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Interference of spacing on the growth and biomass of sweet sorghum

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ABSTRACT: The experiment was conducted at the Vale do Curu Experimental Farm of the Federal University of Ceará in Pentecoste in the State of Ceará, Brazil. The aim was to evaluate the interference of spacing in the growth and biomass production of sweet sorghum. The BRS 511 cultivar was analysed in two experiments in a randomised block design; the first, for growth as a function of the inter-row spacing, in a scheme of subdivided plots, and the second, in a factorial scheme, for biomass as a function of planting density. The following variables were evaluated in Experiment I: Plant height (HP), stem diameter (SD), +3 leaf angulation (LA+3), chlorophyll a and b, the chlorophyll a to b ratio and total chlorophyll. The fresh and dry weight of the leaves (LFW/LDW) and the stems (SFW/SDW), and the total fresh and dry weight (TFW/TDW) were evaluated in Experiment II. A reduction in the inter-row spacing resulted in less plant growth; biomass showed higher values at the smallest spacings between rows and between plants. In Pentecoste, an inter-row spacing of 70 cm is recommended for growing the BRS 511 cultivar. For sweet-sorghum biomass, a reduction in plant density to 50 cm between rows and 0.8 cm between plants is recommended to obtain a yield of 250,000 plants per hectare.
Keywords: *Coffea canephora,* estrobilurinas, *Hemileia vastatrix,* respostas fisiológicas, triazóis.

Interferência do espaçamento no crescimento e biomassa de sorgo sacarino

RESUMO: O experimento foi conduzido na Fazenda Experimental Vale do Curu – Pentecoste/CE da Universidade Federal do Ceará, com o objetivo de avaliar a interferência do espaçamento no crescimento e na produção de biomassa do sorgo sacarino. O cultivar BRS 511 foi analisado em dois experimentos com delineamento em blocos casualizados, o primeiro, crescimento em função do espaçamento entrelinhas em esquema de parcela subdividida. O segundo, biomassa em função da densidade de plantio, em esquema fatorial. Avaliou-se as variáveis altura de plantas (AP), diâmetro do colmo (DC), angulação da folha +3 (AF 3+), clorofila A e B, relação clorofila A/B e clorofila total, para o experimento I. Já para o II, foram avaliadas a massa fresca e seca das folhas (MFF/MSF), do colmo (MFC/MSC) e total (MFT/MST). A redução do espaçamento entrelinhas acarretou um menor crescimento das plantas e a biomassa apresentou maiores valores nos menores espaçamentos entrelinhas e entre plantas. Em Pentecoste – CE, para o crescimento do cultivar BRS 511, recomenda-se o espaçamento entrelinhas de 70 cm. Para a biomassa do sorgo sacarino, recomenda-se reduzir a densidade de plantas para 50 cm entrelinhas e 0,8 cm entre plantas, obtendo-se 250.000 plantas por hectare.
Palavras-chave: *Sorghum bicolor*, etanol, densidade de plantas, semiárido.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a plant belonging to the Poaceae family. It originated in Africa and part of Asia and is the fifth most important cereal in the world after wheat, rice, maize and barley. A product of man's intervention, it has been domesticated over generations (QUEIROZ, 2009; ROSA, 2012).

In developing countries sorghum is used for human consumption, however in other parts of the world it is mainly used in animal feed. In Brazil, it became popular during the 1970s, especially in the regions of Rio Grande do Sul, São Paulo, Bahia and Paraná (ROSA, 2012).

It has a C4 metabolism, a short cycle (120 to 130 days), high photosynthetic efficiency, is well adapted to different environments, does not require large amounts of nutrients, and is tolerant to drought, salinity and toxic aluminium (DURÃES, 2011; OLIVEIRA et al., 2012). It is therefore, a good option for cultivating in semi-arid regions, such as the Northeast of Brazil, since this region has soils that are little-developed and of low permeability, a source of water that is generally dependent on the rainy season, and scarce rainfall concentrated over a short period of time (ARAÚJO, 2011; NUNES et al., 2014; SILVA et al., 2017).

For Pontes (2013), sorghum can be classified according to its suitability, as forage, grain, broom, biomass and sweet. The latter has considerable energy potential in the stem, which has a high sugar content and is suitable for the production of ethanol, sugar and forage, similar to sugar cane, and can be used in a number of industrial applications as a large source of sugars and plant biomass, complementing the agro-industrial sugarcane system as an option during the off-season (DURÃES, 2011; DURÃES, 2012).

Although it is a well-adapted plant, sweet sorghum needs suitable management to achieve desirable levels of productivity. There are several management practices that influence plant production, such as plant arrangement, which interferes with the interception of solar radiation, leaf angle, number of leaves, leaf area and productivity (ARGENTA, 2001).

Variations in planting arrangement have a great impact on crop development, by influencing the competition for essential environmental resources such as water, light and nutrients (COSTA et al., 2017; OLIVEIRA et al., 2017; SILVA et al., 2017). Theoretically, the best arrangement is considered the one with more-uniform plant distribution by area, and that allows the best use of these resources, directly influencing the diameter and height of the plant stem (ARGENTA, 2001; MAY et al., 2012a).

Different plant arrangements give different results for existing sorghum cultivars. May et al. (2012b), when evaluating the sweet sorghum cultivar CMSXS 647, obtained greater biomass production at smaller inter-row spacings and larger plant populations. Whereas, Emygdio; Chielle (2011) found no influence from larger plant populations on biomass production in the BRS 506 cultivar. The aim of this research therefore was to evaluate the interference of spacing in the growth and biomass of sweet sorghum 'BRS 511' in the semi-arid region of the State of Ceará.

2. MATERIAL AND METHODS

The work was carried out from March to June of 2016 at the Vale do Curu Experimental Farm, belonging to the Federal University of Ceará, and located in the district of Pentecoste in the State of Ceará, at UTM coordinates 462620 E, 9577349 S and an altitude of 48 m. According to the Koppen classification, the climate in the region is type BSw'h', i.e. dry semi-arid, with irregular rainfall and a short wet season (ALVARES et al., 2014). Meteorological data for the experimental period are shown in Table 1.

The BRS 511 cultivar of sweet sorghum was used, provided by the Maize and Sorghum unit of the Brazilian Agricultural Research Company - EMBRAPA. Sowing was by hand, using 4 to 5 seeds per hole. Thinning was carried out 15 days after sowing (DAS), leaving only one plant per hole. The experiment was conducted under rainfed conditions.

Taking into account the soil analysis (Table 2), and following the recommendations of Durães et al. (2012), base fertiliser was applied using 30, 50 and 45 kg.ha^{-1} N, P2O5 and K2O respectively; the mineral fertilisers urea, single superphosphate and potassium chloride, were used as the source of each nutrient. Twenty days after sowing, a top dressing of 140 and 45 kg.ha^{-1} N and K2O respectively was applied.

In Experiment I, the cultivar under study was evaluated for plant development and growth at four different inter-row spacings (50, 60, 70 and 80 cm) and one standard plant spacing of 12 cm, for five periods of evaluation (30, 45, 60, 75 and 90 days after sowing). In Experiment II, four different inter-row spacings (50, 60, 70 and 80 cm) and three plant spacings (0.08, 0.12 and 0.16 m) were tested to evaluate the biomass of the cultivar, which was harvested for analysis 110 days after sowing (DAS).

The experimental design was of randomised blocks with four replications. In Experiment I the scheme was divided over time (4 spacings and 5 collection periods) and in Experiment II, in a 4x3 factorial scheme (4 inter-row spacings and 3 plant spacings), making a total area of 624 m², with four blocks of 156 m² and the plots varying from 10 to 16 m² according to the treatment. Each experimental unit consisted of four rows of five metres, with the two central rows as the working area of the plot.

Table 1. Main meteorological parameters from March to July 2016 in Pentecoste, Ceará.
Tabela 1. Principais parâmetros meteorológicos referentes ao período de março a julho de 2016 em Pentecoste, Ceará.

Period	T (ºC)		RH (%)		R (mm)
	9 h	15h	9h	15h	
March*	23.9	35.1	80.6	70.6	41.2
April	23.7	34.7	80.8	75.5	84.8
May	23.0	36.0	72.2	69.5	59.4
June	22.5	36.7	73.9	61.8	99.4
July	22.1	38.1	66.8	51.1	00.0
Total (R)					284.8

Source: FUNCEME R: accumulated rainfall for the months. T: Temperature and RH: Relative Humidity. *Considering the 18th to the 31st.

Table 2. Physico-chemical conditions of the soil at depths of 0-20 and 20-40 cm in the experimental area of the Vale do Curu Farm in Pentecoste, Ceará, Brazil, 2016.
Tabela 2. Condições físico-químicas do solo nas profundidades de 0-20 e 20-40 cm da área experimental da Fazenda Vale do Curu em Pentecoste, Ceará, 2016.

Depth.(cm)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$H^{+}+Al^{3+}$	Al^{3+}	S	T
	cmolc.kg^{-1}							
0 – 20	5.40	2.10	0.22	0.96	0.83	0.05	8.7	9.5
20 – 40	4.70	3.30	0.63	0.74	0.66	0.05	9.4	10.0
	V	M	C	N	MO	P assimilated	C/N	PST
	--- % ---		g.kg^{-1}					
0 – 20	91	1	9.48	0.98	16.34	0.084	10	4
20 – 40	93	1	5.16	0.53	8.90	0.061	10	4
	D.G. g.cm^{-3}	pH H_2O	EC dS.m^{-1}	Coarse Sand	Fine Sand	Silt	Clay	Nat. Clay.
				g.kg^{-1}				
0 – 20	1.37	6.6	0.58	60	556	261	123	80
20 – 40	1.6	6.8	0.70	69	578	258	95	77

Source: Soil and Water Laboratory; Department of Soil Science, UFC; Ceará Foundation for Meteorology and Water Resources - FUNCEME.

2.1 Experiment I

Six plants were chosen at random from the working area of each experimental unit, and measurements taken every two weeks. The growth variables under evaluation were plant height (PH), stem diameter (SD), number of leaves (NL), +3 leaf angulation (LA+3) and relative chlorophyll index.

For PH, each plant was measured from the ground surface to the base of the flag leaf (vegetative stage) or apex of the panicle (reproductive stage), with the results expressed in metres. For SD, a digital calliper was used, and the diameter determined from the mean value of three readings taken at the base, middle and apex of each plant, the result being expressed in millimetres. To determine the NL, a count was made of all fully-expanded leaves. LA+3 was determined with the aid of a protractor using the plant stem as the baseline.

The relative chlorophyll index was calculated from the mean value of three readings taken on the +3 leaf (base, middle and apex) using the ClorofiLOG CFL1030 meter.

2.2 Experimento II

To evaluate the biomass of the cultivar under study a random sample of twelve plants in each experimental unit was harvested 110 days after sowing, at the end of the crop cycle and respecting physiological maturity; these plants were organised into bundles and weighed on a 15 kg digital scale to determine the total fresh weight (TFW).

Four plants were then separated to weigh the fresh and dry matter of the different parts separately: leaves (LFW and LDW) and stems (SFW and SDW). The total dry matter weight (TDW was determined from the sum of the dry matter weight of the different parts.

The data were submitted to tests of normality and homogeneity of variance, and when meeting these assumptions, an analysis of variance (ANOVA) was carried out using Tukey's test (5%) to compare the mean values for plant spacing; polynomial regression was used to analyse the inter-row spacings and growing times. When the data did not meet one of the assumptions, they were submitted to the nonparametric Kruskal-Wallis test (5%).

3. RESULTS

3.1 Experiment I

There was a significant effect from inter-row spacing on stem diameter and +3 leaf angulation. For the factor, days after sowing (DAS), all the variables under study were significant.It can be seen in Figure 1 that the sweet sorghum plants grew considerably from 30 to 75 DAS, increasing from 75 to 200 cm in height. After this period, a reduction in plant size was seen from 80.7 DAS.

Table 3. Summary of ANOVA for the variables of height, diameter and angle in sweet sorghum plants submitted to different inter-row spacings.
Tabela 3. Resumo da ANOVA para as variáveis altura, diâmetro e ângulo de plantas de sorgo sacarino submetidas a diferentes espaçamentos entrelinhas.

SV	DF	Height	Diameter	Angle
		--------------------	*OM*	-------------------
Block	3	2804.704^{ns}	4.408^{ns}	0.004^{ns}
IR	3	900.336^{ns}	13.801*	0.006*
Error 1	9	3,855.921	3.138	0.001
DAS	4	42206.832**	20.208**	0.028**
ELxDAS	12	456.653^{ns}	0.438^{ns}	0.001^{ns}
Error 2	48	587.000	0.757	0.001
Total	79	-	-	-
CV%¹		39.36	12.88	1.82
CV%²		15.36	6.33	1.46

SV: source of variation; DF: degree of freedom; MSR: mean square root; CV: coeficiente of variation; IR: inter-row spacing; DAS: days after sowing. ns, *, ** respectively, not significant, significant at 5% and at 1% probability of error by F-test in the analysis of variance (ANAVA).

The +3 leaf relative to DAS (Figure 2) showed a variation of 37º to 42º in angulation during the experimental period, with the greatest angulation at 90 DAS. In Figure 3, it can be seen that leaf angulation was also influenced by the inter-row spacing, showing larger angulation as the IR was increased. An angulation of 42º was seen at the largest spacing under study. For stem diameter as a function of inter-row spacing (Figure 4), an increase was seen when the plants were submitted to larger spacings. The best values for IR were 70 and 80 cm respectively, with a mean stem diameter of 14.5 mm.

In terms of stem diameter (Figure 5), it can be seen that this adapted differently over time. A mean value of 14.6 mm was found at 30 DAS, which reduced in subsequent evaluations until reaching 12.4 mm at 75 DAS. There was no significant difference for IR in the variables NL, Chlorophyl a, Chlorophyl b, total Chlorophyl and the a to b ratio (Table 4). It was found that the plants had marked values for Chlorophyl a, Chlorophyl b, total Chlorophyl and the a to b ratio respectively, of 35.24, 8.34, 43.49 and 4.24 at 30 DAS (Table 4); this continued to decrease until again starting to increase at 90 DAS.

3.2 Experiment II

From the summary of the analysis of variance (Table 5), it can be seen that there was a significant difference between the variables of leaf fresh weight (LFW), stem fresh weight (SFW), total fresh weight (TFW) and leaf dry weight (LDW) submitted to different inter-row spacings (IR), and that there was no effect from this factor on stem dry weight (SDW) or total dry weight (TDW). It should also noted that all the variables were influenced by plant spacing (PS).

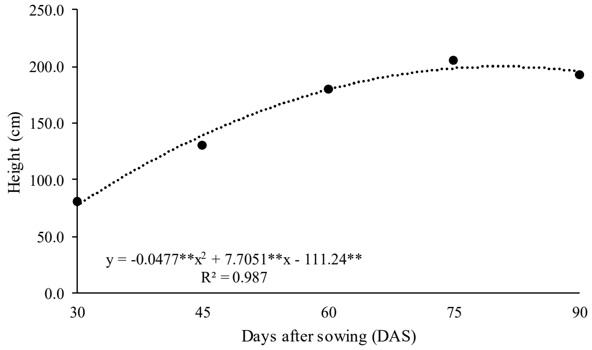

Figure 1. Height as a function of days after sowing (DAS). *, **: significativo pelo teste F a um nível de 5% e 1% respectivamente.
Figura 1. Altura em função dos dias após a semeadura (DAS).
*, **: significant by F-test at a level of 5% and a level of 1% respectively

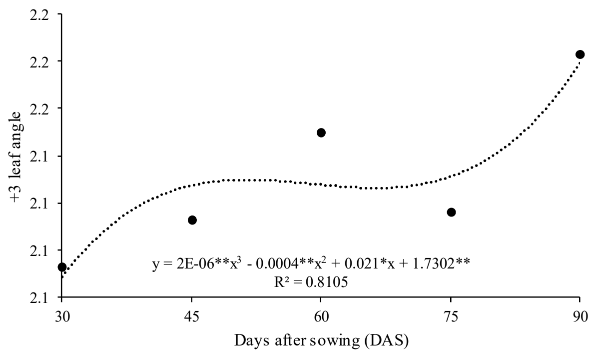

Figure 2. +3 leaf as a function of days after sowing (DAS). *, **: significant by F-test at a level of 5% and a level of 1% respectively. (t*) Data transformed by the Box-Cox system (λ = -0.3282828282).
Figura 2. Ângulo da Folha+3 em função dos dias após a semeadura (DAS). *, **: respectivamente, significância pelo teste F quando significativo ao nível 5% e significativo ao nível de 1%. (t*) Transformação de dados pelo sistema Box Cox (λ = -0,3282828282).

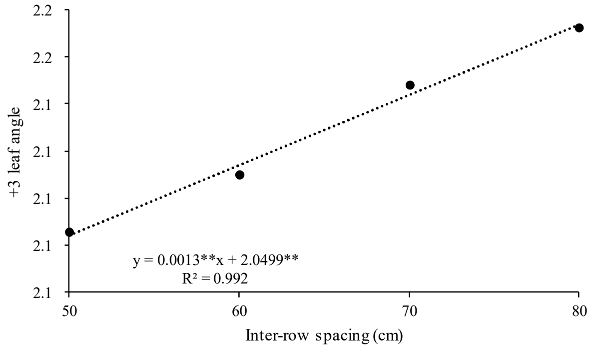

Figure 3. Sheet angle +3 as a function of line spacing.*, ** : significant by F-test at a level of 5% and a level of 1% respectively. (t*) Data transformed by the Box-Cox system (λ = -0.3282828282).
Figura 3. Ângulo da folha +3 em função do espaçamento entrelinhas. *, **: respectivamente, significância pelo teste F quando significativo ao nível 5% e significativo ao nível de 1%. (t*) Transformação de dados pelo sistema Box Cox (λ = -0.3282828282).

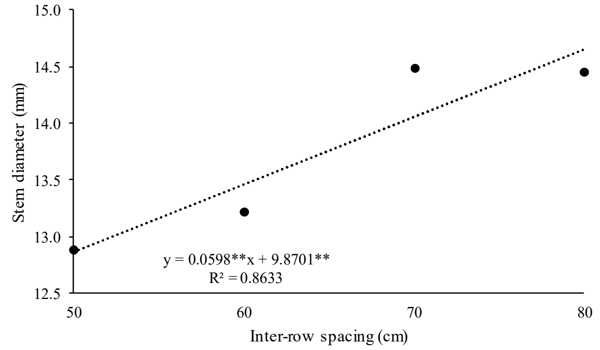

Figure 4. Stem diameter as a function of inter-row spacing. *, **: significant by F-test at a level of 5% and a level of 1% respectively.
Figura 4. Diâmetro do colmo em função do espaçamento entrelinhas. *, **: respectivamente, significância pelo teste F quando significativo o nível 5% e significativo ao nível de 1%.

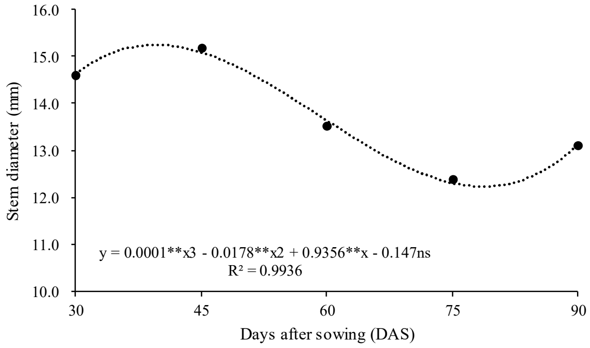

Figure 5. Stem diameter as a function of days after sowing (DAS). ns, *, **: significant by F-test at a level of 5% and a level of 1% respectively.
Figura 5. Diâmetro do colmo em função dos dias após a semeadura (DAS). ns, *, **: respectivamente, significância pelo teste F quando não significativo, significativo ao nível 5% e significativo ao nível de 1%.

In Figure 6A, it can be seen that increases in the inter-row spacing resulted in a reduction in leaf fresh weight, from 7.62 $t.ha^{-1}$ at the smallest spacing, to 4.6 $t.ha^{-1}$ at the largest spacing under study. The same thing happened with plant spacing; it can be seen in Figure 6B that as plant spacing is increased, leaf fresh weight is reduced.

Stem fresh weight (SFW) is reduced when the inter-row spacing is increased, reaching an average of 32.64 $t.ha^{-1}$ SFW (Figure 7A). The fresh stem weight was also reduced when submitted to larger plant spacings (Figure 7B).

When evaluating Figure 8A, it can be seen that the total fresh weight is reduced at larger inter-row spacings, with the highest mean value seen at a spacing of 50 cm (39.2 $t.ha^{-1}$). For plant spacing, the highest mean value seen was 42.5 $t.ha^{-1}$ total fresh weight when the plants were submitted to a spacing of 8 cm (Figure 8B).

Table 4. Growth data, mean values for leaf number (LN), chlorophyll a (CHLa), chlorophyll b (CHLb), total chlorophyll (CHLtotal) and the chlorophyll a to b ratio (A/B RATIO). a, b and c Mean values followed by the same letters in the columns do not differ by the non-parametric Kruskal-Wallis test at a significance level of 5%.
Tabela 4. Dados de crescimento, valores médios para as variáveis número de folhas (NF), clorofila a (CLORa), clorofila b (CLORb), clorofila total (CLORtotal) e relação clorofila A e B (RELAÇ A/B). a, b e c os valores médios seguidos pelas mesmas letras nas colunas não diferem pelo teste não paramétrico de Kruskal-Wallis ao nível de significância de 5%.

FV	NF	CHLa	CHLb	CHLtotal	A/B RATIO
			IR		
50	6.12^{a}	33.98^{a}	7.7^{b}	41.68^{a}	4.45^{a}
60	6.10^{a}	33.79^{a}	7.91^{ab}	41.70^{a}	4.30^{ab}
70	6.80^{a}	35.47^{a}	8.49^{a}	43.95^{a}	4.24^{b}
80	6.71^{a}	33.64^{a}	8.06^{ab}	41.70^{a}	4.22^{ab}
			DAS		
30	5.88^{b}	35.24^{a}	8.34^{a}	43.49^{a}	4.24^{bc}
45	4.88^{d}	32.99^{b}	7.24^{b}	40.23^{b}	4.58^{a}
60	8.88^{a}	33.11^{b}	8.43^{a}	41.54^{b}	3.99^{c}
75	6.41^{b}	33.45^{b}	7.87^{b}	41.32^{b}	4.34^{ab}
90	6.13^{bc}	36.30^{a}	8.31^{a}	44.61^{a}	4.37^{abc}

Table 5. Summary of ANOVA for leaf fresh weight (LFW), stem fresh weight (SFW), total fresh weight (TFW), leaf dry weight (LDW), stem dry weight (SDW) and total dry weight (TDW) as a function of inter-row spacing (IR) and plant spacing (PS).
Tabela 5. Resumo da ANOVA para as variáveis massa fresca das folhas (MFF), massa fresca do colmo (MFC), massa fresca total (MFT), massa seca das folhas (MSF), massa seca do colmo (MSC) e massa seca total (MST) em função do espaçamento entrelinhas (EL) e espaçamento entre plantas (EP).

SV	DF	LFW	SFW	TFW	LDW	MSC	SDW
				-------------------- *MSR* --------------------			
Block	3	7.420^{ns}	29.705^{ns}	124.942 *	0.341^{ns}	19.579^{ns}	26.115^{ns}
Factor a (IR)	3	18.437**	237.345*	347.819**	2.715**	15.088^{ns}	27.359^{ns}
Factor b (PS)	2	48.395**	724.345**	1092.922**	10.465**	102.684**	179.560**
IRxPS	6	3.309^{ns}	84.512^{ns}	70.707^{ns}	0.719^{ns}	8.572^{ns}	15.162^{ns}
Error	33	2.629	62.156	41.327	0.241	12.027	15.289
TOTAL	47	-	-	-	-	-	-
CV		26.48	29.01	19.28	17.41	38.23	31.31

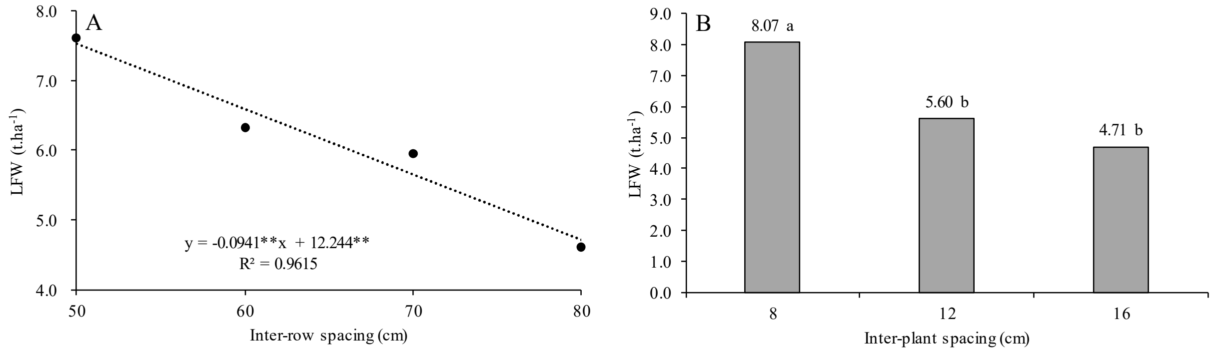

Figure 6. Leaf fresh weight (LFW) as a function of inter-row spacing (cm) (A) and plant spacing (B). Different letters above the columns compare the different plant spacings and indicate a statistical difference by Tukey's test at a level of 5% probability of error. Values with * and ** in the regressions indicate significance levels of 1% and 5% respectively by F-test.

Figura 6. Massa fresca das folhas (MFF) em função do espaçamento entrelinhas (cm) (A) e em função do espaçamento entre plantas (B). Letras diferentes sobre as colunas comparam os diferentes espaçamentos entre plantas e indicam diferença estatística pelo teste de Tukey ao nível de 5% de probabilidade de erro. Valores com *e** nas regressões indicam níveis de significância a 1% e 5% respectivamente, pelo teste F.

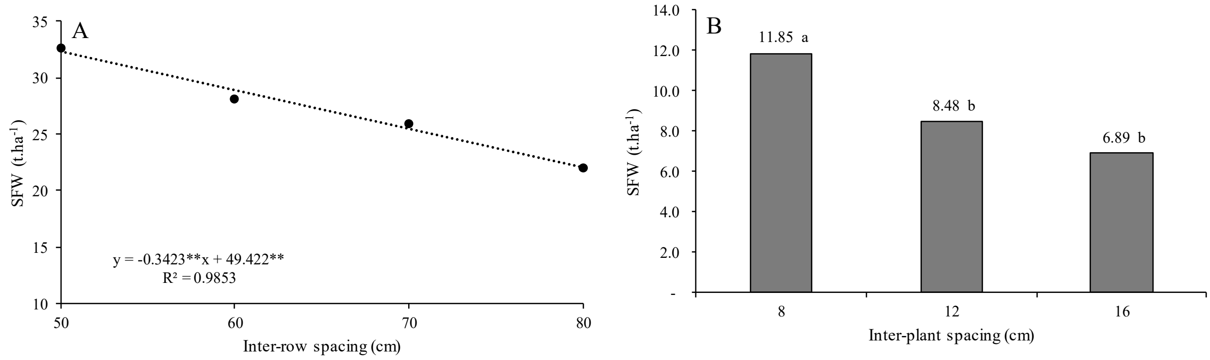

Figure 7. Stem fresh weight (SFW) as a function of inter-row spacing (cm) (a) and plant spacing (b). Different letters above the columns compare the different plant spacings and indicate a statistical difference by Tukey's test at a level of 5% probability of error. Values with * and ** in the regressions indicate significance levels of 1% and 5% respectively by F-test.

Figura 7. Massa fresca do colmo (MFC) em função do espaçamento entrelinhas (a) e do espaçamento entre plantas (b). Letras diferentes sobre as colunas comparam os diferentes espaçamentos entre plantas e indicam diferença estatística pelo teste de Tukey ao nível de 5% de probabilidade de erro. Valores com *e** nas regressões indicam níveis de significância a 1% e 5% respectivamente, pelo teste F.

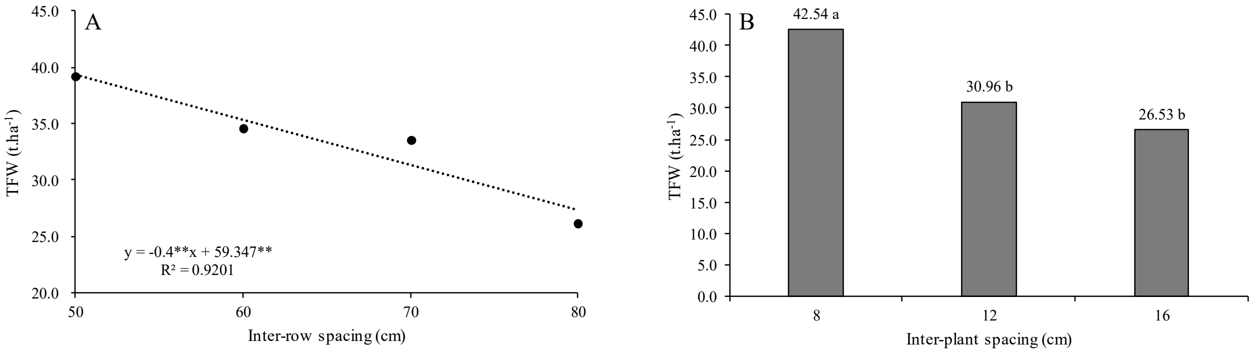

Figure 8. Total fresh weight (TFW) as a function of inter-row spacing (a) and plant spacing (b). Different letters above the columns compare the different plant spacings and indicate a statistical difference by Tukey's test at a level of 5% probability of error. Values with * and ** in the regressions indicate significance levels of 1% and 5% respectively by F-test.

Figura 8. Massa fresca total (MFT) em função do espaçamento entrelinhas (a) e do espaçamento entre plantas (b). Letras diferentes sobre as colunas comparam os diferentes espaçamentos entre plantas e indicam diferença estatística pelo teste de Tukey ao nível de 5% de probabilidade de erro. Valores com *e** nas regressões indicam níveis de significância a 1% e 5% respectivamente, pelo teste F.

Leaf dry weight suffered a reduction as the inter-row spacing increased (Figure 9A), with mean values of 3.43 $t.ha^{-1}$ at an inter-row spacing of 50 cm, and of 2.31 $t.ha^{-1}$ when the inter-row spacing was 80cm. The behaviour was similar when analysing plant spacing, with the highest mean values seen at the lowest spacing under study: 3.71 $t.ha^{-1}$ for leaf dry weight (Figure 9B), 11.85 $t.ha^{-1}$ for SDW (Figure 9C) and 16.6 $t.ha^{-1}$ for TDW (Figure 9D).

4. DISCUSSION

4.1 Experiment I

The oscillation in height seen in the last evaluations (Figure 1) may be associated with the water deficit that affected the plants at 60 DAS, and which occurred during May (Table 1). Many physiological processes in plants are affected by water deficiency, such as growth, which is controlled by cell division and expansion; insufficient water keeps the cells of growth zones in a flaccid condition, reducing the division and expansion coefficient of the cells (TAIZ; ZEIGER, 2017).

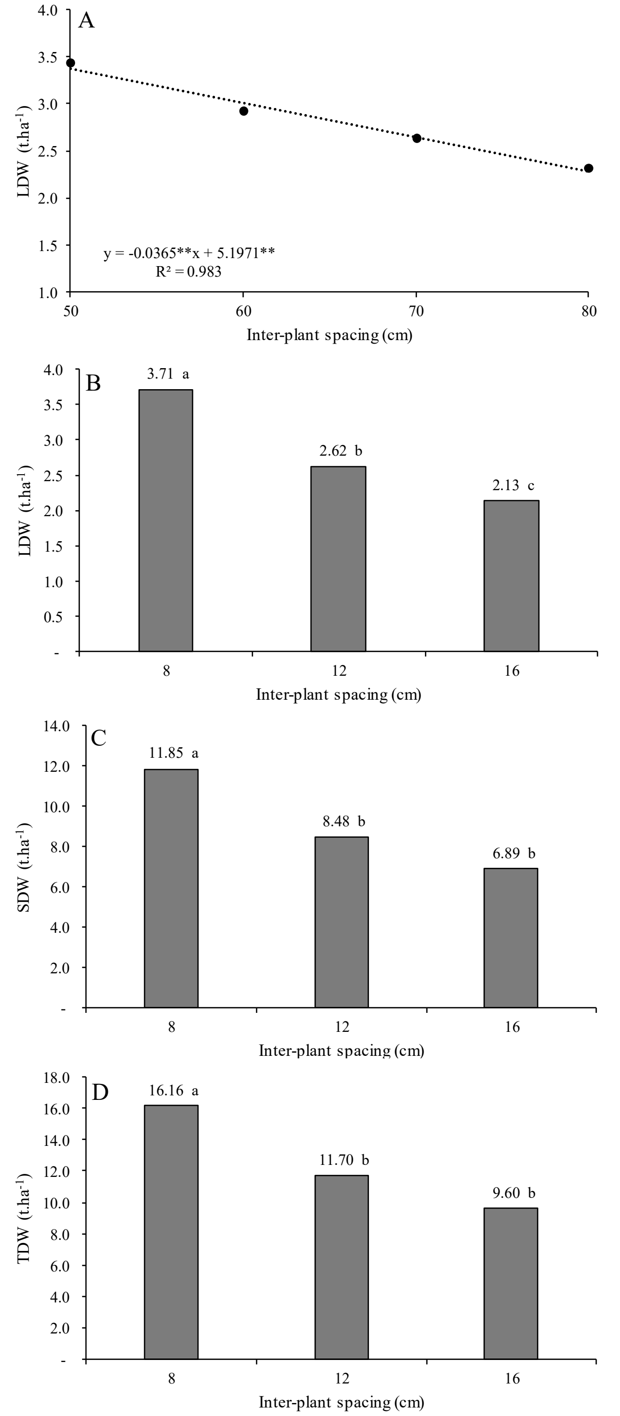

Figure 9. Leaf dry weight (LDW), as a function of inter-row spacing (a) and plant spacing (b). Stem dry weight (SDW) (c) and Total dry weight (TDW) (d) as a function of plant spacing. Different letters above the columns compare the different plant spacings and indicate a statistical difference by Tukey's test at a level of 5% probability of error. Values with * and ** in the regressions indicate significance levels of 1% and 5% respectively by F-test.

Figura 9. Massa seca da folha (MSF), em função do espaçamento entrelinhas (a) e em função do espaçamento entre plantas (b). Massa seca do colmo (MSC) (c) e massa seca total (MST) (d) em função do espaçamento entre plantas.

Letras diferentes sobre as colunas comparam os diferentes espaçamentos entre plantas e indicam diferença estatística pelo teste de Tukey ao nível de 5% de probabilidade de erro. Valores com *,** e ^{ns} nas regressões indicam níveis de significância a 1%, 5% e não significativo respectivamente, pelo teste F.

In the case of sweet sorghum, plant height is of paramount importance to the production of ethanol (AUDILAKSHMI et al., 2010). Biomass production therefore has stem production as its primary component, as this is directly linked to plant height. Plant height and stem diameter are characteristics that are affected by both environmental conditions and management practices, especially the spatial arrangement, in addition to sowing and fertilisation (EMYGDIO; CHIELLE, 2011).

In some species, certain leaves maximise light absorption by following the sun, i.e. they continuously adjust the orientation of their leaves so that they remain perpendicular to the sun's rays (TAIZ et al., 2017). Regulating the leaf angle is an advantage for the sweet sorghum, which thereby avoids absorbing possible excess radiation.

Considering plant architecture, light absorption is greater in leaves inclined perpendicular to the sun's rays, i.e. a vertical leaf orientation reduces the interception of too much light (WERNER, 2001), with greater angulations capturing more light. It can be said that at 90 DAS the photosynthetic processes were stronger. This assertion is also confirmed by Table 4, which shows that there was a greater presence of photosynthetic pigments during this period.

According to Taiz et al. (2017), under natural conditions the leaves at the top of the plant tend to have steeper angles than the lower leaves, and increase the angle of the leaf blade, allowing more sunlight to pass through the canopy. Truong et al. (2015) add that the efficiency with which the sorghum plant intercepts solar radiation is determined by the architecture and by regulating the leaf angle on the stem, and that this is related to genetic factors. This leads to the idea that there are several factors besides spacing which influence leaf angulation, and further study is needed for a better understanding of its relationship with the environment.

When studying the BRS 505 cultivar, May et al. (2012c) found that there was a reduction in stem diameter when the plant population increased, with 16.48 mm at the larger spacings and 14.08 mm at the smaller spacings. This reduction occurred due to the increased intraspecific competition for factors that are essential to the plants, such as light, nutrients and water. The additional plant density resulting from decreases in the IR can therefore cause problems of production loss; furthermore, sweet sorghum is more susceptible to lodging and breaking when it has a smaller stem diameter.

The chlorophyll content (Table 3) is related to the photosynthetic process of the plant. According to Taiz and Zieger (2017), chlorophyll a acts during the first stage of the photosynthetic process, while others, such as chlorophyll b, are pigments that aid in the absorption of light and the transfer of radiant energy to the reaction centres, and are therefore known as accessory pigments. Taiz; Zeiger (2017) explain that the chlorophyll content is influenced by several biotic and abiotic factors and is directly linked to the photosynthetic potential of the plants. Time, therefore, was the only factor among those under evaluation that was different in the chlorophyll analysis.

The decrease over time in both the variables linked to this pigment, was probably due to photo-oxidation from the high rates of luminosity common in semi-arid regions (NUNES et al., 2014; BELTRÃO et al., 2016). Because chlorophyll is unstable, it is in a constant process of synthesis and degradation, and excess light can cause its photodestruction (ARAÚJO, 2009; OLIVEIRA et al., 2011; BELTRÃO et al., 2016). Because of this, it is possible that 'BRS 511' does not have any special mechanisms to protect the photosynthetic system from excess light.

4.2 Experiment II

Similar studies with the BRS506 sweet sorghum cultivar carried out by Fernandes et al. (2014) show gains in total fresh weight when the inter-row distance was reduced from 80 cm to 50 cm. May et al. (2012b), who also evaluated the arrangement of sweet sorghum, found that a reduction in IR offers significant gains in biomass variables. The production of TFW decreased as the inter-row spacing increased; similar results were seen by May et al. (2012b), where there was a reduction of 10.63% in fresh biomass when the inter-row spacing was reduced from 80 to 50 cm. This result shows that sweet sorghum does not have a large capacity for compensating total biomass production for changes in the number of rows grown per hectare.

Results can be found in the literature which explain that increases in biomass are related to several factors besides spacing, such as the species, cultivar and environment (SILVA et al., 2017). It is not necessary to look much further than sweet sorghum to confirm this. As in the study by Rabelo et al (2012), who evaluated another type of sorghum in Minas Gerais (grain sorghum) and found that an IR of 80 cm caused a reduction in the total fresh weight or green matter of the plants, thereby explaining why increasing the IR reduces biomass, there being less intraspecific competition for essential factors. Whereas in an evaluation of forage sorghum in the State of Rio Grande do Sul, Neumann et al (2010) noticed that the biomass of this sorghum increases at larger spacings.

In this experiment, higher values were seen at higher planting densities. This probably happened because, when increasing the density of the sweet sorghum plants by area, it was still possible to capture the resources for acquiring biomass, and exploit them better than when over greater distances, where water and nutrients may be lost or absorbed by plants that are more specialised in capture, such as weeds. Therefore, the increase in plants per hectare was one of the factors to influence the increase in biomass. These results agree with Terra (2010), who, when evaluating grain sorghum, found a greater increase in leaf dry weight at lower planting densities.

The decision on inter-row and plant spacing should be taken with great care, since the use of higher plant densities in the row may be a limiting factor that could hinder the expression of the production potential of new cultivars (May et al., 2012c; SILVA et al., 2017).

It is important to mention that during the experiment the study area was suffering from drought. According to CEDEC (2017), this is the seventy-third in the State of Ceará, and a warning of a water emergency. Even so, the BRS 511 cultivar was able to complete its cycle, growing and acquiring biomass. The cultivation of sweet sorghum is therefore recommended for this region, precisely due to its adaptation to the soil and climate.

5. CONCLUSIONS

For the BRS 511 cultivar to grow in the semi-arid region of Ceará, an inter-row spacing of 70 cm is suggested, with a total population of 166,667 plants per hectare.

For the biomass of sweet sorghum 'BRS 511', a reduction in plant density to 50 cm between rows and 0.8 cm between plants is recommended to obtain a yield of 250,000 plants per hectare.

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