

Full Length Research Paper

Growth analysis, nitrogen accumulation, and yield of sugarcane varieties for the pre-amazon region of Brazil

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The great expansion of sugar cane production to non-traditional regions in Brazil has demonstrated the importance of knowledge on the growth characteristics to maintain the productivity and sustainability of the sector. Among the alternatives available to evaluate different varieties of sugar cane, the growth analysis has been one of the most used tools. The objective of this study was to evaluate the growth and development of three varieties of sugar cane for the Pre-Amazon region of Brazil. The varieties used were RB 867515, RB 863129 and RB 92579, and the following parameters of growth were evaluated: accumulation of biomass on the part area, leaf area, number of plants, height of stems, the nitrogen content in different parts of the plant (stem and leaf⁺³), brix and productivity. For that, samples were collected at 60, 120, 180, 240 and 300 days after planting. For all collecting dates and at 300 days after planting the variety RB 863129 presented better results ($P < 0.05$) for plant height, stem dry weight, N content in leaf⁺³ and final yield compared to the varieties RB92579 and RB 867515. There was no difference for number of plants ($P > 0.05$) for the varieties RB 863129 and RB 92579. Leaf area was greater ($P < 0.05$) for the variety RB 867515; and nitrogen content of stems were greater for the variety RB 92579 at 300 days after planting. Overall, the RB 863129 variety was the most promising for cultivation in this region during the sugarcane-plant season.

Key words: Biomass, crop development analysis, selection of varieties.

INTRODUCTION

Sugarcane cultivation is one of the main agricultural activities in Brazil and comprises the oldest agroindustrial sector, occupying a prominent position in the Brazilian national and international economy. Brazil is the top sugarcane producer worldwide, harvesting approximately 9 million hectares (CONAB, 2016).

In Brazil, as in other sugarcane-producing countries, sugarcane varieties have been continuously developed

and tested to increase yield, obtain higher resistance to pests and diseases, and seek better adaptation to variations in climate, soil, and cutting or management techniques (Abranches and Bolonhezi, 2011). Particularly considering the vast expansion of the sugar-ethanol sector into regions of non-traditional cane production, that is, within the pre-Amazon region of Brazil, there is still a gap in knowledge regarding the crop growth and

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development characteristics for maintaining yield and more sustainable methods in the sector of the region.

Among the alternatives available for studying sugarcane varieties, one of the most used tools has been growth analysis, which is considered a standard method for measuring crop biological productivity, serving as a very important tool to evaluate crop growth under different cultivation conditions (Batista et al., 2013). This method allows identification of the best crop developmental stages by evaluating morphological variables of the plants, such as height, stem diameter, tillering, leaf area, and yield, making it possible to determine the productive capacity of different varieties. These data help in understanding the climatic effect on yield, intervention in agricultural planning, and determining the magnitude of physiological stress and final yield (Simões et al., 2005). Thus, identifying variation during sugarcane development is essential to model and quantify growth in different production environments. For example, Oliveira et al. (2010), evaluating growth and accumulated dry matter in eleven sugarcane varieties (SP 791011, RB 813804, RB 863129, RB 872552, RB 943365, RB 72454, RB 763710, SP 784764, SP 813250, RB 867515, and RB 92579) farmed under full irrigation, found that accumulated stem dry matter was characterized by the following three developmental stages: a first stage characterized by lower accumulated stem dry weight than accumulated leaf+top dry weight (on average 8 Mg ha⁻¹ at 120 days after planting - DAP); a second stage where accumulated stem dry weight was higher (on average 48 Mg ha⁻¹ at 240 DAP); and a third stage starting at 240 DAP with higher accumulated stem dry weight (85 and 72 Mg ha⁻¹) for the 92579 and SP81 3250 varieties, respectively.

Within the context of growth and yield, sugarcane has a high nitrogen requirement. Nitrogen is considered as one of the elements most absorbed by the crop: it is very important in plant nutrition and physiology because it is a constituent of amino acids, proteins, enzymes, and nucleic acids (Keshavaiah et al., 2012). Thus, N transport to the sugarcane plants and within them is important for plant growth and development, making knowledge of these aspects for better crop management necessary (Toppa et al., 2010).

In view of what has been exposed here, with the expectation of expanding the sector in regions of Brazil that are still untapped, that is, within the pre-Amazon region comprising the Low Parnaíba of Maranhão microregion, this study aimed to evaluate the growth and development of three sugarcane varieties (RB 867515, RB863129, RB92579) for the region's edaphoclimatic conditions.

MATERIALS AND METHODS

Description of the experimental site

This study was performed within an area provided by the Várzea farm, in the municipality of Brejo in the Low Parnaíba of Maranhão

region, located at 03°44'33"S latitude, 43°21'21"W longitude. The region's climate is Aw according to the Köppen classification (hot and wet with rainy season in the Brazilian summer and dry in the Brazilian winter). The soil of the experimental site was classified as yellow Oxisol. Soil samples from 0 to 20 cm depth were collected before planting sugar cane and analyzed for pH (0.01 M water suspension, 1:2.5 soil/solution, v/v), organic carbon (Walkley-Black), P and exchangeable Ca, Mg, K, and H+Al according to standard methods used by Embrapa (1999). Particle size analysis was performed using the pipette method (Robinson, 1967). The soil presented the following characteristics: pH in water = 5.1, Ca = 2.2 cmol_c dm⁻³, Mg = 2.5 cmol_c dm⁻³, Na = 0.02 cmol_c dm⁻³, K = 0.11 cmol_c dm⁻³, Al = 0.6 cmol_c dm⁻³, H+Al = 9.4 cmol_c dm⁻³, P = 2.5 mg L⁻¹; sand = 54%, silt = 22%, and clay = 25%.

The highest rainfall is concentrated in December through May, which represents 70 to 80% of the total rainfall. The meteorological data on monthly rainfall (mm) and mean temperature (°C) during the experimental period were collected at the closest Brazilian National Institute of Meteorology station to the experimental site, located in the municipality of Chapadinha (Figure 1). The following sugar cane varieties were used: RB 867515, RB 863129, and RB 92579, and the soil of the experimental site was subjected to conventional tillage in December 2009. The seed pieces were distributed in 30 cm-deep furrows spaced 1.5 m apart, placing the seed pieces continuously, with the basal end in contact with the apical end of the subsequent seed piece. After distributing the seed pieces in the furrows, the stems were cut into billets of approximately three to four buds. The seeds were covered by 5 to 10 cm of soil. The experiment was laid out in randomized complete block design with three replicates, totaling nine plots, each plot having an area of 880 m². The total experimental area was 7920 m². The following five harvests were performed to obtain the data: at 60, 120, 180, 240, and 300 days after planting (DAP). The following growth parameters were determined at every harvest period: accumulated shoot biomass, total leaf area (TLA), number of plants, and stem heights. Nutrient content in the different portions of the plants (leaf⁺³ and stem) was determined at the last harvest (at 300 DAP), and the brix and yield parameters were also determined.

The accumulated dry weight of stem and top+leaves was quantified by collecting three plants of each plot at random. After harvest, each plant was separated into stem and top+leaves, which were labeled and placed in an oven at 60°C to obtain the dry weight (Oliveira, 2008). Total leaf area (TLA m²) was determined by measuring from the first to the sixth leaf of eight plants in two linear meters of sampling area in each experimental plot, measuring leaf length and width in the middle portion with a graduated ruler, using the equation TLA=L.W.c proposed by Buso et al. (2009), where L=length; W=width; c=correction factor.

Biometric data were collected to determine parameters related to plant production following the method proposed by Barbosa (2005), where the number of plants was obtained by counting the plants sampled in two linear meters of each plot, and mean stem height was measured with a graduated ruler, measuring plant height from ground level to the top. Eight plants within the two linear meters of the sampling of each plot were measured. Brix content (%) of the sugarcane was measured using a field refractometer, where three plants were randomly removed per plot, and samples were collected from the stem water. Drops of stem water were extracted from the 4th internode from the soil and from the top of the last internode of the sheath that detaches easily. During the five harvest periods, samples were collected from the plant shoots to evaluate the accumulated nutrient contents. The dry matter of the plant fractions (stem and leaf⁺³) was ground and subjected to digestion to determine the macronutrient levels using the method proposed by Vaccaro et al. (2004). Yield of the sugarcane varieties was obtained by harvesting plants at 300 DAP in an area of 3 m² of each plot, considering the sum of the stem, top, and straw weights.

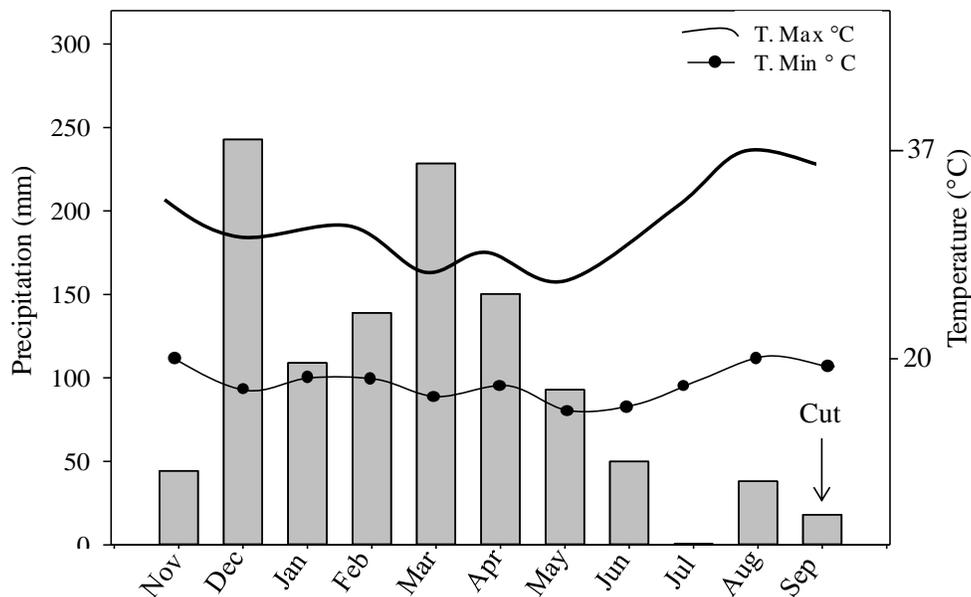


Figure 1. Rainfall (mm) and maximum and minimum temperature (°C) during the experimental period from December 2009 to October 2010.

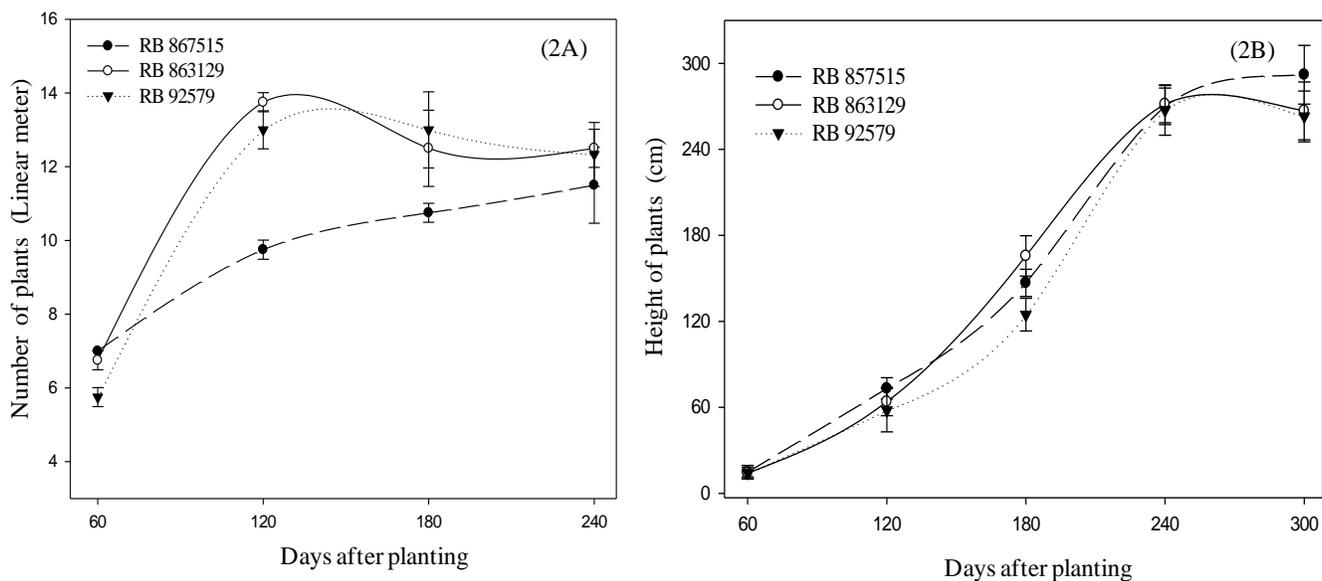


Figure 2. (A) Number of plants of three sugarcane varieties in the sugarcane-plant cycle at different harvest periods; (B)- Mean height of three sugarcane varieties in the sugarcane-plant cycle at different harvest periods.

RESULTS AND DISCUSSION

Plant growth analysis

There were no differences in the number of plants at 60 DAP ($P > 0.05$) for this parameter among the varieties evaluated (Figure 2a). At 120 DAP, maximum tillering was recorded for RB 863129 and RB 92579, exhibiting

mean values of 14 and 13 plants per linear meter, respectively. There was a small increase in this parameter from 60 to 120 DAP for RB 867515. At 180 DAP, there was a slight decrease in this parameter for the RB 863129 variety, whereas number of plants remained constant for RB 92579 and increased for the RB 867515 variety (ten plants per linear meter).

During the last harvest, at 240 DAP, the RB 92579 and

RB 863129 varieties remained at the same level, both with twelve plants per linear meter, while the RB 867515 variety again exhibited a small increase at 240 DAP, with eleven plants per linear meter. In general, the number of plants was higher for the RB 863129 and RB 92579 varieties than for RB 867515 ($P > 0.05$).

According to the results obtained, there was maximum tillering at the early stages of plant development (120 DAP). This intense tillering was attributed to the high availability of water, light, and space to be exploited by the plants at the onset of the cycle, and there was a small natural decline in number of plants after this period (at 180 and 240 DAP), especially because the first tillers were developing and occupying more space in the soil and air during this period, so their leaves were shading out the younger plants that sprout, which exhibit lower chances of developing, some dying before becoming adult plants. Thus, the first tillers are more efficient in competing for water and light.

Costa et al. (2011) evaluating the growth and development of four varieties in four crop cycles, (RB 92579, RB 931530, SP 79 1011, and RB 93509), found a higher increase in tillering at 90 DAP for the varieties under study, and among the varieties studied, RB 92579 exhibited the highest tillering (27 tillers per linear meter), accompanied by a 63% decrease in number of stems at harvest. Silva et al., (2008), found for the IAC 862480 genotype and RB 72454 variety maximum tillering was obtained at 90 days after implementing the treatments, the IAC 86-2480 genotype having a higher number of tillers than RB 72454, with mean tillers of 29 and 18 per linear meter, respectively.

Overall, stem height exhibited a linear growth curve as a function of time in all of the varieties (Figure 2b); and the same trend was observed in the study by Abreu et al. (2013). Between 60 and 120 DAP, the varieties evaluated exhibit essentially the same plant height. At 180 DAP, the RB 863129 variety exhibited a mean plant height of 165 cm, higher ($P < 0.05$) than the RB 867515 and RB 92579 varieties, which exhibited plant height of 146 and 124 cm, respectively (Figure 2b). The three varieties evaluated were characterized by the following very similar mean plant height values at 240 DAP: RB 867515 (270 cm), RB 863129 (271 cm), and RB 92579 (267 cm). The RB 867515 variety exhibited a higher mean plant height at 300 DAP, 292 cm, compared to the RB 863129 and RB 92579 varieties with 266 and 263 cm, respectively, at this harvest period.

According to the results obtained regarding stem height, three developmental stages can be observed for this parameter: a first stage where there was a small increase in stem height (from 60 to 120 DAP). Growth is slow at this early developmental stage, as intense tillering of the crop is still occurring at this stage. The second stage can be described by a rapid growth in stem height, which coincides with the periods of good meteorological conditions of temperature and rainfall (Figure 1). The final

stage from 240 to 300 DAP is characterized by slow growth because photoassimilates are directed to sucrose accumulation during this period. Oliveira et al. (2004) evaluating growth and development of three sugarcane varieties in the sugarcane-plant cycle (RB 72454, RB 855113, and RB 855536), found an early stage characterized by lower stem height due to intense tillering during this same stage and a second stage (from 279 DAP to 377 DAP), characterized by higher stem height growth as a result of good meteorological conditions and reduced tillering rate. Oliveira et al. (2010), studying growth and accumulated dry weight in eleven sugarcane varieties, including the RB 863129, RB 92579, and RB 867515, found variable stem height with slow early growth until 60 DAP, with higher stem height growth rates from 60 to 240 DAP; the RB 863129, RB 867515, and RB 92579 varieties exhibited the following stem heights at this stage, respectively: 291, 304, and 311 cm.

The leaf area parameter remained practically constant for the three varieties studied until 120 DAP (Figure 3a). The leaf area was increased in the three varieties from 120 DAP to 240 DAP, with RB 863129 and RB 867515 having the highest increases of 21 and 22%, respectively. RB 867515 exhibited increased leaf area from 180 DAP to 240, remaining at the same level as RB 863129, whereas the RB 92579 variety had the lowest mean for this parameter. Higher leaf area was observed for the RB 867515 variety at 300 DAP (0.29 m^2), which was higher than the RB 863129 and RB 92579 varieties, which reached values of 0.26 and 0.24 m^2 , respectively. The values significantly differed ($P < 0.05$) for the RB 863129 and RB 867515 varieties compared to RB 92579.

In general terms, from 120 to 240 DAP in this experiment, there was a higher increase in leaf area, as the plants were investing in the production of leaf apparatuses during this developmental stage, also supported by the good rainfall and temperature conditions during this period (December to June) (Figure 1). The reduction in leaf area was observed from 240 to 300 DAP may be explained by lower rainfall and increased temperature during this period and the senescence of older leaves that occurs during this period, with higher plant investment in accumulating sucrose. Santos et al. (2009), in a study performed on the RB 75126 variety, found similar behavior for the leaf area index to the observations in this study, where there was a slow growth period until 60 DAP, followed by a rapid growth period (from 60 to 120 DAP) and then a decrease starting from 300 DAP, where the final period was affected by the maturation process and sucrose concentration. These results also corroborate Vieira et al. (2013), found that water stress causes reduced leaf area, as it accelerates the senescence process of the green leaves.

Accumulated stem dry weight did not differ among the varieties evaluated for the first harvest at 60 DAP, and this parameter only increased significantly for the three

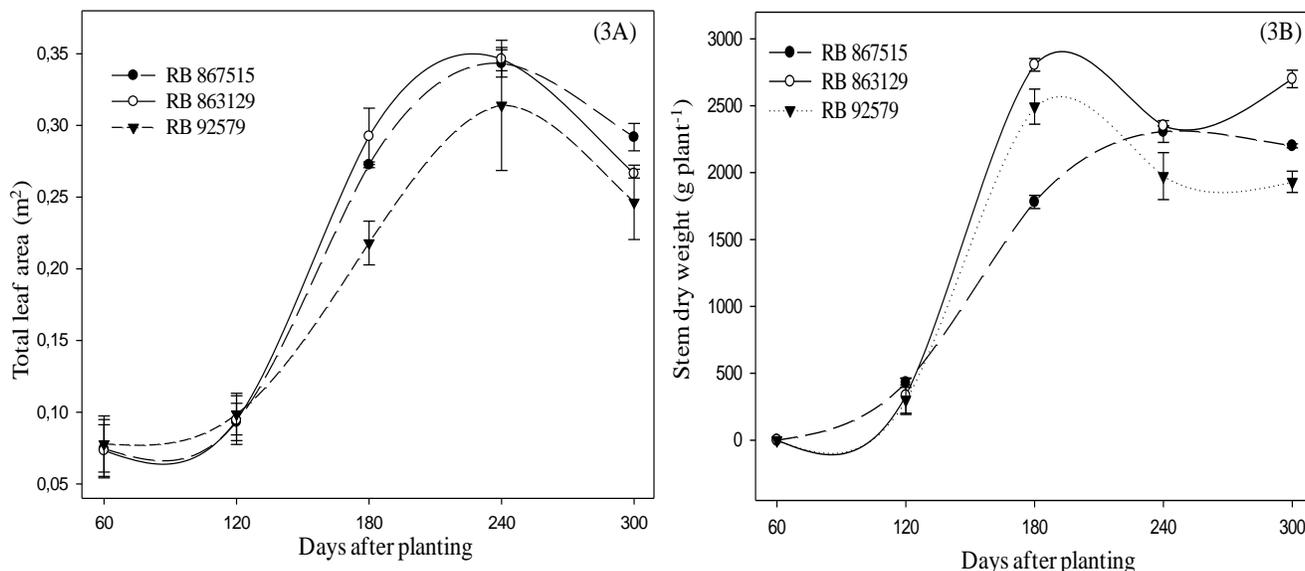


Figure 3. (A) Total leaf area (TLA) of three sugarcane varieties in the sugarcane-plant cycle at different harvest periods; (B) Stem dry weight of three sugarcane varieties in the sugarcane-plant cycle at different harvest periods.

varieties at 120 DAP. However, it did not significantly differ among them ($P > 0.05$), with values of 429, 332, and 302 g plant⁻¹ for the RB 867515, RB 863129, and RB 92579 varieties, respectively (Figure 3b). There was a higher increase ($P < 0.05$) in stem dry weight at 180 DAP (2805 g plant⁻¹) for the RB 863129 variety compared to the other varieties. The RB 867515 variety exhibited a large increase in stem dry weight from 180 DAP to 240 DAP, with values close to the ones obtained for the RB 863129 variety, followed by the RB 92579 variety (2349 and 1974 g plant⁻¹, respectively). During this harvest period, the stem dry weight decreased from a value of 2493 at 180 DAP to a value of 1974 g plant⁻¹ at 240 DAP for the RB 92579 variety.

During the last harvest, at 300 DAP, the RB 863129 variety exhibited higher ($P < 0.05$) stem dry weight (2700 g plant⁻¹) than the other varieties (Figure 3b). The results obtained for accumulated stem dry weight show two distinct stages: a first stage that occurs from 60 to 120 DAP, where there was slow accumulation of stem dry weight, because during this early stage of plant development, there is a prevalence of phytomass allocated to leaves+green tops; and a second stage from 120 to 180 DAP characterized by rapid growth, where there was a prevalence of phytomass allocated to stems. In fact, Alvarez and Castro (1999), evaluating raw and burned sugarcane shoot growth for the SP 701143 variety, also found these two distinct stages for accumulated stem dry weight, where one stage was characterized by a slow increase from 30 at 120 DAP, and a second stage was characterized by a higher accumulation starting at 120 DAP. The first stage was characterized by intense tillering, and the final stage had

a predominance of phytomass in the stems. Oliveira et al. (2007), evaluating biomass production in three sugarcane varieties (RB 72454, RB 855113, and RB 855536), observed the same trend.

The results obtained also showed a proportional relationship between leaf area and accumulated stem dry matter, where the two varieties that exhibited higher accumulation (RB 863129) also exhibited higher leaf area, showing that leaf area is directly associated with the quantity of light absorbed, affecting the total photosynthesis rate, thus providing a higher accumulated biomass in the plants. These results corroborate the findings of Abranche and Bolonhezi (2011), who evaluated the vegetative development of five clones and two varieties of sugarcane and found that the best results obtained for accumulated stem dry weight had a proportional relationship between leaf area (AF/m²) and accumulated biomass and dry matter.

Nitrogen accumulation

Regarding nitrogen content in the leaves⁺³, there was higher accumulated N during the early stage of crop development (at 60 DAP) and a decline during the following stages (at 180, 240, and 300 DAP) for all varieties (Figure 4a). Among the three varieties studied, the RB 863129 variety exhibited higher nitrogen content in the leaves⁺³ ($P < 0.05$) at 120 and 180 DAP compared with the other varieties evaluated.

Higher accumulated N during the early stages of plant development is due to the metabolic activity of the leaves during this period, and this decline during the final stages

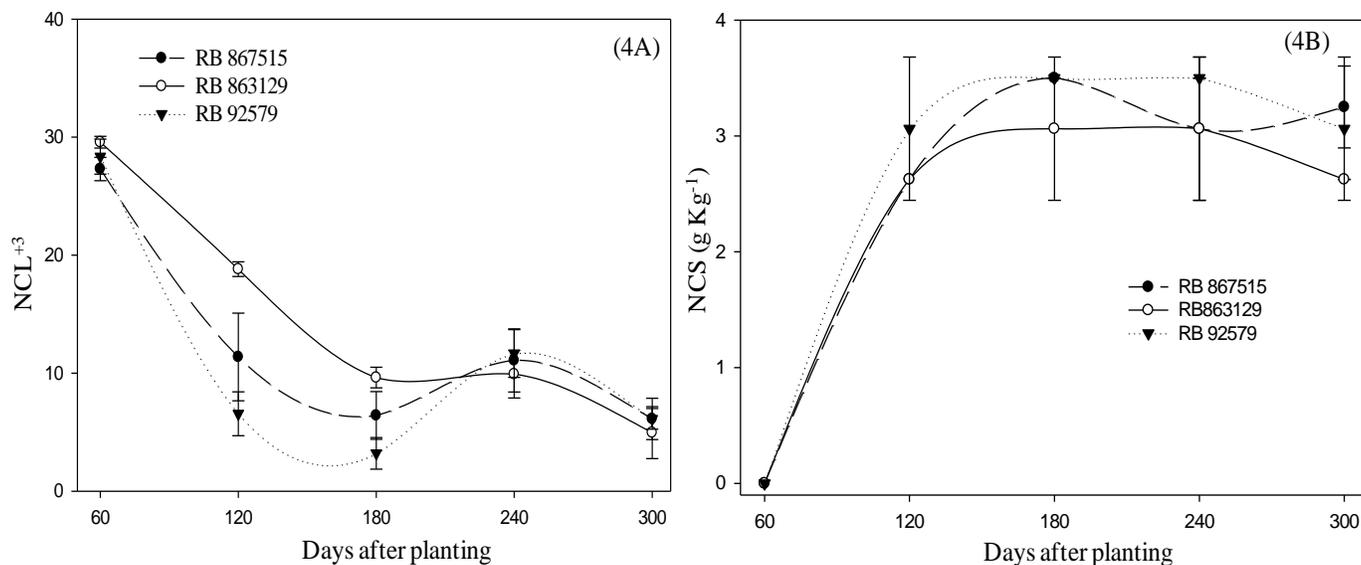


Figure 4. (A) N content in the leaves+3 of three sugarcane varieties in the sugarcane-plant cycle at different harvest periods; (B) Stem N content of three sugarcane varieties at different harvest periods.

of plant development can be predominantly explained by the effect of diluting nitrogen on plant biomass, imposed by the crop's growth, and by the effect of leaf senescence during the plants' physiological maturity. Leite (2011) evaluating the accumulation of phytomass and nutrients in sugarcane, observed a significant decrease (of 40 kg ha⁻¹) in accumulated nitrogen in leaves+top at 237 DAP, linking this result to nitrogen mobility within the plants and leaf senescence during the period of sugarcane plant physiological maturity.

Oliveira et al. (2011) evaluating nutrient accumulation and allocation in sugarcane for the RB 92579, RB 867515, RB 943365, and SP 81-3250 varieties, observed higher accumulated N at 120 DAP in the leaves compared to that in the stems because the quantity of dry matter produced by 120 DAP was higher for stems, whereas the highest N accumulation occurred in the leaves for the RB 867515 variety, with mean extraction ranging between 62 and 78 kg ha⁻¹ of N. For stem nitrogen content, the RB 92579 variety exhibited higher nitrogen content in the stems ($P < 0.05$) compared with the RB 867515 and RB 863129 varieties at 120 DAP. However, the RB 867515 variety exhibited an increase in this parameter at 180 DAP, not differing from the RB 92579 ($P > 0.05$) variety, demonstrating that these two varieties are higher in this parameter at 180 DAP compared to RB 863129 (Figure 4b). The RB 92579 variety continued, accumulating higher N levels in the stems compared to the other varieties at 240 DAP, whereas there was a decrease in N levels in the stems for RB 867515 from 180 to 240 DAP (Figure 4b).

Overall, during the last harvest, at 300 DAP, the RB 92579 variety accumulated higher N levels ($P < 0.05$) than

the other varieties. Stem-accumulated N is low at 60 and 120 DAP and high at 180, 240 and 300 DAP. This pattern most likely occurred because during the early stages of development, the crop has higher metabolic activity in the leaves, which consequently exhibit the highest N levels, whereas N accumulation decreases during the later stages of crop development.

Brix content and final yield

The brix value observed at 300 DAP was within the expected range of maturation, given that the environmental conditions during the crop cycle were favorable (Figure 5), and there were no significant differences among the varieties ($P > 0.05$).

Marques and Silva (2008) evaluating plant growth and maturation in three sugarcane varieties, including RB 867515, found that this variety exhibited a brix value of only 15% after ten months of plant growth. Martins and Munhoz (2009) evaluating qualitative traits using different maturers in three sugarcane varieties (RB 72454, RB 835486, and RB 855113), observed brix values ranging between 13 and 15%, which were lower than the values found in this study, as observed in Figure 5a.

In evaluating the yield of the three varieties regarding productivity, the RB 863129 variety shown better performance ($P < 0.05$) (Figure 5b), with a total mean yield of 144 t ha⁻¹ (120 and 24 for stems and tops+leaves, respectively), whereas the RB 867515 and RB 92579 varieties produced 112 and 111 t ha⁻¹ (with 93 and 19, 85 and 26 for stems and tops+leaves, respectively). The RB 863129 variety exhibited higher yield, which was directly

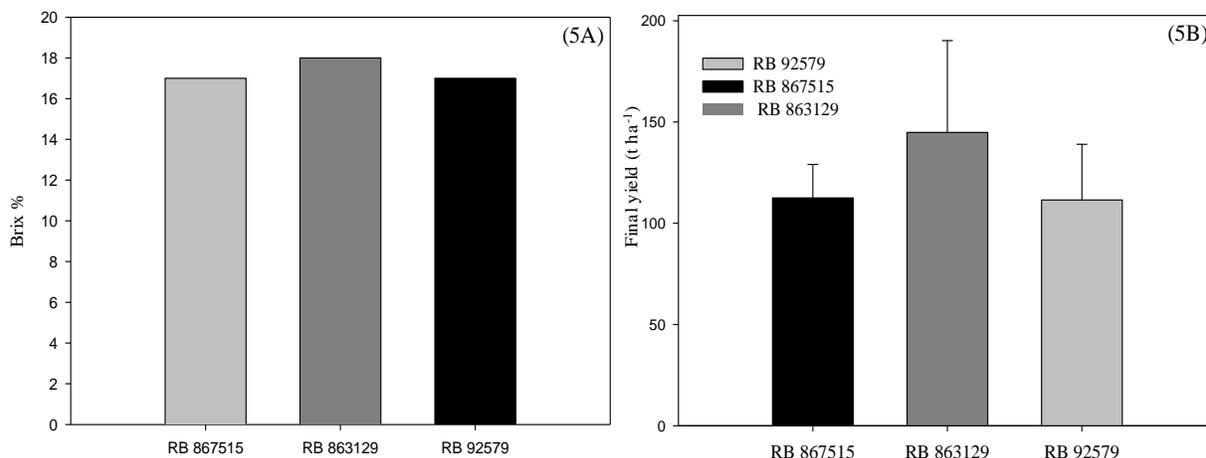


Figure 5. (A) Brix percentage in three sugarcane varieties in the sugarcane-plant cycle at 300 DAP; (B) Yield of three sugarcane varieties in the sugarcane-plant cycle at 300 DAP.

correlated with its good performance in the parameters observed in the growth analysis, such as number of plants, stem dry weight, and leaf area, as shown in Figures 2a, 3a, and b. Capone et al. (2011) studying the behavior of 15 sugarcane cultivars, found that the cultivars that exhibited the best yields also exhibited the best traits for number of plants per hectare and plant height, demonstrating a direct correlation between these traits and yield. Nassif et al. (2012), observing the parameterization and evaluating the DSSAT/Canegro model for Brazilian sugarcane varieties, also found a direct proportional relationship between accumulated stem dry weight, leaf area index, and yield. The RB 863129 variety exhibited a higher yield than the regional and Brazilian national means (57 and 77 t ha⁻¹, respectively) (Conab, 2012).

Conclusions

According to evaluation of the parameters in growth and yield analysis, the RB 863129 variety was the most promising for cultivation in this region during the sugarcane-plant season. The good performance observed for this variety must also be attributed to the good local meteorological conditions, with high rainfall and temperatures (during the rainy season). Within the Brazilian pre-Amazon region, there still exists a gap in the information on varieties that would be best for the region's edaphoclimatic conditions. The findings of this study can be considered for decisions when implementing new producing areas.

Conflict of Interests

The authors have not declared any conflict of interests.

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REFERENCES

- Abranches JL, Bolonhezi AC (2011). Desenvolvimento inicial de variedades e clones de cana-de-açúcar em latossolo vermelho distrófico, aparecida do Taboado-MS. *Rev. Bras. de Ciênc. Agrár.* 6:369-375.
- Abreu ML, Silva MA, Teodoro I, Holanda LA, Sampaio Neto GD (2013). Crescimento e produtividade de cana-de-açúcar em função da disponibilidade hídrica dos tabuleiros Costeiros de Alagoas. *Bragantia* 72:262-270.
- Alvarez IA, Castro PRC (1999). Crescimento da parte aérea de cana crua e queimada. *Sci. agric.* 56:1069-1079.
- Barbosa EA (2005). Avaliação fitotecnia de cinco variedades de cana-de-açúcar para o município de Salinas-MG. 70 f. Tese - (Mestrado em agronomia, área de concentração em fitotecnia) – Universidade Estadual do Sudoeste da Bahia, Vitória da Conquista, 2005.
- Batista ELS, Zolnier S, Ribeiro A, Lyra GB, Silva TG, Boehringer D (2013). Modelagem do crescimento de cultivares de cana-de-açúcar no período de formação da cultura. *Rev. bras. eng. agríc. ambient.* 17:1080-1087.
- Buso PHM, Koehler HS, Daros E, Zambon JLC, Ido OT, Filho JCB, Weber H, Oliveira RA, Neto HZ (2009). O sistema radicular da variedade RB 855536 de cana-de-açúcar no plantio em minitolete e tolete. *Sci. agrar.* 10:343-349.
- Capone A, Lui JJ, Silva TR, Dias MAR, Melo A (2011). Avaliação do comportamento de quinze cultivares de cana-de-açúcar na Região Sul do Tocantins. *J. Biotec. Biodivers.* 2:70-78.
- Companhia Nacional de Abastecimento (CONAB). Acompanhamento da safra brasileira de cana-de-açúcar 2016/2017.
- Companhia Nacional de Abastecimento - CONAB. Safra 2011/2012. Terceiro Levantamento (novembro/2012). Available: <<http://www.conab.gov.br>>. Accessed: April 2013.
- Costa CTS, Ferreira VM, Endres L, Ferreira DTRG, Gonçalves ER (2011). Crescimento e produtividade de quatro variedades de cana-de-açúcar no quarto ciclo de cultivo. *Rev. Caatinga* 24:56-63.

- EMBRAPA (1999). Manual de Análises Químicas de Solos, Plantas e Fertilizantes. Brasília: Embrapa Comunicação para Transferência de Tecnologia, Brasília.
- Keshavaiah KV, Palled YB, Shankaraiah C, Channal HT, Nandihalli BS, Jagadeesha KS (2012). Effect of nutrient management practices on nutrient dynamics and performance of sugarcane. *Karnataka J. agr. sci.* 25:187-192.
- Leite JM (2011). Acúmulo de fitomassa e de macronutrientes da cana-de-açúcar relacionadas ao uso de fontes de nitrogênio (Doctoral dissertation, Escola Superior de Agricultura "Luiz de Queiroz").
- Marques TA, Silva WH (2008). Crescimento vegetativo e maturação em três cultivares de cana-de-açúcar. *Rev. biol. ciênc. terra.* 8:54-60.
- Martins T, Munhoz R (2009). Avaliação de caracteres qualitativos em variedades de cana-de-açúcar submetidas a aplicação de diferentes maturadores químicos. *Rev. Agron. Meio Ambiente,* 2:367-379.
- Nassif DSP, Marin FR, Filho WJP, Resende RS (2012). Parametrização e avaliação do modelo DSSAT/Canegro para variedades brasileiras de cana-de-açúcar. *Pesqui. agropecu. bras.* 47:311-318.
- Oliveira ECA, Freire FJ, Oliveira RI, Oliveira AC, Freire MBG (2011). Acúmulo e alocação de nutrientes em cana-de-açúcar. *Rev. Ciênc. Agron.* 42:579-588.
- Oliveira ECA, Freire FJ, Oliveira RI, Santos MBG, Freire MBGS, Neto DES, SILVA SAM (2010). Extração e exportação de nutrientes por variedades de cana-de-açúcar cultivadas sob irrigação plena. *Rev. bras. ciênc. solo.* 34:1343-1352.
- Oliveira ECA, Oliveira RI, Andrade BMT, Freire FJ, Júnior MAL, Machado PR (2010). Crescimento e acúmulo de matéria seca em variedades de cana-de-açúcar cultivadas sob irrigação plena. *Rev. bras. eng. agríc. ambient.* 14:951-960.
- Oliveira ECA (2008). Dinâmica de nutrientes na cana-de-açúcar irrigado em sistema de produção. 2008. 73 f. Tese (Mestrado em ciência do solo) – Universidade Federal Rural de Pernambuco, Recife, 2008.
- Oliveira RA, Daros E, Zambon JLC, Weber H, Ido OT, Filho JCB, Ribas KCZ, Silva DKT (2007). Área foliar em três cultivares de cana-de-açúcar e sua correlação com a produção de biomassa. *Pesqui. Agropecu. Trop.* 37:71-76.
- Oliveira RA, Daros E, Zambonweber JLC, Ido OT, Ribas KCZ, Koehler HS, Silva DKT (2004). Crescimento e desenvolvimento de três cultivares de cana-de-açúcar, em cana-planta, no estado do Paraná. *Sci. Agrar.* 5:87-94.
- Robinson JBD (1967). Soil Particle-size fractions and nitrogen mineralization. *J. Soil Sci.*, 18(1):109-117.
- Santos VR, Filho GM, Albuquerque AW, Costa JPV, Santos CG, Santos ACI (2009). Crescimento e produtividade agrícola de cana-de-açúcar em diferentes fontes de fósforo. *Rev. bras. eng. agríc. ambient.* 13:389-396.
- Silva MA, Silva JAG, Enciso J, Sharma V, Jifon J (2008). Yield components as indicators of drought tolerance of sugarcane. *Sci. Agric.* 65:620-627.
- Simões MS, Rocha JV, Lamparelli RAC (2005). Indicadores de crescimento e produtividade da cana-de-açúcar. *Sci. Agric.* 62:23-30.
- Toppa EVB, Jadoski CJ, Julianetti A, Hulshof T, Ono EO (2010). Aspectos da fisiologia de produção da cana-de-açúcar (*Saccharum officinarum* L.). *Pesqui. Appl. Agrotec.* 3:215-221.
- Vaccaro S, Brun EJ, Shumacher MMV, König FG, Kleinpaul IS, Ceconi DE (2004). Comparação entre três diferentes métodos de análise de tecido vegetal. *Bol. Pesqui. Florest.* 48:15-28.
- Vieira GHS, Mantovani EC, Sediya GC, Cecon PR, Delazari FT (2013). Época de interrupção da irrigação na cultura da cana-de-açúcar. *Irriga.* 18:426-441.