Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252023v36n416rc

Growth and production of sugarcane varieties under supplementary irrigation and no irrigation

Crescimento e produção de variedades de cana-de-açúcar sob irrigação suplementar e sequeiro

Cesar J. da Silva[1], Danilton L. Flumignan[1], Sálvio N. S. Arcoverde[2]*, Éder Comunello[1]

[1]Researcher, Empresa de Pesquisa Agropecuária, Dourados, MS, Brazil. [2]Graduate Program in Agricultural Engineering, Universidade Federal da Grande Dourados, Dourados, MS, Brazil.

ABSTRACT - The area cultivated with sugarcane in Mato Grosso do Sul, Brazil, has increased significantly in recent years, in which to meet the demand of the mills, the use of adapted varieties has proved to be a fundamental strategy, combined with the use of irrigation, especially in periods of water deficit. The study aimed to evaluate the growth and yield of four sugarcane varieties (CTC 4, RB966928, RB975201, and RB92579) in plant cane cultivated with and without irrigation. The experiment was conducted at Embrapa Western Agriculture (Embrapa Agropecuária Oeste) in Dourados, MS, Brazil. A randomized block design arranged in a 2 x 4 factorial scheme with three replications was used. At 90, 150, 210, 270, 330, and 390 days after planting (DAP), stalk height and diameter, leaf area index (LAI), and dry biomass were evaluated. The soil cover percentage (%SC) was determined through aerial images taken with a drone, with evaluations made from planting to the maximum soil cover. Total recoverable sugar (TRS), number of stalks m^{-1}, stalk (STY), and sugar (SGY) yield were evaluated at 390 DAP (harvest). The RB975201 variety has the highest growth in height, stem diameter, and LAI when grown under irrigation or without irrigation, and the CTC 4 variety has the smallest. The irrigated production system increases the growth of stalks, LAI, and degree of soil cover for the sugarcane varieties in plant cane and a greater amount of stems m^{-1}, STY, and SGY, highlighting the varieties RB92579 and RB975201.

Keywords: Biomass. Energy crop. Growth indexes.

RESUMO - A área cultivada com cana-de-açúcar em Mato Grosso do Sul, Brasil tem aumentado significativamente nos últimos anos, em que para atender à demanda das usinas o uso de variedades adaptadas tem se mostrado estratégia fundamental, aliado ao uso da irrigação, sobretudo em períodos de déficit hídrico. Objetivou-se avaliar o crescimento e a produção de quatro variedades de cana-de-açúcar (CTC 4, RB966928, RB975201, RB92579), em cana-planta, cultivadas sob irrigação e sequeiro. O experimento foi conduzido na Embrapa Agropecuária Oeste, em Dourados, MS, Brasil em um delineamento em blocos ao acaso, em esquema fatorial 2 x 4, com três repetições. Aos 90, 150, 210, 270, 330 e 390 dias após o plantio (DAP) avaliou-se a altura e o diâmetro de colmos, o índice de área foliar (LAI) e a biomassa seca. O percentual de cobertura do solo (% SC) foi determinado, através de imagens aéreas tomadas com drone, com avaliações feitas desde o plantio até a máxima cobertura do solo. O açúcar total recuperável (TRS), o número de colmos m^{-1}, a produtividade de colmos (TSH) e de açúcar (TUH) foram avaliados aos 390 DAP (colheita). A variedade RB975201 apresenta maior crescimento em altura, diâmetro de colmo e LAI quando cultivada em sequeiro ou irrigação, a variedade CTC4, o menor. O sistema produtivo irrigado proporciona aumento no crescimento de colmos, LAI e grau de cobertura do solo para as variedades de cana-de-açúcar, em cana-planta, assim como maior quantidade de colmos m^{-1}, TSH e TUH, destacando-se as variedades RB92579 e RB975201.

Palavras-chave: Biomassa. Cultura energética. Índices de crescimento.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

Received for publication in: November 7, 2022.
Accepted in: April 14, 2023.

***Corresponding author:**
<salvionapoleao@gmail.com>

INTRODUCTION

Approximately 83% of the world sugarcane production is concentrated in ten countries, with Brazil being the largest producer, with about 37% of the production, which represents 746 million tons per year (FAO, 2021). Sugarcane is a high energy biomass species, with sugar stored in its stalk, and is used as a raw material for ethanol and sugar production. In addition, the lignocellulosic residue generated after sugar extraction can produce biofuels or other bioproducts (AWE; REICHERT; FONTANELA, 2020).

However, the low yield of varieties can affect the number of sugarcane derivatives, so studying the growth of the crop and adapting management to phenological stages becomes important, especially to maximize plant growth, with special attention to the effects of water deficiency, because besides limiting yield, it reduces its genetic potential (JANE et al., 2020)

Water deficit affects various aspects of plant growth, with its most pronounced effects being reducing plant size, leaf area, and yield. The impact caused by water deficit depends considerably on the phenological stage in which it occurs and the duration of the stress (INMAN-BAMBER et al., 2005). According to Dias et al. (2012), plant height, shoot biomass yield, soluble solids, and fiber contents are efficient indicators for selecting sugarcane varieties for tolerance to water deficit. When irrigated, sugar and alcohol production depends on several factors, such as the amount of water applied by irrigation (ABREU et al., 2013), the variety used (ARCOVERDE et al., 2019a), the type and management of the soil (ARCOVERDE et al., 2019a), and the climate of the region (DIAS; SENTELHAS, 2018). In this sense, Oliveira et al. (2012) verified increases in stalk yield with irrigation on a Latossolo Vermelho distrófico in Janaúba - MG and found different responses of the varieties RB85-5453 and SP80-1816 when subjected to three different irrigation suppression seasons (165, 195 and 225 days).

Investments in irrigation technology and the launch of new varieties are some technological advancement alternatives for Brazilian sugarcane fields (FARIAS et al., 2008; ARCOVERDE et al., 2019a). Combining irrigation with varieties adapted to edaphoclimatic conditions increases juice quality and stalk and sugar yield (ABREU et al., 2013). However, a large part of the irrigated sugarcane fields is being conducted in inadequate areas with low fertility, using varieties that are not responsive to irrigation, which limits the vertical growth of the crop and increases the cost of this technology.

On the other hand, in the sugarcane growing region of South-Central Brazil, there are doubts about the agronomic potential and magnitude of the yield increments of sugarcane submitted to supplementary irrigation. These doubts about the irrigation response are related especially to the low water deficit and occurrence of some rainfall even in the winter period, associated with Latossolos with good water retention capacity and milder temperatures, which reduces evapotranspiration (FIETZ et al., 2017).

In this context, this study aimed to evaluate the shoot growth and production of four sugarcane varieties, in plant-cane, under irrigation and rainfed conditions, in a sugarcane production environment classified as A (PRADO et al., 2008) in the climatic conditions of the southern region of the state of Mato Grosso do Sul.

MATERIAL AND METHODS

Location and characterization of the experimental area

The experiment was installed in the experimental area of Embrapa Western Agriculture (Embrapa Agropecuária Oeste) (22º16'31" S, 54º48'54" W; and 406 m altitude) in Dourados, MS, Brazil, on a Latossolo Vermelho distroférrico (SANTOS et al., 2018), a predominant soil in most sugarcane-producing areas in the state of Mato Grosso do Sul, Brazil. The relief is flat, with a slope of up to 3%, and the soil is deep and of clayey texture (65 to 70% clay), with a soil water holding capacity of 83 mm for the first meter of useful soil depth. The chemical characterization of the soil in the layers 0.00 to 0.10; 0.10 to 0.20, and 0.20 to 0.40 m is shown in Table 1.

Table 1. Chemical characterization of the soil before installation of the experiment.

Layer	[1]pH $CaCl_2$	[2]Al	[3]Ca	[3]Mg	[4]P	[5]K	V	m
--- cm ---		---------- $cmol_c$ dm^{-3} ----------			----- mg dm^{-3} -----		--------- % ---------	
0- 0.10	5.17	0.00	3.34	1.31	25.90	0.68	51.68	0.00
0.10-0.20	4.96	0.10	3.19	1.20	19.37	0.56	45.37	1.98
0.20-0.40	4.68	0.30	2.54	0.78	8.81	0.26	34.06	7.73

[1]potentiometry; [2]titulometry; [3]atomic absorption spectrophotometry; [4]extracted by Mehlich-1 extractor, by molecular absorption spectrometry; [5]flame emission spectrophotometry.

According to Fietz et al. (2017), the climate of the region, according to the Köppen-Geiger classification, is Cwa, humid mesothermal, with hot summers and dry winters. The least rainy period is concentrated from the first ten days of June to the second ten days of September, with the second ten days of August being the period with the lowest rainfall. The highest rainfall occurs from October to March, with December being the rainiest month. As for the average temperature of the region, Dourados can be divided into two periods, the first with averages above 20 ºC (August to April) and the second below 20 ºC (May to July). The lowest temperatures occur in June and July due to the cold fronts penetrating the region. The highest temperatures prevail in December and January.

According to Figure 1, which contains data from the Embrapa Western Agriculture weather station located in Dourados, MS, during the experimental period (April 2018 to July 2019), the average temperature in the region was 22.7 ºC, with a maximum of 37.5 ºC on January 23, 2019, and a minimum of 0.9 ºC on July 6 and 7, 2019. Total precipitation was 1700.8 mm, with October 2018 being the wettest month (306.3 mm), and the period from April to August 2018 was highlighted by little rainfall (158.7 mm in five months).

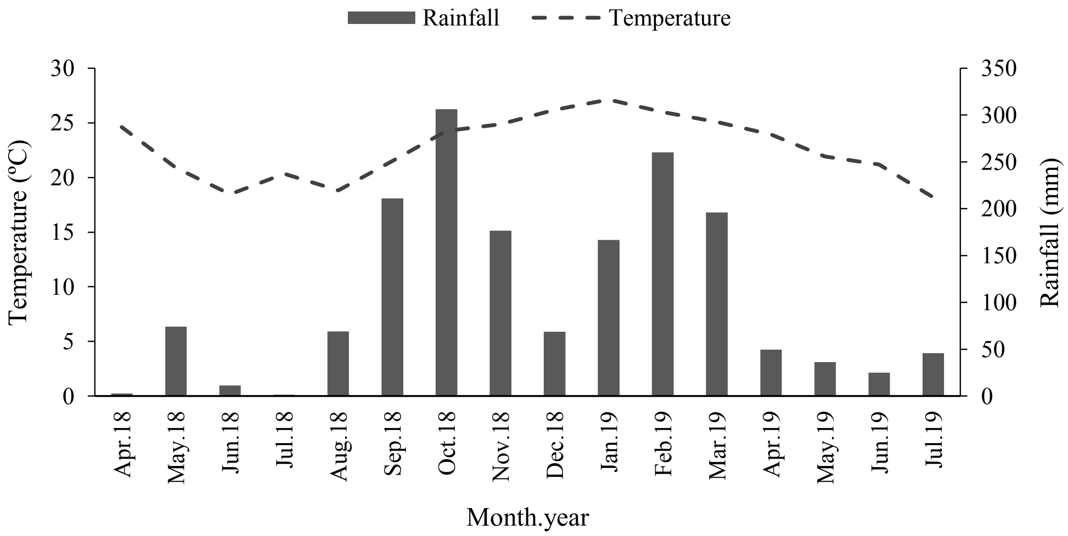


Figure 1. Monthly rainfall and temperature data in the experimental area (April 2018 to July 2019) collected by the weather station (22º16'30" S, 54º49'05" W; and 408 m altitude) located at Embrapa Western Agriculture in Dourados, MS, Brazil.

Installation and conduction of the experiment

The soil preparation operations for sugarcane planting conducted in March 2018 included plowing with a 28" disc plow to incorporate 3 Mg ha^{-1} of dolomitic limestone with 85% ECCE; harrowing with a middle disc harrow (26" discs) to incorporate another 3 Mg ha^{-1} of limestone; and harrowing with a light disc harrow, to level and de-compact the soil. After soil preparation, the experimental area was plowed, and 130 kg ha^{-1} of P_2O_5 and 27.5 kg ha^{-1} of N were applied to the bottom of the furrow using Monoammonium phosphate (MAP).

The sugarcane varieties were planted in April 2018 in an area of 0.55 ha (85 x 65 m) manually at a spacing of 1.50 m between rows. Topdressing fertilization was performed 70 days after planting with 90 kg ha^{-1} of N and 135 kg ha^{-1} of K_2O (NPK formula 20-00-30). Fertilizer was applied in a row beside the cane row, incorporating at a depth of approximately 10 cm. Weed control was accomplished by applying the herbicide atrazine at 6 L ha^{-1}, 2500 g a.i. ha^{-1} and a concentration of 500 g L^{-1}.

The plots comprised seven rows 15 meters long, with 1.5 m spacing between rows, totaling 157.5 m^2 per plot. The remaining area was used as a border. The experimental design used was the randomized block design in a 2 x 4 factorial arrangement, with the treatments consisting of two water management (irrigated and rainfed) and four sugarcane varieties (CTC 4, RB966928, RB975201, and RB92579), with three repetitions. The harvest was conducted in July 2019 (16 months after planting).

The variety CTC 4 has high sucrose content and medium maturity and is recommended for favorable environments (CANAONLINE, 2018). The RB966928 variety has a high agricultural yield and early and medium maturation and is recommended for favorable environments (RIDESA, 2010). The RB975201 variety has a high agricultural yield, production stability, and late maturity and is recommended for favorable environments (RIDESA, 2015). The RB92579 variety has a high agricultural yield, high sucrose content, and medium to late maturation (RIDESA, 2010).

Of the whole experimental area (0.55 ha), 1/3 was conducted under rainfed management (0.19 ha) and 2/3 under irrigation (0.36 ha). In the period between planting until 100 days after planting (DAP), irrigation was performed by a conventional sprinkler system with a capacity to apply a gross water depth equal to 6 mm hour^{-1} and using a 1 m high riser pipe. During the first 33 days, besides the irrigated area, the rainfed area also received water application to ensure the adequate formation of the sugarcane crop.

Because the height of the plants prevented the use of sprinkling after 100 DAP, this system was replaced by a surface drip system composed of polyethylene hoses, with drippers with a flow equal to 1.8 L h^{-1}, injected into the hose every 50 cm and using a drip line next to each sugarcane planting row.

The irrigation management work defined the time of application and the amount of water to be applied, adjusted based on the operation time of the irrigation systems. It was based on the water status in the soil and the monitoring of the climatic conditions through a sequential water balance, aiming to ensure adequate water availability to the plants.

A large (approximately 14 ton) weighing lysimeter, installed in the center of the experimental area, was used to measure evapotranspiration from irrigated RB966928 cane. The evapotranspiration rates were measured daily using the water balance in the lysimeter, considering the water inputs to the system (rainfall and irrigation), the output by drainage, and the variation in soil water storage. The surface runoff was considered null due to the elevated edge of the lysimeter. Irrigation management was performed based on the lysimeter data, climatic monitoring, and the physical and hydric characterization of the local soil.

Thus, the irrigated area received a net water depth equivalent to 368 mm throughout the cane-plant cycle, while the rainfed area received 113.4 mm, those applied during the first 33 DAP (Table 2). To favor cane maturation, irrigation was suspended 84 days before harvest in the irrigated system.

Table 2. Rainfall and net water depths (mm) applied via irrigation in irrigated and rainfed areas.

Period	Rain	Irrigated	Rainfed*
Planting up to 33DAP**	2.8	113.4	113.4
From 34 DAP to 100 DAP	85.7	131.3	-
From 101 DAP to 365DAP	1.467	123.3	-
From 366 DAP to harvest	145.3	-	-
Total in 16 months of plant cane	1,700.8	368	113.4

*Rainfed was irrigated until 33 DAP to allow the adequate formation of the sugarcane field; ** DAP = days after planting.

Biometrics and productivity

The stalk height and diameter, leaf area index (LAI), and shoot biomass were evaluated on ten plants marked in the two central rows of each plot (useful area) at 90; 150; 210; 270; 330, and 390 DAP.

Stalk height measurements were made using a graduated tape with a resolution of 1 mm to measure the distance from the base of the stalk to the dewlap of the +1 leaf (ABREU et al., 2013; ARCOVERDE et al., 2019b). Stalk diameter was measured with a caliper (ARCOVERDE et al., 2019b), with the measurement being taken at the base of the stalks, 5 cm from the soil surface.

Leaf area (LA) was determined by counting the number of green leaves (fully expanded leaves with a minimum of 20% green area) and by measuring the length and width of the +3 leaves. The LAI (dimensionless) was determined from the LA values, according to Equation 1 described in Abreu et al. (2013):

$$LAI = [(ALA/Asoil)\ x\ nº\ of\ tillers\ per\ meter] \qquad (1)$$

where: ALA is the average leaf area of a plant (m^2), and Asoil is the area occupied by a plant (m^2).

To determine the dry biomass, each tiller was separated into dry leaves, green leaves, sheath, and stem, and then their masses were determined. They were then taken to an air-forced circulation oven at a temperature of 65 °C, and the masses were determined after stabilization, as described in Pereira et al. (2013). At 390 DAP, the number of stalks per meter was determined directly, that is, by counting the stalks of the useful plot (two rows 10 meters long). Manual harvesting of the stalks was performed with the removal of four bundles of 10 stalks in the two central rows of the useful area of the experimental units, where the stalk yield (STY) was determined, expressed in Mg ha^{-1}, using the data of the mass of the sugar cane bundles and the number of stalks per hectare, utilizing a simple rule of three. The estimate of sugar yield (SGY) was done by multiplying the data of total recoverable sugar (TRS) by the results of STY in each experimental unit, where the determination of the TRS values was done through the technological quality analysis, according to the methodology in force in the SPSSC (Sugar Cane Payment System, by the Sucrose Content), described in Fernandes (2003).

Percentage of soil cover

The percentage of soil cover (%SC) was evaluated through aerial images taken with a Dji® Phantom 4 Advanced drone. The evaluations were made from planting until maximum soil cover, totaling 13 evaluations in ten months.

The drone was equipped with a 20 MP RGB camera. The flights were always performed early in the morning, at an altitude of 100 m, taking 16 images of the experimental area, which, after processing, resulted in a single image (orthomosaic) with a resolution of 3 cm per pixel.

When the images of the first flight were analyzed, a control area was demarcated within each treatment so that all flights were analyzed on the same sample of plants. This sample was 45 m^2 and corresponded to three neighboring rows of sugarcane with 10 m each.

In the image analysis, the green was highlighted in the processing step, and then the image was classified into leaf and non-leaf. The %SC was calculated by dividing the total number of pixels classified as a leaf by the total number of pixels in the image.

Statistical Analysis

Regression analysis was performed for stalk height and diameter, LAI, and biomass, and the curve that best fitted each situation was selected based on the coefficient of determination and the significance of the regression coefficients by the t-test at 1% probability. The data obtained at harvest were submitted to analysis of variance by the F-test followed by the application of the Tukey test ($p<0.05$). The statistical software AGROESTAT (BARBOSA; MALDONADO JÚNIOR, 2015) was used for the analyses.

RESULTS AND DISCUSSION

Growth Analysis

The sugarcane showed linear growth in height for all four varieties under both irrigated and rainfed conditions (Figures 2A and 2B). At 390 DAP, greater stalk heights were observed under irrigation for the varieties RB975201 and RB92579 (Figure 2A) and RB975201 under rainfed conditions (Figure 2B). On the other hand, the CTC 4 variety showed less linear growth in height over time, especially under irrigated management.

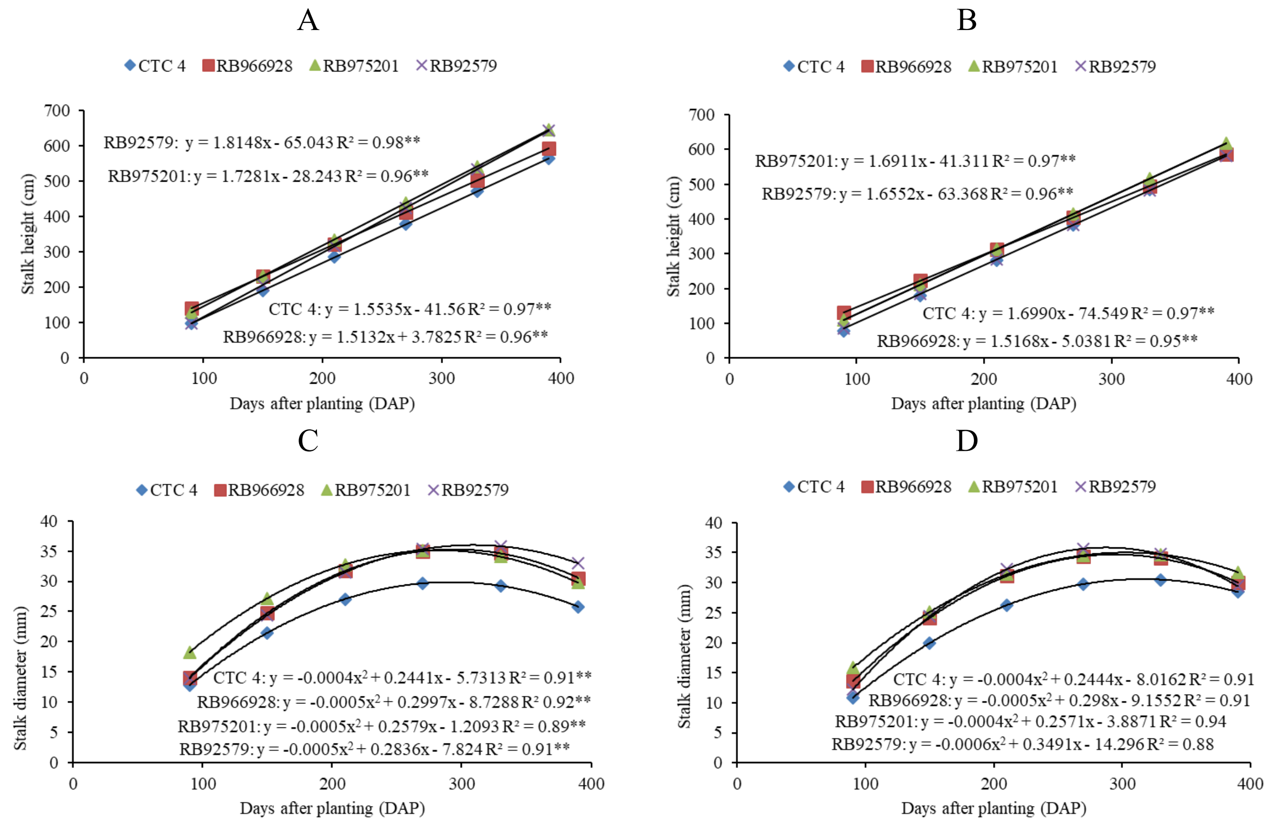


Figure 2. Growth of sugarcane varieties in stalk height under irrigation (A) and rainfed (B) and stalk diameter under irrigation (C) and rainfed (D). **Significant at 1%, by t test.

Under irrigation, growth rates were 1.55 cm day^{-1}, 1.14 cm day^{-1}, 1.10 cm day^{-1}, and 0.97 cm day^{-1}, respectively, for the varieties CTC 4, RB975201, RB92570, and RB966929, while under rainfed conditions these were 1.70 cm day^{-1}; 1.11 cm day^{-1}; 0.98 cm day^{-1}, and 0.89 cm day^{-1}; therefore, only CTC 4 was superior under rainfed conditions. These values are below the maximum rates of 1.678 to 2.618 cm day^{-1} found by Jane et al. (2020) in plant cane under irrigation. However, they agree with growth values obtained for the varieties RB93509, SP79-1011, and RB931530 (fourth cycle of irrigated ratoon-cane) of 1.01 cm day^{-1}; 0.9 cm day^{-1}, and 0.8 cm day^{-1}, respectively (COSTA et al., 2011). These authors found for the variety RB92579 a growth rate of 1.21 cm day^{-1}, similar to that obtained in this study for this variety under irrigation.

Under rainfed conditions, Arcoverde et al. (2019b) verified for variety RB985476 maximum rates of 2.20 cm day^{-1} and 2.13 cm day^{-1} under no-till and reduced tillage, respectively; while minimum rates of 1.25 cm day^{-1} were verified for variety RB855156 under reduced tillage, and 1.44 cm day^{-1} for variety RB975201 under no-till. This value of 1.44 cm day^{-1} in the RB975201 variety was higher than that obtained for the same variety in this study, cultivated under similar edaphoclimatic conditions, both under rainfed and irrigated conditions.

According to Uchôa et al. (2009), the continuous growth of sugarcane plants may be related to the high competitiveness for light. Campos et al. (2014) point out that the continuous and uniform growth may have contributed to the increased photosynthetic efficiency of the plants, in addition to the increment in stalk length being a potential indication of responsive varieties even under conditions of low water availability to the plants.

Sugarcane under irrigated management showed a maximum stalk diameter between 258 and 305 DAP, depending on the variety. Similarly, the maximum point was obtained later in rainfed management, between 291 and 322 DAP. In both water management, the stalk diameter decreased until the last evaluation, at 390 DAP (Figure 2).

Smaller diameters were observed for the CTC 4 variety in both systems. In the irrigated system, the varieties RB975201 and RB92579 stood out regarding growth in diameter (Figure 2C), similar to what was observed for stalk height (Figure 2A). Under rainfed conditions, the growth in the stalk diameter of the CTC 4 variety was slower than the others, but at 390 DAP, its diameter approached the others (Figure 2D).

Similar results were observed by Arcoverde et al. (2019b), evaluating the growth of eight sugarcane varieties grown under rainfed conditions on a Latossolo Vermelho distroférrico. The authors observed maximum stalk diameter at approximately 300 DAP, with a slight decrease until harvest (395 DAP), for all varieties, both under no-till and reduced till. Abreu et al. (2013) point out that knowledge of growth patterns during the production cycle of varieties is important in production planning to adjust the periods of maximum growth to those of greater water availability, aiming to increase the yield of sugarcane.

The responses of the varieties for LAI and biomass are presented in Figure 3. In general, it was observed that the variety RB975201 showed the highest LAI during the cycle of plant cane, both in irrigated and rainfed management. On the other hand, the lowest LAI values were observed for the CTC 4 variety.

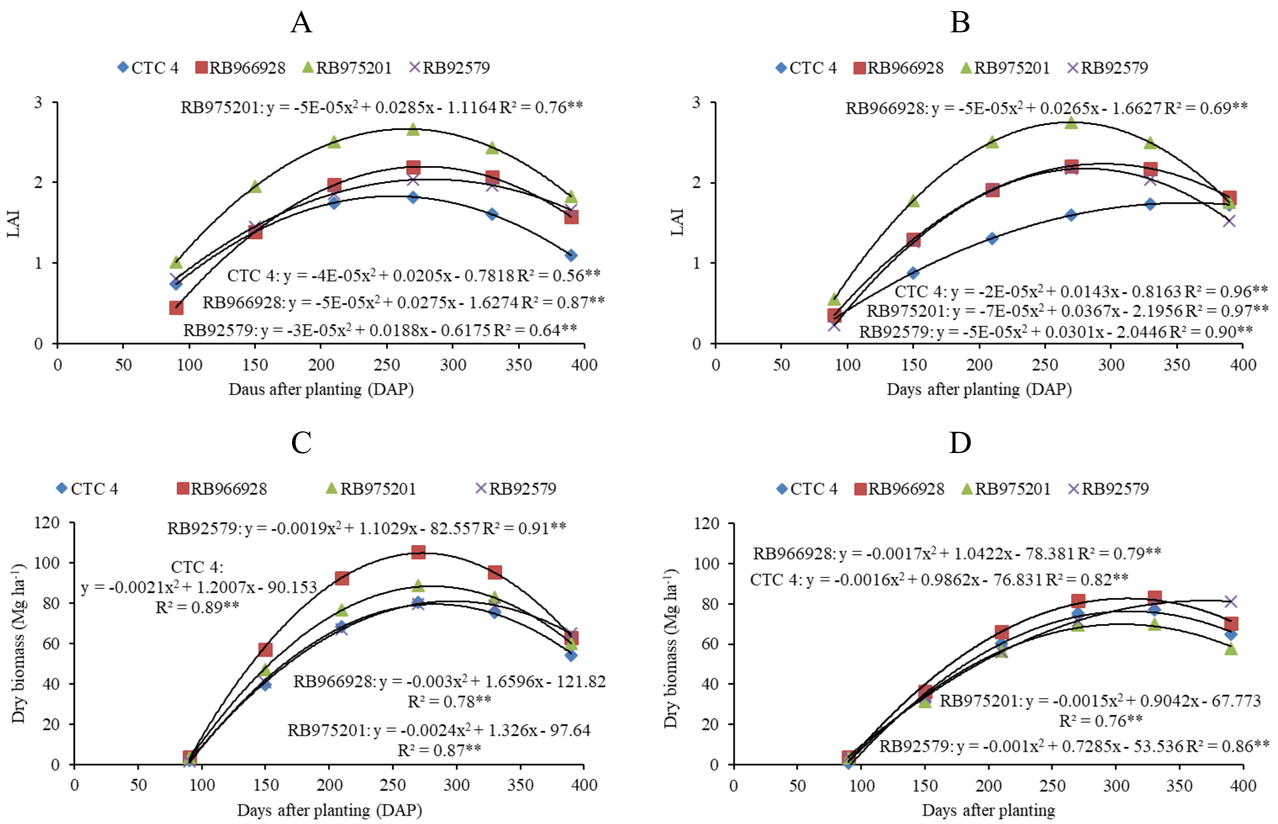


Figure 3. Leaf area index (LAI) of sugarcane varieties under irrigation (A) and rainfed (B); dry biomass of irrigated (C) and rainfed (D) plants. **Significant at 1%, by the t-test.

It is observed that, for the variety RB975201, the highest values of LAI when cultivated under irrigation or rainfed conditions are related to the greatest growth in height and diameter in these management systems, a fact that reveals the importance of the development of leaf area for the establishment of the crop and the closure of the canopy, as well as for the maximization of the interception of photosynthetically active radiation (ABREU et al., 2013). On the other hand, a greater tendency for LAI growth is noted for CTC 4 when grown under irrigation, which agrees with the lower stalk growth and the greater difference in height and diameter to the other varieties in this system, compared to that observed in the rainfed system. The variety CTC 4 showed a particular behavior of delay in producing leaf area throughout the cycle as a water management function. Although the maximum LAI was slightly above 1.5 in irrigated management in both systems, this was obtained earlier in the evaluation performed at 270 DAP, unlike rainfed management at 390 DAP. This finding corroborates the result obtained by Farias et al. (2008) that evaluated the growth of the shoot and the root system of the variety SP 79 1011 cultivated in Latossolos of medium texture under irrigated and rainfed systems in the state of Paraíba.

For dry biomass of the varieties grown under irrigation and rainfed conditions (Figure 3), a quadratic behavior of growth was observed in both systems, with the variety RB966928 showing a tendency for greater biomass accumulation when irrigated; however, at 390 DAP, its biomass was equivalent to that obtained for the variety RB92579. Similar results were found for the biomass accumulation in the varieties grown under dryland conditions, but at 390 DAP, the highest dry biomass was observed for the variety RB92579, followed by RB966928 and CTC 4 and, finally, RB975201, which showed, among the varieties, the lowest accumulation of dry biomass during the cycle of plant cane under rainfed conditions. When analyzing the average growth of the four varieties in irrigated and rainfed systems, a linear increase in height was observed over time, with a trend toward slightly greater stalk height in irrigated systems (Figure 4A); however, this behavior was not observed for the diameter (Figure 4B) whose values showed a quadratic trend for both systems, reaching a maximum at 271 DAP and 287 DAP in irrigated and rainfed conditions, respectively. These results agree with those found by Arcoverde et al. (2019b), who analyzed the growth of eight sugarcane varieties in plant cane in the same soil and climate conditions of this study associated with the rainfed regime verified the maximum stalk diameter close to 300 DAP.

The average leaf area index of the varieties showed a quadratic growth behavior (Figure 4C), with higher values during the entire cycle of the plant cane when it was grown under irrigation. In this system, the maximum point of LAI occurred at 336 DAP, when an increase of 50% in LAI was observed concerning rainfed conditions, where the maximum LAI was reached at 269 DAP. The better water conditions in the irrigated system provided greater continuity in the height and diameter of the stalks of the sugarcane varieties and, consequently, in the LAI.

The difference found in the LAI in the irrigated system was not reflected in the proportional increase of average biomass (Figure 4D) for the varieties, since close to harvest, despite the water deficiency in rainfed conditions (April to July), the varieties responded with accentuated growth, being equal or superior in dry biomass accumulation when compared to the irrigated system. In rainfed conditions, there was a delay in the dry biomass accumulation, reaching a maximum value at 315 DAP, while in irrigated conditions, this maximum accumulation occurred at 287 DAP. This indicates that the varieties, when cultivated under rainfed conditions, on average, required a longer period for the shoot growth than when cultivated under irrigation.

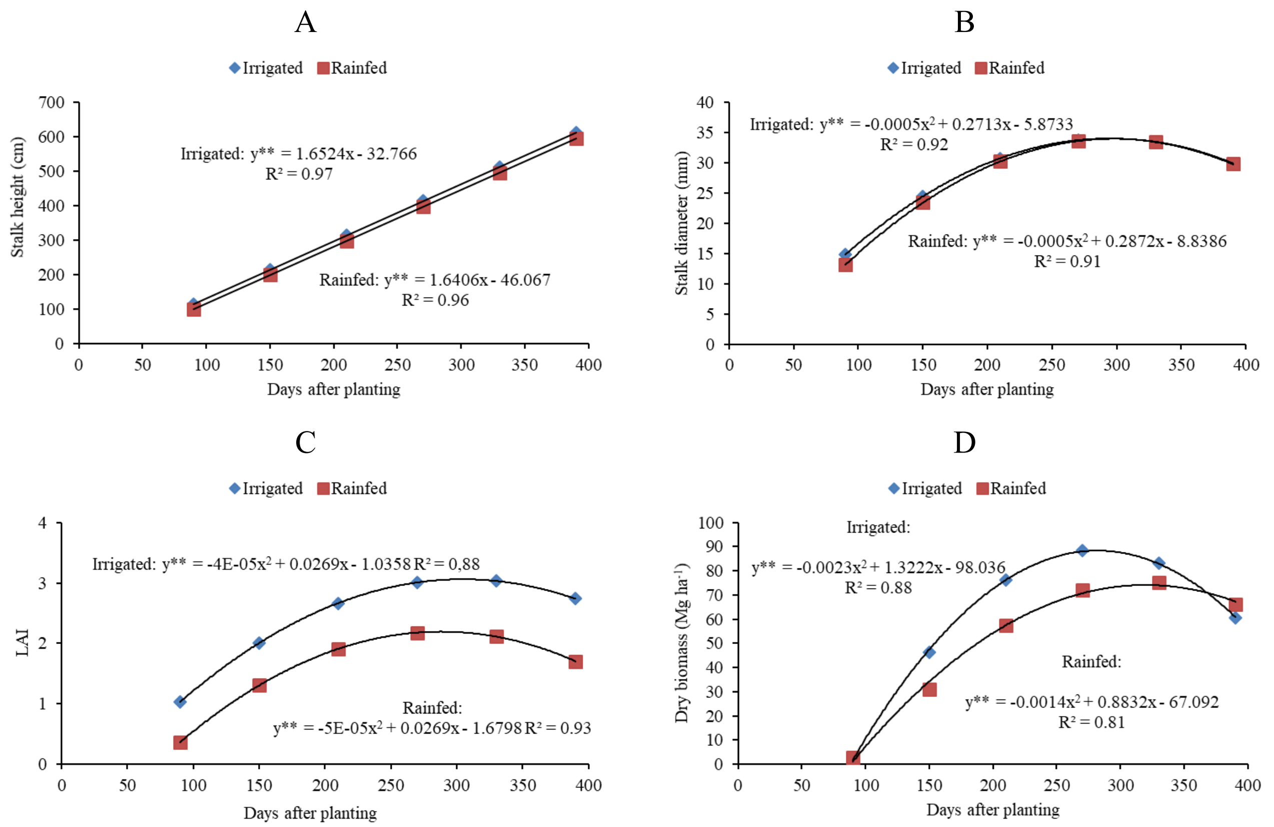


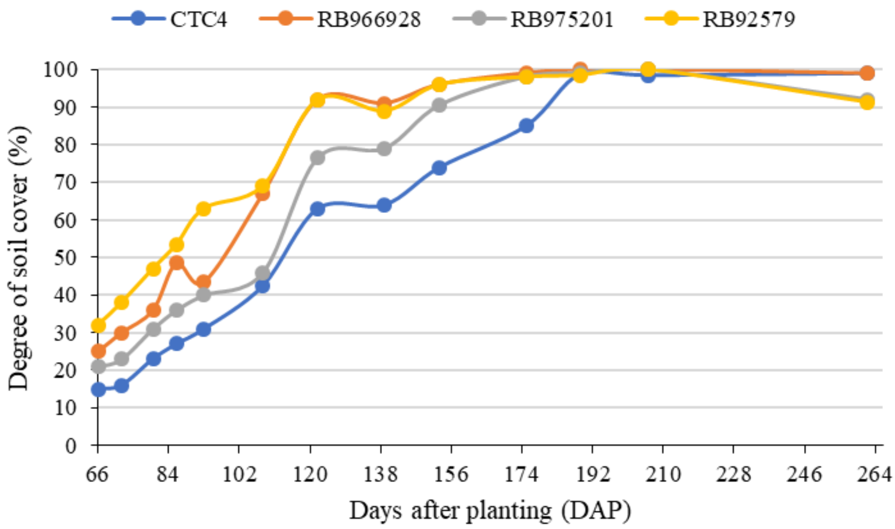
Figure 4. Stalk height (A), Stalk diameter (B), Leaf area index (C), and dry biomass (D) of plant cane from four varieties grown under irrigation and rainfed conditions. **Significant at 1%, by the t-test.

Analysis of soil cover by the vegetative canopy

Analyzing the soil cover (%SC) by the vegetative canopy of the sugarcane varieties under irrigation, an increase in the degree of the cover was generally observed for all varieties until around 180 DAP, when the maximum cover was reached (Figure 5A). Until this period, the highest degree of soil cover was observed for the varieties RB966928 and RB92579, followed by RB975201 and CTC 4 (the variety with the latest cycle). After reaching the maximum level of soil cover, the RB966928 variety managed to maintain this level, matching the degree of cover observed for CTC 4, while there was a decrease in the degree of soil cover for the other varieties.

Similar behavior occurred when these varieties were grown under rainfed conditions (Figure 5B). In this case, the maximum degree of soil cover reached a little later, at 188 DAP; in other words, there was a slight delay in the speed of soil cover. Regarding the differences between varieties, up to the maximum degree of soil cover, similar growth was observed for all varieties except for CTC 4, which was always lower. However, after this period, as seen under irrigation, the varieties RB966928 and CTC 4 maintained higher levels of soil cover, while there was a slight decrease in the degree of soil cover for the other varieties. In both systems, these results obtained for RB966928 and CTC 4 can be attributed mainly to the early and medium maturity cycle of these varieties that favored a greater speed in vegetative growth in a more pronounced way until the end of the tillering phase.

A



B

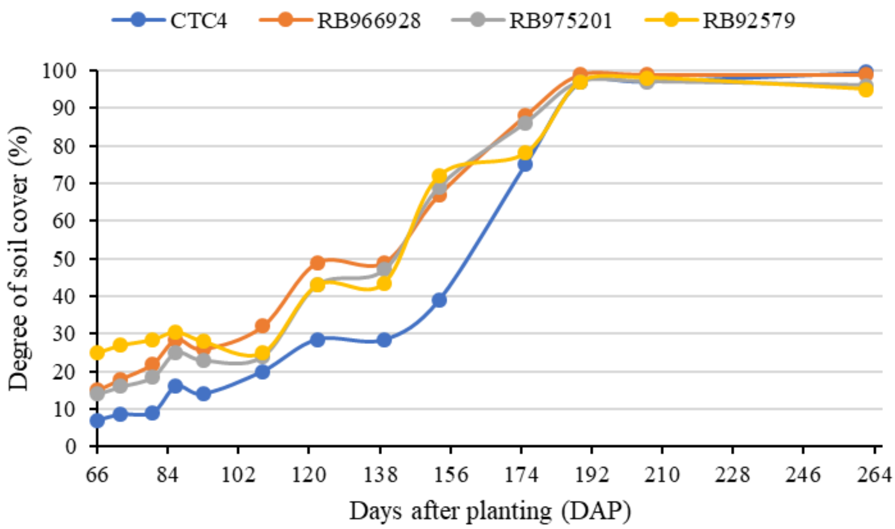


Figure 5. Percentage of soil cover by the vegetative canopy of plant cane from four varieties grown under irrigated (A) and rainfed (B) conditions.

As for the average degree of soil cover of the varieties under irrigated and rainfed conditions (Figure 6), there was a significant superiority in soil cover by the vegetative canopy during most of the sugarcane-plant cycle when cultivating under irrigated conditions. These results are due to the higher shoot growth (Figures 4A and 4B), which is consequently evidenced by the higher development of the irrigated plants in terms of LAI (Figure 4C) and dry biomass (Figure 4D).

This result shows that the production system of irrigated sugarcane offers greater protection to the soil against erosive processes when compared to rainfed crops because it presents intense tillering and growth of the shoot in the initial phase of the crop, thus providing a more homogeneous and dense vegetation cover (ENDRES et al., 2006). This benefit is especially important in the case of sugarcane production systems because during the formation of sugarcane fields, the area is uncovered, and the slow growth of the plant cane under dry conditions allows for a large period of exposure and vulnerability to erosion. With irrigation, this period can be reduced.

Another advantage of the greater and faster soil cover in irrigated sugarcane fields is the greater competition promoted by the crop with weeds. This was verified by Martinelli et al. (2011) when studying weed control practices in sugarcane crops, highlighting that cultivars with fast initial growth and high soil shading capacity are less affected by weed interference, thus promoting more efficient cultural control.

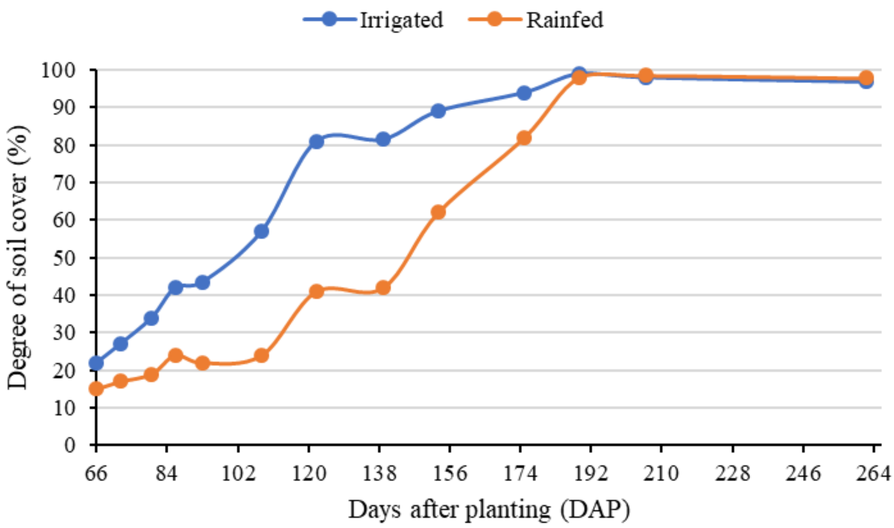


Figure 6. Average degree of soil cover of plant cane from four varieties grown under irrigated and rainfed conditions.

Yield

The stalk yield (STY) showed a significant difference between the systems evaluated, with a superiority of 34.3 Mg ha^{-1} in the irrigated system (Table 3). All varieties showed higher STY when grown under irrigated conditions, where the varieties RB92579 and RB975201 stood out, followed by the variety RB966928 and, lastly, with lower performance, CTC 4. Among the four varieties, the one that most increased its stalk yield when irrigated was RB975201 (46.1 Mg ha^{-1}), while the one that gave the least response was CTC 4 (18.8 Mg ha^{-1}). This better result of STY presented by RB975201 was consistent with its better response to supplementary irrigation, which reflected positively on stalk growth, LAI, and degree of soil cover. In contrast, CTC 4 showed less growth and LAI, which led to a lower degree of soil cover, regardless of the production system. This lower degree of soil cover may have influenced the decrease in STY in both systems evaluated since the greater exposure of the soil and greater evaporation possibly reduced the water content in the soil for much of the crop cycle until 180 DAP when maximum soil cover was configured (Figures 5A and 5B).

Although the irrigated system also showed higher average values of stalk m^{-1} and SGY, there was an average increase in TRS in the rainfed system, probably due to the water deficit at the end of the crop cycle (Figure 1). The two varieties with the highest STY presented the lowest average values of TRS and SGY, except for RB92579, when cultivated under rainfed conditions. The varieties RB975201 and RB92579 also showed an increase in stalks that can be used in industry when cultivated under irrigation, possibly influencing the increase in STY for the same varieties.

The values for STY obtained for the varieties under the conditions of this study are higher than those verified by Arcoverde et al. (2019b), who, when evaluating eight varieties under rainfed conditions, observed STY values between 131.6 and 174.7 Mg ha^{-1}; while the SGY values in this study are close to those found by the authors between 16.83 and 27.10, however, they observed for RB966928 and RB975201 average values of 25.7 and 19.6, representing 16% and 26% difference. In contrast, for the same varieties, Arcoverde et al. (2019a) observed an average TRS value for RB966928 of 151.1 kg Mg^{-1}, similar to that verified in this study, while for

RB975201 they verified 141.1 kg Mg^{-1}, against 129.1 kg Mg^{-1} obtained in this study, which represents a difference of approximately 9% in TRS. This result is due to the different ripening cycles of the two varieties, with RB966928 (early) finding adequate time and conditions for ripening. The genetic potential of the RB966928 variety, according to Arcoverde et al. (2019c), with early-medium maturity characteristics, high tillering, and yield stability, was predominant concerning the RB975201 variety, which has late maturity, lower tillering capacity, and requires favorable environments to express its maximum genetic potential. It is worth noting that in high fertility soils and with supplementary irrigation, the sugarcane has greater stimulus to continue vegetating and less induction to trigger the natural ripening process. Adopting practices to induce maturation and increase the TRS at harvest time is important in this condition. Strategies can be used to supplement nutrition with boron, magnesium, and potassium, apply ripeners, and especially suspend irrigation with technically programmed advances.

Table 3. Number of stalks m^{-1}, stalk yield (STY), total recoverable sugar (TRS), and sugar yield (SGY) of plant cane from four varieties cultivated under irrigation and rainfed conditions.

System	CTC 4	RB966928	RB975201	RB92579	Average
		Number of stalks m^{-1}			
Irrigation	17.5 Aa	13.9 Ab	13.1 Ab	13.8 Ab	14.6 A
Rainfed	17.0 Aa	13.1 Ab	11.6 Bbc	12.6 Bc	13.6 B
Average	17.3 a	13.5 b	12.4 c	13.2 bc	
		STY (Mg ha^{-1})			
Irrigation	208.3 Ac	234.8 Ab	238.5 Aa	240.3 Aa	231.0 A
Rainfed	189.5 Bc	198.5 Bb	192.4 Bc	206.6 Ba	196.7 B
Average	198.9 c	216.7 b	215.4 b	223.4 a	
		TRS (kg Mg^{-1})			
Irrigation	134.4 Aab	144.4 Aa	124.8 Abc	114.4 Bc	129.5 B
Rainfed	137.7 Ab	149.8 Aa	129.1 Ab	137.6 Ab	138.5 A
Average	136.0 b	147.1 a	126.9 c	126.0 c	
		SGY (Mg ha^{-1})			
Irrigation	28.0 Abc	33.8 Aa	29.8 Ab	27.5 Ac	29.8 A
Rainfed	26.1 Bb	29.7 Ba	24.8 Bb	28.5 Aa	27.3 B
Average	27.0 b	31.8 a	27.3 b	28.0 b	

Uppercase letters compare systems within varieties; lowercase letters compare varieties within systems. Means followed by the same horizontal or vertical letter do not differ by the Tukey test ($p>0.05$).

Oliveira et al. (2012) observed that adequate water availability throughout the sugarcane growth period could provide greater nutrient availability to the plant root system and increase stalk yield, especially under full irrigation. Moreover, according to Morais et al. (2017), the height and diameter of stalks are the main components that most correlate with the stalk yield together tillering, a fact stated by Silva et al. (2014), especially when it is associated with an adequate water availability condition in the soil, which enables responsive varieties to manifest their genetic potential better.

Given the significant gains in stalk yields in the plant cane, which ranged from 18 Mg ha^{-1} to 47 Mg ha^{-1} for the varieties CTC 4 and RB 975201, respectively, in a crop where the water deficit was not as pronounced as normal (irrigation of 368 mm in 16 months), further studies and evaluations should be considered regarding the technical and economic feasibility of supplementary irrigation of sugarcane under soil and climate conditions similar to those in this study. As the crop is reimbursed by the total production of sugar (SGY), it is important to associate practices to induce ripening in irrigated sugarcane fields, which can enhance yield per area through a greater accumulation of biomass (STY) promoted by irrigation in the vegetative phase and greater accumulation of sugars (TRS) induced by ripeners.

CONCLUSION

The RB975201 variety has the highest growth of stalk height and diameter and LAI, while the CTC4 variety has the lowest values in both production systems.

The irrigated production system provided increased growth of stalk and LAI, and degree of soil cover of plant cane from varieties, as well as a greater amount of stalks m^{-1}, STY, and SGY, with the RB92579 and RB975201 varieties standing out. On the other hand, better TRS results were obtained for the varieties grown under rainfed conditions.

ACKNOWLEDGEMENTS

The authors thank the CNPq and FUNDECT (PRONEM - Grant term 077/2015) for the financial support for the execution of the project.

REFERENCES

ABREU, M. L. et al. Crescimento e produtividade de cana-de-açúcar em função da disponibilidade hídrica dos Tabuleiros Costeiros de Alagoas. **Bragantia**, 72: 262-270, 2013.

ARCOVERDE, S. N. S. et al. Soil physical attributes and production components of sugarcane cultivars in conservationist tillage systems. **Revista Engenharia Agrícola**, 39: 216-224, 2019a.

ARCOVERDE, S. N. S. et al. Growth and sugarcane cultivars productivity under notillage and reduced tillage system. **Revista Ceres**, 66: 168-177, 2019b.

ARCOVERDE, S. N. S. et al. Crescimento inicial de cultivares de cana-de-açúcar em plantio de inverno sob preparos conservacionistas do solo. **Engenharia na Agricultura**, 27: 142-156, 2019c.

AWE, G. O.; REICHERT, J. M.; FONTANELA, E. Sugarcane production in the subtropics: Seasonal changes in soil properties and crop yield in no-tillage, inverting and minimum tillage. **Soil and Tillage Research**, 196: 1-12, 2020.

BARBOSA, J. C.; MALDONADO JUNIOR, W. **AgroEstat - sistema para análises estatísticas de ensaios agronômicos**. Jaboticabal: FCAV/UNESP, 2015. 396 p.

CAMPOS, P. F. et al. Variedades de cana-de-açúcar submetidas à irrigação suplementar no cerrado goiano. **Engenharia Agrícola**, 34: 1139-1149, 2014.

CANAONLINE. **Variedade de cana CTC 4 passa a ser uma das favoritas do setor**. 2018. Disponível em:<http://www.canaonline.com.br/conteudo/variedade-de-cana-ctc-4-passa-a-ser-uma-das-favoritas-do-setor.ht>. Acesso em: 14 jun. 2022.

COSTA, C. T. S. et al. Crescimento e produtividade de quatro variedades de cana-de-açúcar no quarto ciclo de cultivo. **Revista Caatinga**, 24: 56-63, 2011.

DIAS, C. M. O. et al. Indicadores fitotécnicos, de produção e agroindustriais em cana-de açúcar cultivada sob dois regimes hídricos. **Revista Caatinga**, 25: 58-65, 2012.

DIAS, H. B.; SENTELHAS, P. C. Sugarcane yield gap analysis in Brazil: a multi-model approach for determining magnitudes and causes. **Science of Total Environmet**, 638: 1127-1136, 2018.

ENDRES, P. F. et al. Quantificação das classes de erosão por tipo de uso do solo no município de Franca – SP. **Engenharia Agrícola**, 26: 200-207, 2006.

FARIAS, C. H. A. et al. Índices de crescimento da cana-de-açúcar irrigada e de sequeiro no Estado da Paraíba. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 12: 356-362, 2008.

FERNANDES, A. C. **Cálculos na agroindústria da cana-de-açúcar**. 3 ed. Piracicaba, SP: STAB, 2003. 416 p.

FIETZ, C. R. et al. **O clima da região de Dourados, MS**. Dourados, MS: EMBRAPA, 2017, 31 p. (Série Documentos, 138).

FAO - Food and Agriculture Organization. **Corporate statistical database**. 2021. Disponível em: <http://www.fao.org/faostat/en/#data>. Acesso em: 3 jul. 2022.

INMAN-BAMBER, N. G. et al. Sugarcane physiology: integrating from cell to crop to advance sugarcane production. **Field Crops Research**, 92: 115-117, 2005.

JANE, S. A. et al. Adjusting the growth curve of sugarcane varieties using nonlinear models. **Ciência Rural**, 50: e20190408, 2020.

MARTINELLI, C. A. et al. Interferência de plantas daninhas na cultura da cana-de-açúcar e algumas práticas de controle. **Revista Científica Eletrônica de Agronomia**, 20: 1-6, 2011.

MORAIS, K. P. et al. Produtividade de colmos em clones de cana-de-açúcar. **Revista Ceres**, 64: 291-297, 2017

OLIVEIRA, F. M. et al. Avaliação tecnológica de variedades de cana-de-açúcar influenciadas por diferentes adubações e supressões de irrigação. **Revista Ceres**, 59: 832-840, 2012.

PEREIRA, W. et al. Acúmulo de biomassa em variedades de cana-de-açúcar inoculadas com diferentes estirpes de bactérias diazotróficas. **Revista Ciência Agronômica**, 44: 363-370, 2013.

PRADO, H. et al. Solos e ambientes de produção. In: DINARDO-MIRANDA et al. (Eds.). **Cana-de-açúcar**. Campinas, SP: Instituto Agronômico, 2008. p. 179-204.

SANTOS, H. G. et al. **Sistema Brasileiro de Classificação de Solos**. 2018. 5. ed. Disponível em: <https://www.embrapa.br/solos/busca-depublicacoes//publicacao/1094003/sistema-brasileirode-classificacao-de-solos>. Acesso em: 3 jul. 2022.

RIDESA - Rede Interuniversitária para o desenvolvimento do setor alcooleiro. **Catálogo nacional de variedades "RB" de**

cana-de-açúcar. 2010. Disponível em: <https://www.ridesa.com.br/_files/ugd/097ffc_e328a69f7b78434088b21262cab3c75f.pdf>. Acesso em: 3 jul. 2022.

RIDESA - Rede Interuniversitária para o desenvolvimento do setor alcooleiro. **Catálogo nacional de variedades "RB" de cana-de-açúcar**. 2015. Disponível em: https://www.ridesa.com.br/_files/ugd/097ffc_630ca4e433634264a1315ef02f4fb1d5.pdf. Acesso em 3 jul. 2022.

SILVA, M. A. et al. Potencial produtivo da cana-de-açúcar sob irrigação por gotejamento em função de variedades e ciclos. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 18: 241-249, 2014.

UCHÔA, S. C. P. et al. Crescimento e produtividade agrícola de cana-de-açúcar em diferentes fontes de fósforo. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 13: 389-396, 2009.