{-3}$), RG is the grain yield (kg ha $^{-1}$), and ET $_c$ total is the total crop evapotranspiration (mm). A factor of 10 is intended to convert the water depth (mm) into the volume of water applied (m^3 ha^{-1}).

The RG (kg ha^{-1}) was calculated from the dry mass of the grains (13% moisture), collected in the useful area of 4.0 m2 of each plot and subsequently estimated for one hectare via Equation 7.

$$\mathrm{RG} = \left(\frac{M}{C*E}\right) 10.000 \quad (7)$$

where RG is the grain yield (kg ha $^{-1}$); M is the mass harvested in the sampled area (4.0 m^2, in kg); C is the length of the rows planted in the sampled area (m); and E is the spacing between rows (m). The factor of 10,000 is intended to convert the area from m^2 to ha.

4.6 Statistical analysis

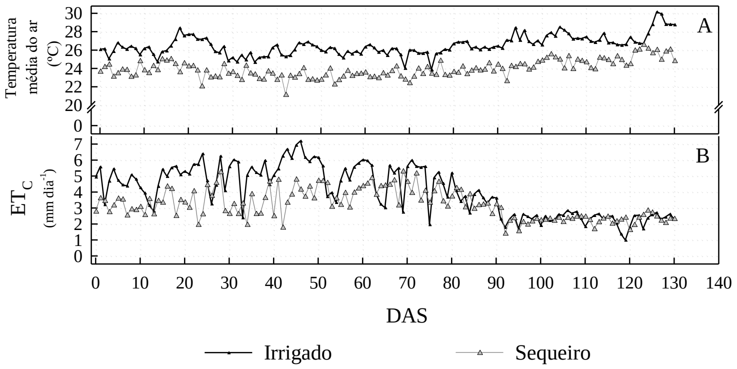
Univariate cluster analysis was used according to the Scott–Knott test. (1974) ($p \leq 0.05$), to avoid ambiguities in comparing means.

5 RESULTS AND DISCUSSION

5.1 Weather conditions

The meteorological conditions to which the soybean cultivars were exposed varied between the experiments (Figure 1). During the irrigated experiment, the average air temperature (26.5 °C) was higher than that observed in the dryland experiment. The average maximum air temperature recorded at 126 days after sowing (DAS) (March 20, 2019) in the irrigated experiment was 30.2 °C, with a minimum of 23.9 °C at 75 DAS (January 28, 2019).

Figure 1. Average daily air temperature (A) and crop evapotranspiration (B) during two soybean cultivation cycles, one under irrigation, from November 14, 2018, to April 3, 2019, and the other under rainfed conditions, from June 20, 2019, to October 28, 2019, in Rio Largo, Alagoas.



Source: Authors (2022).

Compared with those during the irrigated cycle, the air temperatures during the dryland experiment tended to decrease. Because it was conducted within the rainy season of the coastal listlands region, the maximum average daily air temperature in this cycle was 26.6 °C at 123 DAS (10/21/2019), with an average of 24 °C and a minimum of 21.2 °C at 42 DAS (08/01/2019) (Figure 1A).

Souza *et al.* (2004) evaluated the air temperature in the coastal tablelands region of Alagoas from 1972--2001 and reported that the period between May 21st and October 10th is the one that best meets the optimal thermal needs of agricultural crops. However, considering that the optimal temperature for soybean development is between 20 and 30 °C (LOPES; LIMA, 2015), in both experiments, there were no thermal limitations on plant growth and development.

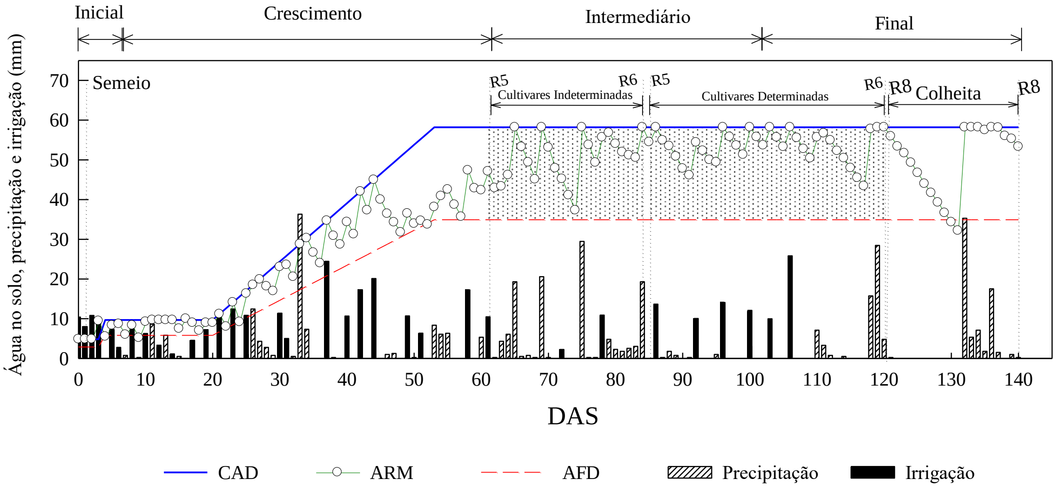
The ETc during the irrigated cycle was 12% greater than that during the rainfed experiment (Figure 1B), which can be explained by the higher incidence of radiation, which consequently increased the temperature of the vegetative canopy and soil, consequently increasing the plant transpiration gradient and water evaporation to the atmosphere. The ETc values recorded in the first cycle were as follows: a maximum of 7.20 mm day $^{-1}$ at 46 DAS (12/30/18), a minimum of 0.99 mm day $^{-1}$ at 119 DAS (03/13/19) and an average of 3.90 mm day $^{-1}$. Considering the 140 days of cultivation, at the end of the experiment, 589 mm were totaled. The ETc in drylands totaled 422 mm in 130 days of cultivation, with a maximum of 5.31 mm at 69 DAS (08/28/2019), an average of 3.22 mm and a minimum of 1.42 mm at 92 DAS (09/20/2019). Evapotranspiration is one of the main factors influencing the relationships among soil, plants, water and the atmosphere because the level of water used by a crop is directly related to the development of stress in plants (ALLEN *et al.*, 1998).

5.2 Soil water balance

5.2.1 Irrigation experiment

After 140 days of irrigated cultivation, the water balance included 375 mm of rainfall. The rainiest month was January (109.20 mm), with November being the least rainy (25.0 mm). The highest rainfall value recorded was 36.32 mm day $^{-1}$ at 33 DAS (12/17/2018), with an average rainfall of 2.70 mm day $^{-1}$ (Figure 2). There was excess water only at 28 days (20% of the cultivation cycle), and at 70 days (50%) of the cultivation cycle, there was no rain.

Figure 2. Variation in soil water storage (ARM, mm) for soybean cultivation under irrigation from November 14, 2018, to April 3, 2019, as determined by the Thornthwaite and Matter water balance in Rio Largo, Alagoas.



Source: Authors (2022).

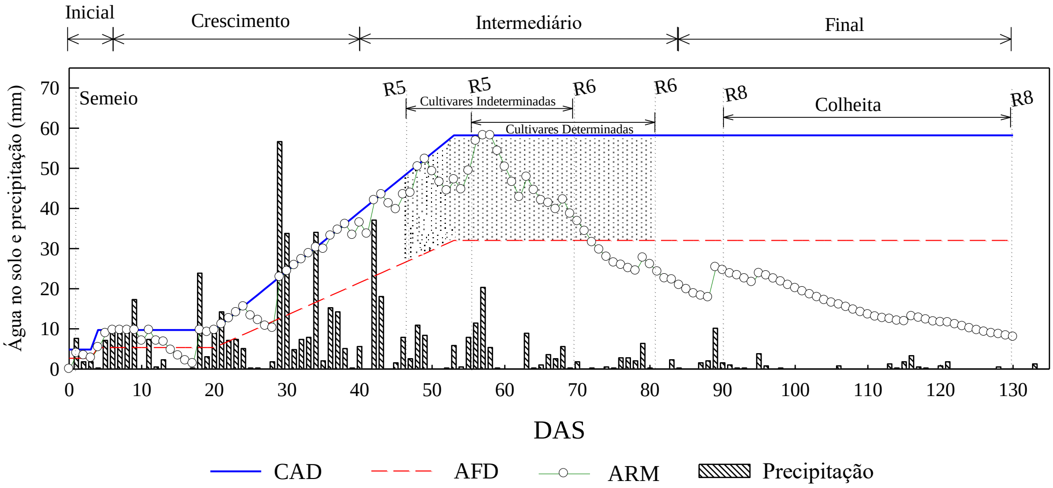
The irrigation depth applied throughout the cycle totaled 345.30 mm, with maximum, minimum, and average values of 25.85, 2.26, and 10.46 mm, respectively. There was an increase in water availability to the crop, as observed by the effective rainfall of 720 mm, which resulted in an ARM above the readily available water (Figure 2). Moreover, the ARM did not compromise the periods of greatest sensitivity to water shortages, especially during the grain-filling stages (R5--R6).

Studies conducted with water replacement levels have shown that moderate soil water deficits for short periods during vegetative stages generally do not reduce soybean yield. However, if this deficit occurs during the pod enlargement and grain filling stages, it negatively affects production components (ANDA *et al.*, 2019; MONTOYA *et al.*, 2017; GAVA *et al.*, 2015).

5.2.2 Rainfeeding experiment

With respect to the water balance in the dryland experiment, the total rainfall was 547.37 mm during the 130 days of cultivation. July was the wettest month (269.50 mm), and October was the least rainy month (11.20 mm). Water availability to plants continued until the 73rd DAS, but it was insufficient to support the entire production cycle of the cultivars. Three periods of low soil water storage were observed: the first between the 14th and 17th DAS, the second between the 25th and 27th DAS, and the third at the 73rd DAS, which were equivalent to 11.7, 23.0, and 79.0 mm, respectively. The first and second periods without rain occurred during the initial stages of soybean growth and development. The third, in which the ARM fell drastically, occurred during the grain-filling stage (R6). There was excess rainfall during 24 days of the growing cycle (18.46%), with 44 days (33%) without rain. The greatest amount of rainfall occurred at 29 DAS, which was equivalent to 56 mm (Figure 3).

Figure 3. Variation in soil water storage (ARM, mm) for soybean cultivation, from June 20, 2019, to October 28, 2019, as a function of days after sowing, determined by the Thornthwaite and Matter water balance in Rio Largo, Alagoas .



Source: Authors (2022).

The indeterminate growth cultivars started the R5-R6 stages from the 50th to the 70th DAS; however, the determinate growth cultivars, M 8349 and BRS-9383, started these stages at the 56th and 65th DAS, respectively; therefore, they presented lower water availability at these stages than the indeterminate growth cultivars did.

5.3 Production components

5.3.1 Analysis of variance

In both experiments (irrigated and rainfed), there was a significant difference between cultivars at 1% probability for the following variables: height of insertion of the first pod, number of pods per plant, weight of a thousand grains, harvest index, water productivity and grain yield (Table 4).

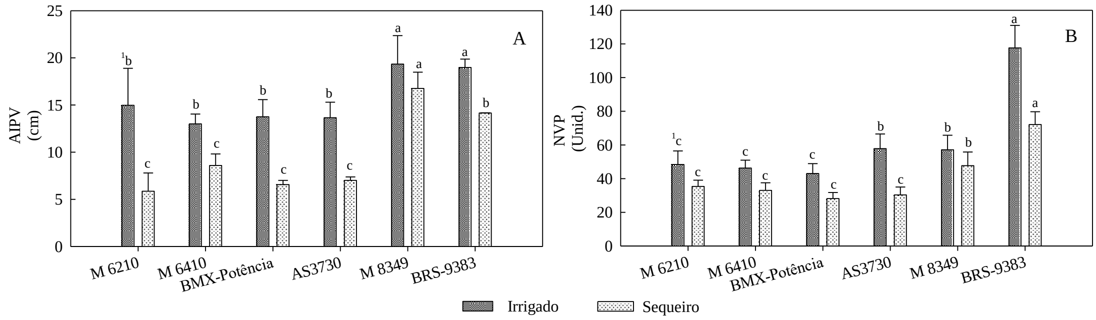
Table 4. Analysis of variance for the production components of irrigated soybean cultivars, with a cycle from 11/14/18 to 04/03/19, and rainfed, with a cycle from 06/20/2019 to 10/28/2019, in Rio Largo, Alagoas.

		Mean Square Values [2]					
Sources of variation	GL	***Irrigated***					
		AIPV	NVP	MMG	IC	SHOVEL	ID
Cultivars (C)	5	30.70**	3932.90 **	2385.64**	477.34**	0.144**	914.70**
Block	4	9.27 ns	118.82 ns	311.07 ns	63.43 ns	0.083 ns	51.92 ns
Residue	20	4.61	66.38	107.93	45.96	0.018	119.22
Total	29	-	-	-	-	-	-
CV (%)		13.75	13.20	5.49	19	12.28	12:30
		Dryland					
		AIPV	NVP	MMG	IC	SHOVEL	ID
Cultivars (C)	5	102.63 **	1387.54**	1047.47**	0.078**	0.065**	314.0**
Block	4	0.26 ns	7.63 ns	13.44 ns	0.0013 ns	0.002 ns	13.36 ns
Residue	20	1.66	36.94	18.92	0.0041	0.004	18.55
Total	29	-	-	-	-	-	-
CV (%)		13,14	14.78	2.79	17.75	8.82	8.75

[1] Degrees of freedom; [2] **Significant at the 1% level; ns not significant according to the F test. CV: coefficient of variation; first pod insertion height (FIAP, cm), number of pods per plant (NPP, unit), thousand-grain weight (MMG, g), harvest index (HI), water productivity (WP, kg m $^{-3}$) and grain yield (GY, kg ha $^{-1}$).
Source: Authors (2022).

For the AIPV of the irrigated cultivars, two contrasting groups were formed: the first with averages of 19.0 (BRS-9383) and 19.30 cm (M 8349) and the second with averages ranging from 13.0 (M 6410) to 15.0 cm (M 6210) (Figure 4A). Cultivar selection as well as management practices should focus first on pod insertion heights of at least 10 cm, which avoids losses in mechanized harvesting (CARMO *et al*. 2018; CARVALHO *et al*., 2010). In the present work, the AIPV values were greater than 10 cm under both irrigated and dryland conditions.

Figure 4. Height of Insertion of the First Pod (A) and Number of Pods per Plant (B) of irrigated soybean cultivars, cultivation cycle from 11/14/18 to 04/03/19, and in dryland, cultivation cycle from 06/20/2019 to 10/28/2019, in Rio Largo, Alagoas.



[1] Means followed by the same letter do not differ from each other according to the Scott–Knott test (1974), with p<0.05.
Source: Authors (2022).

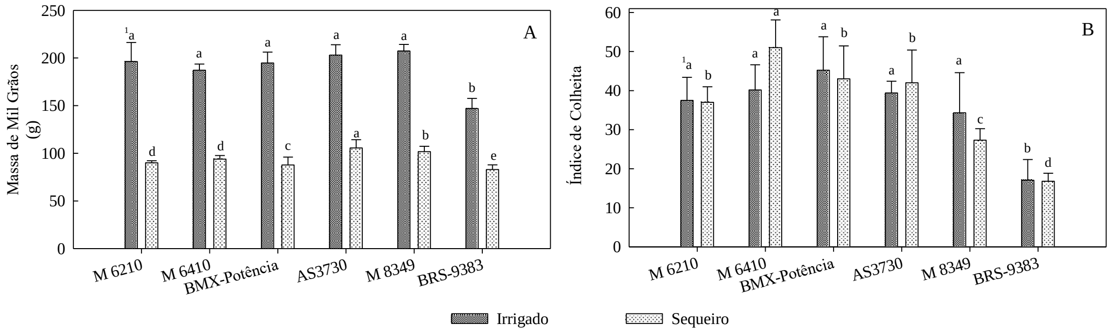
For the AIPV in drylands, two groups were also formed: the first with averages of 14.15 (BRS-9383) and 16.80 cm (M 8349) and the second with averages ranging from 5.85 (M 6210) to 8.60 cm (M 6410). In general, the average AIPV of the irrigated experiment was 15.61 cm, which was 37.10% greater than the average AIPV of the dryland experiment (9.82 cm) (Figure 4A).

Regarding the NVP of the cultivars under irrigation, the observed means were grouped into three contrasting groups: the first with 118.0 units (BRS-9383); the second with means ranging from 57.80 (AS 3730) and 57.16 units (M 8349); and the third with means ranging from 43.0 (BMX-Potência) to 48.40 units (M 6210) (Figure 4B). This variation can be attributed to the genetic characteristics of each cultivar in relation to plant architecture, growth habits and the number of races.

The NVP in the dryland experiment was also grouped into three groups: the first with 72.12 units (BRS-9383), the second with 47.71 units (M 8349) and the third with means ranging from 28 (AS 3730) to 35.34 units (M 6210) (Figure 4B). Comparing the overall mean NVP between the irrigated and dryland cultivars, a 33.40% reduction in the values recorded in the dryland experiment was observed in relation to those recorded in the irrigated experiment, possibly due to the abortion of flowers and pods in the dryland experiment. According to Mauad *et al*. (2010), the NVP is determined by the balance between the number of flowers produced per plant and the proportion of those that develop into pods.

For the MMG of the irrigated cultivars, the Scott–Knott test generated two contrasting groups, one with means ranging from 187.20 (M 6410) to 207.23 g (M 8349) and another in which the lowest MMG value of 147.92 g was observed (BRS-9383) (Figure 5A).

Figure 5. Thousand-grain mass (A) and harvest index (CI) (B) data of irrigated soybean cultivars, with cultivation cycles from 11/14/18 to 04/03/19, and dryland, with cultivation cycles from 06/20/2019 to 10/28/2019, in Rio Largo, Alagoas.



[1] Means followed by the same letter do not differ from each other according to the Scott–Knott test (1974), with $p<0.05$.
Source: Authors (2022).

For the MMG in the dryland experiment, the Scott–Knott test yielded five groups: the first with an average of 176.0 g (AS 3730); the second with an average of 170.0 g (M 8349); the third with an average of 156.27 g (BMX-Potência); the fourth with average observed values of 146.27 (M 6410) and 150 g (M 6210); and the fifth with an average of 137.80 g (BRS-9383) (Figure 5A).

There was a 17.60% reduction in the average MMG of the cultivars in the dryland experiment compared with the irrigated experiment. According to Carmo *et al.* (2018), soybean cultivation under water deficit increases the number of small and wrinkled grains, since reduced water availability for plants reduces photosynthetic rates and the duration of the grain-filling period.

Different results were reported by Procópio *et al.* (2018) when eight soybean cultivars with different plant populations were evaluated in SEALBA from 2016--2017. The authors reported an average Hundred Grain Mass (MCG) for the first year (2016) of 19.84 g among the cultivars and 18.62 g in the second year (2017). Rocha *et al*. (2012) evaluated 32 soybean genotypes under low-latitude conditions in the state of Piauí and reported average MCG values ranging from 15.29 to 20.78 g.

The observed values show that NVP is offset by increased MMG, enabling satisfactory productivity. This is possibly because a lower NVP reduces competition for photoassimilates, which contributes to a higher MMG (Figures 4B and 5A).

For the CI of the cultivars under irrigation, the observed values ranged from 17.0 to 45.0 (Figure 5B). The cultivars with the shortest cycles (Table 2) presented higher CIs, which shows that the cultivars in this group had a greater capacity to convert dry matter into grain yield.

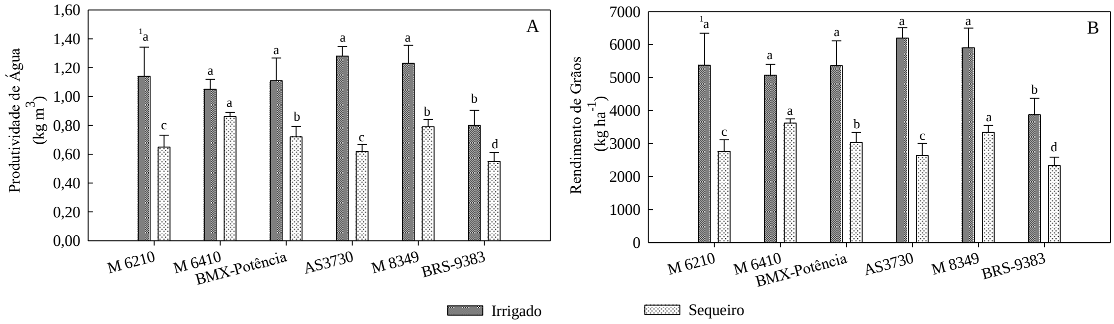
For the IC of the cultivars in dryland conditions, four groups were formed: in the first group, the maximum IC value was 52.0 for the cultivar M 6410; in the second group, the average value varied from 37.0 (M 6210) to 40.0 (BMX-Potência); in the third group, the IC was 27.0 (M 8349); and in the fourth group, the lowest IC recorded was 17.0 (BRS-9383) (Figure 5B).

In general, when the average IC of irrigated cultivars (35.60) is compared with that of rainfed cultivars (36.20), a small decrease of 1.60% is observed, resulting from the reduction in dry matter of plants in rainfed conditions, which increases the conversion capacity of cultivars in rainfed conditions.

In terms of the BP of the irrigated cultivars, the highest value observed was

1.30 kg m $^{-3}$ (AS 3730), which was 38% higher than the lowest average value of 0.80 kg m $^{-3}$ (BRS-9383). The Scott–Knott test generated two groups: the first with averages ranging from 1.05 (M 6410) to 1.30 (AS 3730) kg m $^{-3}$ and the second with only cultivar BRS-9383, which presented an average of 0.80 kg m $^{-3}$ (Figure 6A).

Figure 6. Water productivity (A) and grain yield (B) of irrigated soybean cultivars; cultivation cycle from 11/14/18 to 04/03/19; and, in drylands, cultivation cycle from 06/20/2019 to 10/28/2019 in Rio Largo, Alagoas.



[1] Means followed by the same letter do not differ from each other according to the Scott–Knott test (1974), with $p<0.05$.
Source: Authors (2022).

Water productivity (WP) is an important indicator for water management in agriculture, as it considers grain yield through plant water consumption. The results obtained in this study show that the WP of irrigated cultivars was 36.60% greater than that of rainfed cultivars, as irrigation replenishes water lost through ETc, especially during periods of sensitivity to water deficit, thus increasing grain productivity. Divergent values were reported by Montoya *et al*. (2017), who reported WP values between 0.47 and 0.65 kg m $^{-3}$. In general, studies with irrigated soybean cultivars have shown WP values ranging from 0.55 to 1.15 kg m $^{-3}$ (GAJIĆ *et al*., 2018; GARCIA y GARCIA *et al*., 2010). These results corroborate the data from this study and confirm that soybean water productivity is greater under irrigation.

The observed averages for the BPs of the cultivars in rainfed conditions ranged from 0.86 to 0.55 kg m $^{-3}$. The Scott–Knott test generated four contrasting groups: the first with 0.86 kg m $^{-3}$ (M 6410); the second with 0.72 (M 8349) and 0.79 (BMX-Potência) kg m $^{-3}$; the third with 0.62 (AS 3730) and 0.65 (M 6210) kg m $^{-3}$; and the fourth with the lowest water–grain conversion of 0.55 kg m $^{-3}$ in cultivar BRS-9383 (Figure 6A). These values are within the range reported for BP in rainfed soybean. Alfonso *et al.* (2020) evaluated rainfed soybean cultivars with different cover crop systems and reported BP values between 0.593 and 0.83 kg m $^{-3}$. Demirtas *et al.* (2010) reported BP values ranging from 0.41 to 0.64 kg m $^{-3}$ for rainfed soybean crops in the subhumid region of Turkey.

The average RGs observed in the irrigated cultivars were grouped into two groups: one with the highest productivities, with RGs in the range of 5,070 (M 6410) to 6,180 (AS 3730) kg ha $^{-1}$, equivalent to 84.5 to 103 bags, respectively, and another with only the lowest RG, equal to 3,870 kg ha $^{-1}$ (cultivar BRS-9383), equivalent to 64.5 bags (Figure 6B).

According to Battisti *et al*. (2018), a lack of water is one of the main factors for the loss of soybean productivity nationwide, especially in Northeast China. A comparison of the general average of cultivars under irrigation (5,280 kg ha $^{-1}$) (88 bags) with those under rainfed conditions (3,000 kg ha $^{-1}$) (50 bags) revealed a reduction of approximately 43%, which highlights the effect of water deficit on cultivar productivity.

The RGs under dryland conditions widely varied across the cultivars. The Scott–Knott test revealed four distinct groups: the first had values ranging from 3,336 (M 8349) to 3,600 (M 6410) kg ha $^{-1}$ (55, 60 and 60 bags, respectively); the second group had 3,030 (BMX-Potência) kg ha $^{-1}$ (50, 50 bags); the third group had 2,640 (AS 3730) and 2,760 (M 6210) kg ha $^{-1}$ (44 and 46 bags, respectively); and the fourth group had the lowest productivity value, with RGs equal to 2,340 (BRS-9383) kg ha $^{-1}$ (39 bags) (Figure 6B). These results show that the sowing of late-cycle cultivars must coincide with greater water availability through precipitation during critical grain-filling periods.

Santiago *et al*. (2019) evaluated 50 soybean genotypes in Alagoas under rainfed conditions in 1st- and 4th-year cultivation areas with a history of sugarcane production and reported RGs ranging from 2,470 (M 8349) to 2,515 (BRS-9383) kg ha $^{-1 \text{ in the 1st-year area}}$. However, in the 4th-year cultivation area, the cultivars presented the opposite trend, with RGs ranging from 3,148 (BRS-9383) to 3,357 kg ha $^{-1}$ (M 8349).

Procópio *et al*. (2018) evaluated eight soybean cultivars under rainfed conditions with different plant populations in the municipalities of Alagoas and reported average RGs of 2,370 kg ha $^{-1}$ (BRS-GISELE) and 2,203 kg ha $^{-1}$ (BRS-270) in São Miguel dos Campos; 3,958 kg ha $^{-1}$ (BRSGO-8661) and 4,332 kg ha $^{-1}$ (BRS-9280) in Jundiá; and 1,783 kg ha $^{-1}$ (BRSGO-8660) and 2,169 kg ha $^{-1}$ (BRSGO-9160) in Campo Alegre, highlighting the productive potential of soybean even when it is grown under rainfed conditions.

Viana *et al*. (2017) evaluated five soybean cultivars in the southern Agreste region of Pernambuco and reported RGs ranging from 606.30 to 1,616.80 kg ha $^{-1}$. Rocha *et al*. (2012) evaluated 13 soybean genotypes under low-latitude conditions in Teresina, Piauí, and observed a variation in RG from 1,485 to 3,585 kg ha $^{-1}$.

However, Cruz *et al*. (2014), when evaluating five soybean cultivars in five sowing seasons in western Bahia, reported a GR of 4,142 kg ha $^{-1}$ in the first sowing season of the cultivar BRS-CORISCO. Bohn *et al*. (2016) evaluated soybean cultivars from the southwestern region of the Cerrado of Piauí and reported that of the 15 cultivars tested, 10 presented productivities higher than 3,500 kg ha $^{-1}$ and that only M 8527 presented a GR of 3,000 kg ha $^{-1}$. These results indicate that the grain yield of soybean cultivars is lower under rainfed conditions since the lack of water during critical development periods reduces productivity.

Table 5 shows the observed averages for the production components. Notably, the values in bold indicate the best cultivars within the variables studied, according to the Scott–Knott test (1974).

Table 5. Observed averages for the production components of irrigated soybean cultivars, cultivation cycles from 11/14/18 to 04/03/19, and dryland cultivation cycles from 06/20/2019 to 10/28/2019 in Rio Largo, Alagoas.

			Irrigated			
Cultivate	AIPV	NVP	MMG	IC	SHOVEL	ID
M 6210	14.97	48.40	**196.30**	**37.50**	**1.14**	**5,373.60**
M 6410	13.00	46.30	**187.19**	**40.16**	**1.05**	**5,071.0**
BMX-Power	13.76	43.00	**194.70**	**45.23**	**1.11**	**5,361.60**
AS 3730	13.65	57.80	**202.94**	**39.40**	**1.28**	**6,198.0**
M 8349	**19.34**	57.16	**207.23**	**34.30**	**1.23**	**5,904.0**
BRS-9383	**18.98**	**117.60**	146.92	17.05	0.80	3,871.20
Overall average	15.62	61.71	189.21	35.61	1.10	5,296.57
			Dryland			
Cultivate	AIPV	NVP	MMG	IC	SHOVEL	ID
M 6210	5.85	35,34	90.0	37.00	0.65	2,766.60
M 6410	8.59	33.04	93.90	**51.00**	**0.86**	**3,624.0**
BMX-Power	6.56	28.16	87.75	43.00	0.72	3,031.20
AS 3730	7.01	30,33	**105.65**	42.00	0.62	2,631.60
M 8349	**16.76**	47.71	101.75	27:30	0.79	**3,340.20**
BRS-9383	**14,15**	**72.12**	82.97	16.80	0.55	2,328.00
Overall average	9.82	41.12	93.67	36.18	0.70	2,953.60

Height of first pod insertion (AIVP, cm), number of pods per plant (NVP, unit), thousand-grain mass (MMG, g), harvest index (CI), water productivity (WP, kg m^{-3}) and grain yield (RG, kg ha^{-1}). The cells in bold indicate the best cultivars within the studied variables, according to the Scott–Knott test (1974).

Source: Authors (2022).

On the coastal plateau of Alagoas, water availability is a determining factor for soybean yield, especially during the critical period of plant development. Therefore, cultivars that received water during the sensitivity phases were more productive in both experiments.

6 CONCLUSION

Water demand influences soybean productivity, as cultivars under irrigation have good production rates.

The planting of long-cycle cultivars in Alagoas should coincide with greater water availability during critical grain-filling periods.

Cultivars M 6410 and M 8349 presented the best yields and are therefore recommended for planting in the region.

The cultivar BRS-9383 had a lower yield than the other cultivars in both the irrigated and rainfed experiments.

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