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ORIGINAL ARTICLE

Sugarcane yield and performance as a function of harvesting speed in dry and rainy periods[1]

Produtividade e desempenho da cana-de-açúcar em função da velocidade de colheita em períodos seco e chuvoso

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HIGHLIGHTS:

Speeds from 5 km h^{-1} increased internode length at 360 days after cutting in both harvest seasons.
Speed of 5 km h^{-1} increased culm diameter and leaf area, respectively, at 270 and 360 days after cutting in sugarcane.
Rainy season is important for tillering and culm diameter.

ABSTRACT: Mechanized sugarcane harvesting can have negative implications, depending on soil moisture and climate conditions. Among the associated challenges is soil compaction, caused by heavy machinery traffic under inadequate moisture and speed conditions, which limits sugarcane yield and longevity. Therefore, the objective of this study was to evaluate sugarcane yield and agroindustrial performance as a function of harvesting speed during dry and rainy seasons. A two-year experiment was conducted in the eastern region of Paraíba state, Brazil, during the dry and rainy seasons, using a randomized block design. Harvester speeds (2, 3, 4, 5, and 6 km h^{-1}) were used in two harvesting seasons (dry season – Site 1; and rainy season – Site 2), with four replicates. The results indicated that harvesting in the dry season resulted in a greater number of culms per meter, culm diameter, internode length, and leaf area at the end of the ratoon cycle. Conversely, the rainy season favored culm height and internode number. Harvester speed of 5 km h^{-1} increased leaf area and culm diameter in ratoon cane. It was concluded that sugarcane harvested in the dry season exhibited better vegetative performance throughout the ratoon cycle. Furthermore, different harvesting speeds did not significantly affect the industrial quality of the cane, regardless of the harvest season.

Key words: *Saccharum* spp., mechanized harvesting, harvester, operational efficiency

RESUMO: A colheita mecanizada de cana-de-açúcar pode ter implicações negativas, dependendo da umidade do solo e das condições climáticas. Entre os desafios associados está a compactação do solo, causada pelo tráfego de máquinas pesadas em condições inadequadas de umidade e velocidade, o que limita a produtividade e a longevidade da cana-de-açúcar. Portanto, o objetivo deste estudo foi avaliar a produtividade da cana-de-açúcar e o desempenho agroindustrial em função da velocidade de colheita durante as estações seca e chuvosa. Um experimento de dois anos foi conduzido na região leste da Paraíba, Brasil, durante as estações seca e chuvosa, usando um delineamento em blocos casualizados. As velocidades da colhedora (2, 3, 4, 5 e 6 km h^{-1}) foram utilizadas em duas estações de colheita (estação seca - Local 1; e estação chuvosa - Local 2), com quatro repetições. Os resultados indicaram que a colheita na estação seca resultou em maior número de colmos por metro, diâmetro do colmo, comprimento do entrenó e área foliar no final do ciclo. Por outro lado, a estação chuvosa favoreceu a altura do colmo e o número de entrenós. A velocidade da colhedora de 5 km h^{-1} aumentou a área foliar e o diâmetro do colmo na cana-soca. Concluiu-se que a cana-de-açúcar colhida na estação seca apresentou melhor desempenho vegetativo ao longo do ciclo. Além disso, diferentes velocidades de colheita não afetaram significativamente a qualidade industrial da cana, independentemente da época de colheita.

Palavras-chave: *Saccharum* spp., colheita mecanizada, colhedora, eficiência operacional

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Introduction

Brazil is the world's largest producer of sugarcane (*Saccharum* spp.) and one of the main suppliers of sugar and ethanol in the world (Resende et al., 2025). Large-scale bioenergy production benefits from the green sugarcane system, which contributes positively to social and economic objectives, in addition to the environmental aspects essential in the management of agricultural processes (Castro et al., 2018; Cherubin et al., 2021). Harvest management strategies using new sugarcane agricultural mechanization techniques and timely care of field operations can reduce costs and improve the quality of sugarcane production (Silva et al., 2021; Dahab & Abdalla, 2023).

In tropical countries, such as Brazil, which has a continental geographic area, sugarcane producing regions have contrasting climatic conditions, such as dry and rainy seasons (Vianna & Sentelhas, 2016; Mohanraj et al., 2021). Environmental factors such as periods of drought cause water stress in sugarcane, which in addition to reducing leaf area due to increased senescence of photosynthetically active leaves, reduces transpiration rates, common in varieties considered sensitive to water restriction (Verma et al., 2021). On the other hand, the greater water supply during the harvest period can cause changes in the physiology of sugarcane according to the genotype and production environment (Zhu & Gong, 2014; Ashagre & Khan, 2020; Saavedra-Díaz et al., 2024). However, changes in the morphological characteristics of plants are expressed in various ways and depend on crop management conditions.

The operating speed of a sugarcane harvester directly influences operating costs, including fuel consumption, machine depreciation, and maintenance and repair expenses (Martins et al., 2021). Although these machines can operate at up to 9.0 km h^{-1}, their optimal performance is observed at speeds between 3.0 and 6.0 km h^{-1} (Ripoli & Ripoli, 2009). In areas unsuitable for mechanized harvesting, higher speeds result in greater raw material losses (Xavier et al., 2020).

Studies indicate that adopting an adequate feeding speed and maintaining a stable sugarcane transport rate are essential to improve cutting efficiency (Zhou et al., 2024). However, there are still discrepancies in the literature regarding the ideal harvesting speed for sugarcane yield characteristics. Manhães et al. (2014), studying harvester speeds, did not observe significant differences in ratoon performance. However, Silva et al. (2015), working with the RB92579 variety, reported that a travel speed of 3.2 km h^{-1} is the most suitable for mechanized sugarcane harvesting. In contrast, Martins et al. (2021) observed that an average speed of 7 km h^{-1} showed the best economic performance in the harvesting operation.

Therefore, studies are needed to address the lack of research on the effects of harvesting speed on the yield and agro-industrial quality of sugarcane under different seasonal conditions. It was hypothesized that mechanized sugarcane harvesting at higher speeds results in industrial quality equivalent to that of lower speeds, but with greater operational efficiency, without compromising the subsequent agronomic development of the crop. Therefore, the present research aimed to evaluate the yield and agro-industrial performance of sugarcane as a function of harvesting speed in the dry and rainy seasons.

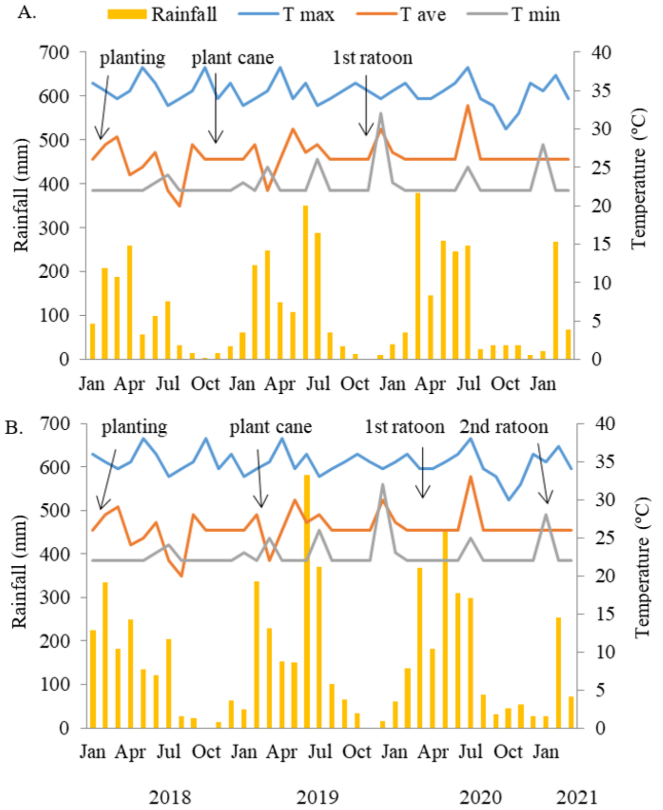
Material and Methods

Field experiments were carried out in two areas predominantly cultivated with sugarcane, in the humid coastal plains of the state of Paraíba, Northeast Brazil. These areas were located on the Boa Vista farm, here called Site 1 (06° 53′ 06″ S; 35° 03′ 30″ W, altitude of 64 m), and Babilônia farm, called Site 2 (06° 55′ 45″ S; 34° 58′ 06″ W, altitude of 64 m), which correspond to central reference points of the study areas. Crop management in both experimental areas followed standard management practices adopted in the region. The soil in the selected study sites had a predominantly sandy texture. The soil in both areas was classified as Oxisol (Soil Survey Staff, 2022), which corresponds to a Latossolo Vermelho-Amarelo in the Brazilian Soil Classification System (EMBRAPA, 2018).

The region's climate is hot and humid type As' according to Köppen's classification (Alvares et al., 2013), with an average annual temperature of 26 °C and average annual precipitation of 1,400 mm. The region's rainy season is concentrated between the months of January and July, while the dry season occurs from August to December. The experimental period for the dry season (Site 1) included manual harvesting in December 2019, followed by biometric assessments. For the rainy season (Site 2), harvesting began in March 2020, with subsequent biometric evaluations continuing until the second harvest in March 2021. Rainfall data were obtained from reports provided by the company, which maintains acrylic rain gauges installed at each farm to record precipitation. Temperature data were retrieved from the database of the National Institute of Meteorology. Rainfall and temperatures recorded monthly in both locations during the period of the experiments are shown in Figure 1.

The experiments were conducted in two experimental areas representative of the sugarcane region of the Northeast Paraíba, with sandy soils and similar edaphoclimatic conditions: Site 1 (dry season) and Site 2 (rainy season). A randomized block design was adopted, with four replicates and five mechanized harvesting speeds (2, 3, 4, 5, and 6 km h^{-1}), applied in the second cut and evaluated in the third cut of the crop. The harvesting speeds evaluated were selected based on the criteria described by Ripoli & Ripoli (2009). To minimize the influence of the human factor on machine operation, operational standardization was used, performing the evaluations at the same time and maintaining the same equipment and operator in all plots, instructed to maintain the speed previously defined for each treatment. Each plot consisted of four furrows of approximately 800 m, in alternating double spacing of 1.50 × 0.80 m. It should be noted that the objective was not to directly compare the locations, but rather to evaluate the effect of speeds under contrasting soil moisture conditions, which is why no detailed soil analysis was performed. Figure 2 presents a diagram (sketch) of how the treatments were arranged and the spacing of the crops.

In the rainy season, harvesting was carried out on rainy days. In the dry season, the same procedure as in the rainy



The designations 1st ratoon and 2nd ratoon indicate the first and second harvests in each site. Harvest years: Site 1 – 2019; Site 2 – 2020 and 2021.

Figure 1. Monthly temperature (T max - maximum, T ave - average and T min -minimum) and rainfall (mm) in two sugarcane experimental sites: Site 1 (dry season harvest, A) and Site 2 (wet season harvest, B)

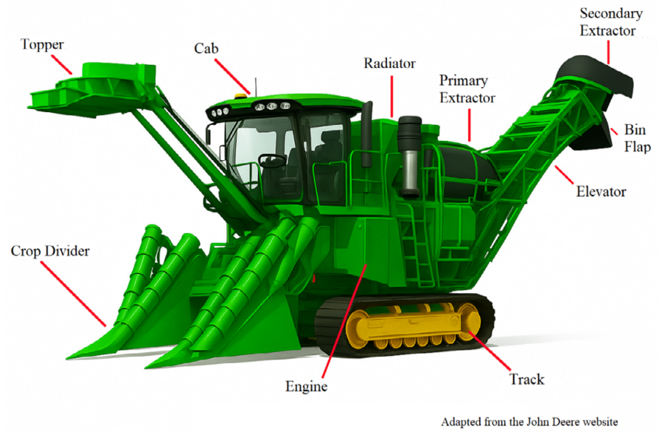


Figure 3. John Deere CH670 combine external components

season was maintained, using the same equipment. The machine used for the harvesting process was the CH670 model from the John Deere® brand (Figure 3), which harvests two rows in alternating spacing.

To study the machine's harvesting speeds in the field, the harvester was configured to vary the angular speed of the primary extractor fan between 750 and 900 rpm and the secondary extractor fan was kept turned off. The base cutting pressure was maintained at 900 to 1200 psi and the exhaust pressure at 1050 psi, while the chopping knives were kept synchronized throughout the harvesting operation. The harvesting operation consisted of loading the sugarcane into tractor-transshipment combinations, which subsequently unloaded the harvested sugarcane into trucks, in a loading yard, designed to transport the sugarcane to the plant's industrial park.

The assessments began with monitoring the dynamics of tillering in the initial stages and later biometric assessments to monitor the dynamics of plant growth. Plant tillering assessments consisted of manually counting the number of sugarcane tillers within a distance of 5 m from the two central rows of the plot at 30, 90, 180, 270 and 360 days after cutting (DAC), throughout the 3rd cut sugarcane ratoon. The dynamics of sugarcane growth was monitored through assessments of biometric characteristics in 10 plants randomly collected in the central rows of the plot. The plants were evaluated for their average culm height (cm), measured from the base to

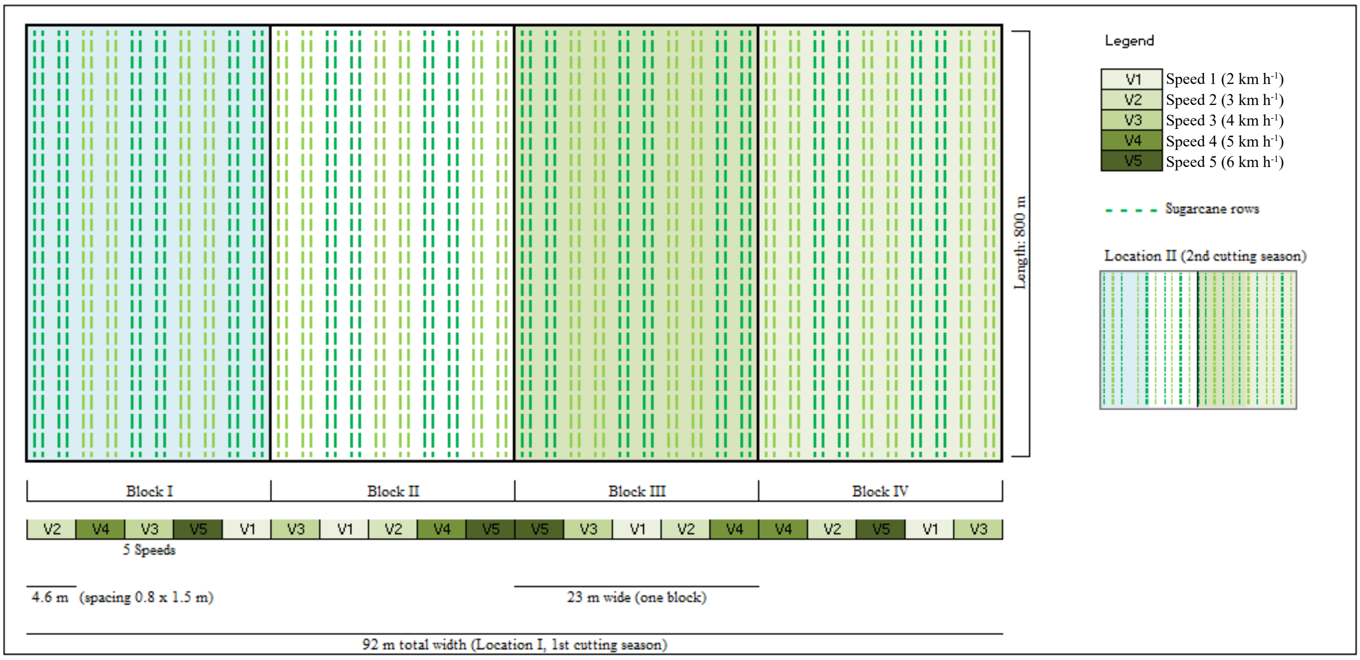


Figure 2. Distribution of treatments within blocks, spacing between rows and total plot dimensions

the insertion of the +1 leaf, using a measuring tape; culm diameter (mm), obtained with a digital caliper, measuring the average diameter; internode number, by counting the number of internodes of the selected plants, disregarding the last node where the green leaf is inserted; and, average length of the internode (cm), measured by the ratio of the useful length of the culm to the average number of internodes per culm.

Total leaf area (LA) was also calculated using Eq. 1, according to Hermann & Câmara (1999):

$$LA = L \times W \times N \times 0.75 \tag{1}$$

where:

LA - total leaf area (cm^2);

L and W - length and width, respectively, of the leaf +3 (cm), that is, the third leaf, from top to bottom, fully expanded with a visible ligule, obtained with a measuring tape; and,

N - number of open leaves with at least 20% green area, measured based on leaf pigmentation, and 0.75 is the correction factor for leaf area.

Finally, the industrial quality of the stalk was evaluated in the late harvest phase in the dry and rainy seasons.

To evaluate the industrial quality of sugarcane, a composite sample of culms was taken for laboratory analysis. Fiber content, soluble solids content (°Brix), apparent sucrose in the juice (Pol), apparent purity of the juice (purity) and reducing sugar (RS) were determined. The variables used to determine the industrial quality of sugarcane were measured as described by CONSECANA (2006).

Initially, individual analysis of variance was carried out, which showed that the assumption of homogeneity of variances between locations was met for all response variables, considering as a criterion the ratio of the mean squares of the residuals being equal to or less than seven. Subsequently, a joint analysis of the two cultivation areas was carried out using the "easyanova" package. The means of the locations (or seasons) were compared using the F test or Tukey test (comparisons between speed levels) adopting $p \leq 0.01$ and $p \leq 0.05$. All analyses were performed using the statistical software R, version 4.0 (R Core Team, 2020).

Results and Discussion

The summary of the joint analysis of the experiments is presented in Table 1. A significant effect of the interaction of harvest season × harvester speed was recorded on culm height at 270 days after cutting (DAC), on culm diameter at 270 and 360 DAC and on internode length at 270 DAC. The number of industrialized culms was significantly influenced by harvest season only at 30, 270, and 360 DAC, and the internode number was affected by the speed at 360 DAC. Regarding leaf area, harvest speed only influenced it at 270 DAC, while harvest season significantly affected this variable at 180, 270, and 360 DAC.

In this research, there were no significant differences between the harvesting speeds of the harvester at the most critical time for the plant, which is under humid soil conditions. Culm yield did not vary under the different harvesting speeds of the harvester in the rainy season, which is supposedly a more damaging season for the sugarcane field compared to the dry season. This result is in agreement with Rossi Neto et al. (2018), who state that variations in stalk yield are linked to environmental climatic conditions in each ratoon.

For all variables evaluated, a significant effect of harvest season was recorded in at least three moments (DAC) of the development of sugarcane plants. For the number of culms, the effect of season was significant at 30, 270, and 360 DAC. For culm height, significant differences were found for season at 90, 180, 270, and 360 DAC, and for the interaction between speed × season at 270 DAC. For culm diameter, speed was significant at 90 and 360 DAC, season at 180, 270, and 360 DAC, and speed × season at 270 and 360 DAC. For the internode number, speed was significant at 360 DAC, while season was significant at 180, 270 and 360 DAC. For internode length, speed was significant at 360 DAC, season at 90, 180, and 270 DAC, and the interaction speed × season at 270 DAC. Finally, for leaf area, speed was significant at 270 DAC, while season was significant at 180, 270 and 360 DAC.

Sugarcane grown without irrigation in the Northeast of Brazil has low yield compared to irrigated areas, directly reflecting the reduction in plant physiological performance and culm yield. The occurrence, intensity and duration of abiotic stresses such as water restriction cause morphophysiological changes in the plant, with a reduction in gas exchange, greater sensitivity in stomatal conductance, leaf transpiration, net photosynthesis, and water use efficiency (Marchiori et al., 2017). The results of this research reveal the effects of climatic conditions at the harvest time on the agronomic performance of sugarcane.

The number of sugarcane culms per linear meter was significantly ($p \leq 0.01$) higher in the rainy season than in the dry season at 30 DAC (Figure 4). However, the number of culms at 90 and 180 DAC was equal between the two harvesting seasons, and at 270 and 360 DAC it was greater in the dry season when compared to the rainy season. No significant effect was found as a function of the harvester's harvesting speed. Stimuli to the number of industrialized culms, an important component in grass yield, are favored by the indirect effect of straw on plants, with increased moisture retention in the soil due to the supply of organic matter and availability of nutrients throughout the ratoon cycles (Borges et al., 2020).

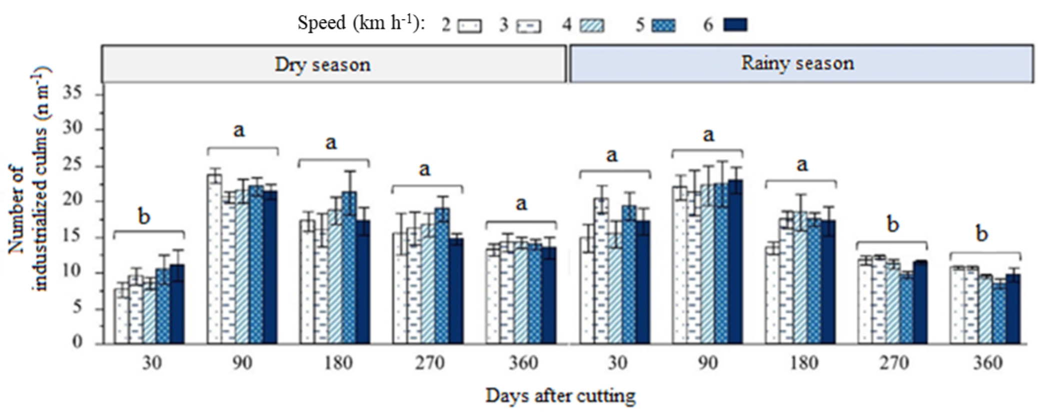
Culm height at 90, 180 and 360 DAC was lower in the dry season than in the rainy season and there was no difference between the harvester speeds (Figure 5A). In the dry season, at 270 DAC, culm height was the same for the different harvesting speeds of the harvester, but in the rainy season the culm height recorded for the speed of 3 km h^{-1} was greater than that for the speed of 5 km h^{-1}. This result obtained at a speed of 3 km h^{-1} compared to 5 km h^{-1} may be associated with the less aggressiveness of the cut and the less mechanical stress imposed on the ratoons at lower speeds (Martins et al., 2019), which favors initial regrowth and stem elongation.

Furthermore, the culm height values recorded for the speed of 3 km h^{-1} in the dry season were similar to those recorded in the rainy season at 270 DAC.

Table 1. Summary of the joint analysis of variance for number of industrialized culms, culm height, culm diameter, internode number, internode length and leaf area along the ratoon sugarcane, after harvest carried out according to harvester speed in dry and rainy seasons

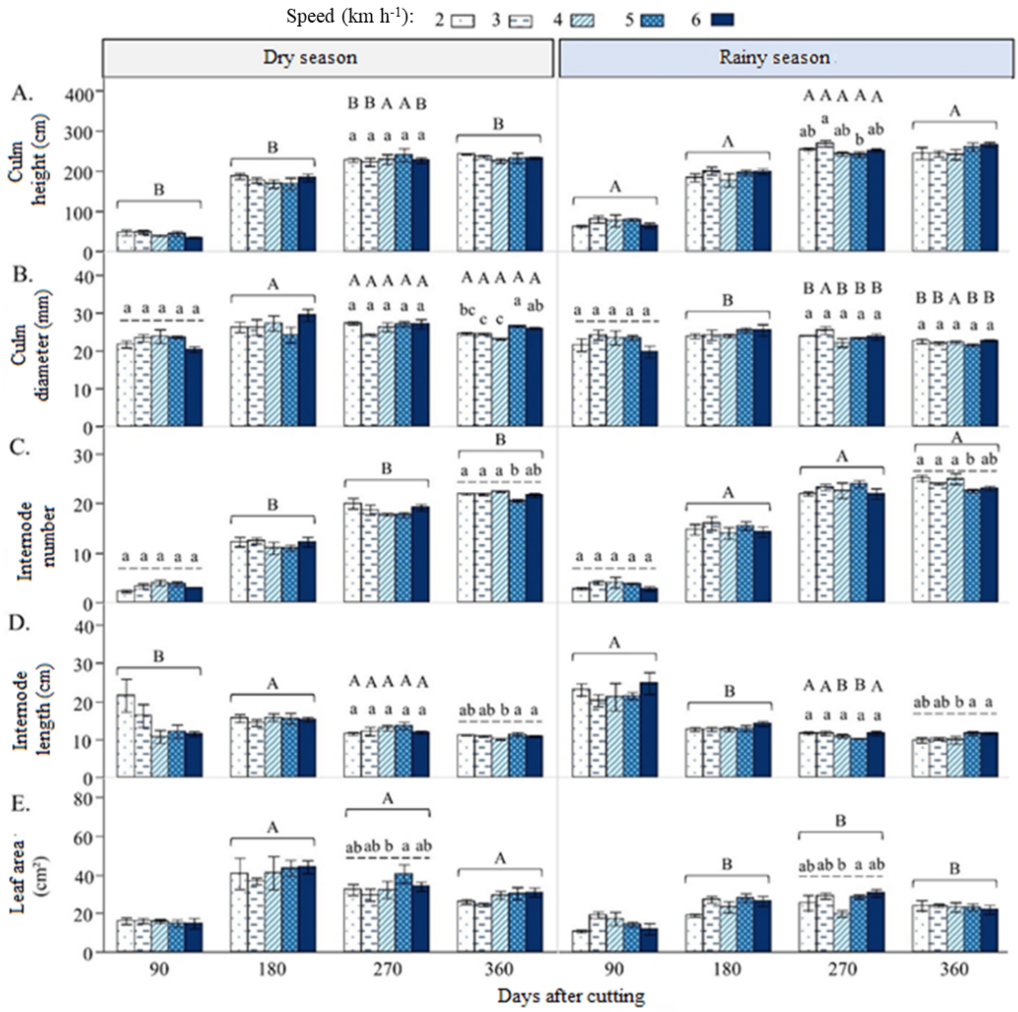
SV	DF	Mean squares				
		Days after cutting				
		30	90	180	270	360
Number of industrialized culms (Tillering)						
Speed	4	23.68^{ns}	3.95^{ns}	19.83^{ns}	2.06^{ns}	1.71^{ns}
Season	1	642.32**	1.10^{ns}	15.62^{ns}	265.22**	160.00**
Speed × Season	4	6.88^{ns}	2.89^{ns}	11.31^{ns}	11.91^{ns}	2.68^{ns}
Season × Block	6	22.52	21.10	13.79	16.25	8.05
Error	24	9.64	15.45	15.54	6.57	1.55
CV (%)		25.66	17.48	22.44	19.62	12.30
Culm height						
Speed	4		282.66^{ns}	410.35^{ns}	92.35^{ns}	304.03^{ns}
Season	1		9030.02**	2073.60*	5175.62**	3027.60**
Speed × Season	4		142.71^{ns}	306.97^{ns}	553.50*	347.91^{ns}
Season × Block	6		115.82	897.91	866.95	808.40
Error	24		211.05	306.81	161.87	205.85
CV (%)			24.07	10.38	5.84	6.78
Culm diameter						
Speed	4		21.52*	8.94^{ns}	2.52^{ns}	3.24**
Season	1		0.14^{ns}	43.26*	72.09**	75.07**
Speed × Season	4		0.62^{ns}	8.13^{ns}	9.74*	4.84**
Season × Block	6		2.31	15.69	3.26	0.63
Error	24		7.61	7.16	2.53	0.49
CV (%)			11.71	10.96	6.29	12.87
Internode number						
Speed	4		3.21^{ns}	3.15^{ns}	0.95^{ns}	6.25**
Season	1		0.40^{ns}	96.10**	167.69**	51.18**
Speed × Season	4		0.33^{ns}	1.85^{ns}	5.86^{ns}	0.85^{ns}
Season × Block	6		0.85	4.43	2.30	1.42
Error	24		1.05	4.01	3.18	0.81
CV (%)			31.67	14.90	8.53	14.32
Internode length						
Speed	4		48.30^{ns}	1.28^{ns}	0.16^{ns}	2.96**
Season	1		599.69**	50.08**	15.30**	0.55^{ns}
Speed × Season	4		46.15^{ns}	1.46^{ns}	4.56*	1.29^{ns}
Season × Block	6		31.82	3.33	3.07	2.33
Error	24		22.59	2.75	1.35	0.53
CV (%)			27.12	11.78	10.85	8.08
Leaf area						
Speed	4		29.77^{ns}	48.86^{ns}	86.23*	8.68^{ns}
Season	1		8.93^{ns}	2686.32**	497.51**	249.80**
Speed × Season	4		23.29^{ns}	39.18^{ns}	54.63^{ns}	24.28^{ns}
Season × Block	6		4.62	92.88	61.51	22.76
Error	24		19.35	73.76	30.69	16.88
CV (%)			27.76	26.59	17.30	15.36

SV - Source of variation; DF - Degrees of freedom; Error - Standard error; CV - Coefficient of variation. ns, **, * - Non significant and significant at p ≤ 0.01 and p ≤ 0.05, respectively, by the F test



Different letters indicate a significant difference between harvest seasons using the F test at p ≤ 0.05. Error bars represent standard error (n = 4)

Figure 4. Number of culms under different harvester speeds (2 to 6 km h^{-1}) and two harvesting seasons (dry season and rainy season), over two agricultural years (2nd and 3rd cuts)



Different letters, lowercase for speed and capital letters between harvest seasons, indicate a significant difference by the Tukey test and F test, respectively, at the p ≤ 0.05. Error bars represent standard error (n=4)

Figure 5. Culm height (A), culm diameter (B), internode number (C), internode length (D) and leaf area (E) of sugarcane under different harvester speeds (2 to 6 km h^{-1}) and two harvesting seasons (dry season and rainy season), over two agricultural years (2nd and 3rd cuts)

Culm height and internode number were greater in sugarcane harvested in the rainy season compared to the dry season, in all growth assessments, except for culm height at speeds of 4 and 5 km h^{-1} at 270 DAC and the internode number at 90 DAC, which were similar in both seasons. This fact may be associated with physical-chemical changes in the soil due to the accumulation of residues after harvest (Coonan et al., 2020), favoring plant growth in the rainy season. Furthermore, sugarcane growth is closely linked to water restriction, influencing the reduction in the remobilization of water, nutrients and transport of carbohydrates to the roots, leading to lower cell elongation rates in the stem, consequently, in the length of the stem internodes (Marchiori et al., 2017).

Culm diameter at 90 DAC was similar between the two harvest seasons and, despite the not significant effect by the F test, for the speed factor the Tukey test indicated similarity between the harvester's harvesting speeds regardless of the harvest season (Figure 5B). From 180 DAC onwards, culm diameter was greater in the dry season than in the rainy season, with the exception of the values recorded for the speed of 3 km h^{-1} at 270 DAC and for the speed of 4 km h^{-1} at 360 DAC, which were similar in both harvesting seasons. Only in the dry season and at 360 DAC there was a significant difference in culm diameter as a function of the harvester's harvesting speed, with the largest culm diameter recorded for the speed of 5 km h^{-1}, which did not differ from the speed of 6 km h^{-1}.

Sugarcane culm diameter is positively correlated with agricultural yield and, often, with sugar content (Tolera et al., 2024). Thus, the positive effect observed at a speed of 5 km h^{-1} is significant, since operations that favor this variable can result in higher yield. This finding differs from the result reported by Manhães et al. (2014), who evaluated harvesting speeds of 2, 3, and 4.5 km h^{-1} and found no significant differences in ratoon damage; that is, within the usual operating ranges, this speed does not compromise regrowth. However, the same authors concluded that a speed of 4.5 km h^{-1} is the most advantageous, as it is more economically viable due to its greater operational capacity.

Culm diameter and leaf area showed superiority in the dry season compared to the rainy season from 180 DAC until the final phase of sugarcane growth, except for culm diameter for the speed of 3 km h^{-1} at 270 DAC and for the speed of 4 km h^{-1} at 360 DAC, which were similar in both seasons. Research indicates that drought stress can inhibit leaf and

Table 2. Summary of the analysis of variance and average values of the qualitative attributes of sugarcane, in the 3rd cut cane ratoon, at harvest in the rainy season

SV	DF	Mean squares									
		CanePol	Brix	JuiceRS	JuicePol (%)	Purity	CSP	Fiber	TRS (kg t^{-1})	CaneRS (%)	TPH (t ha^{-1})
Block	3	28.263	1.188	0.043	1.601	8.750	1.217	2.427	132.54	0.020	1.008
Speed	4	9.475^{ns}	0.203^{ns}	0.039^{ns}	0.560^{ns}	9.937^{ns}	0.487^{ns}	6.405^{ns}	56.414^{ns}	0.025^{ns}	2.197^{ns}
Error	24	15.707	0.566	0.036	0.905	8.546	0.810	2.631	94.390	0.016	1.160
CV%		8.50	15.11	13.90	8.28	13.75	10.02	9.78	11.20	11.97	15.34
Mean		46.50	14.72	1.37	11.48	77.90	8.98	16.59	86.74	1.06	7.02

SV - Source of variation; DF - Degrees of freedom; CanePol - Apparent sucrose content in sugarcane; Brix - Soluble solids content; JuiceRS - Juice reducing sugar; JuicePol - Apparent sucrose content in the juice; CSP - Corrected Sugarcane Pol; Fiber - Industrial sugarcane fiber; TRS - Total Recoverable Sugar; CaneRS - Cane reducing sugar; TPH - Ton of Pol per Hectare; CV - Coefficient of variation. ns, **, * - Non significant and significant at $p \leq 0.01$ and $p \leq 0.05$, respectively, by the F test

stem expansion, tiller production and causes changes in the orientation of stem extension (Gomathi et al., 2015). In this research, harvesting sugarcane in the dry season, which does not mean water restriction during the final growth phase, favored leaf expansion and culm diameter of the second ratoon plants. In this context, it is important to mention that the lower growth of the leaf area, reduction in the appearance of new leaves and increased leaf abscission may occur due to the higher concentration of abscisic acid in the plant, which is associated with the amount of light absorbed and the total photosynthetic activity of the plant, reducing the production of photoassimilates (Smit & Singels, 2006).

The results for leaf area at 270 DAC indicated the existence of an operational optimum for ratoon cane regrowth. A speed of 5 km h^{-1} produced the largest leaf area, while a speed of 4 km h^{-1} resulted in the lowest value, a pattern consistently observed in both harvest seasons (dry and rainy). Possibly, at a speed of 4 km h^{-1}, although the operation is slower and apparently more careful, the prolonged exposure of the cane to the harvester's cutting mechanisms and wear (such as feed rollers and cutting base) may result in greater mechanical stress and localized soil compaction around the base of the plant.

According to Marques Filho et al. (2025), the type of soil, equipment, depth and operating speed modify the soil structure negatively, compromising the capacity for production and development of new tillers, resulting in a significantly reduced leaf area.

On the other hand, at a speed of 4 km h^{-1}, the harvester operates more efficiently, reducing the time of interaction between the mechanisms and the sugarcane and, consequently, minimizing damage from mechanical stress and compaction. The ratoon crop suffers less injury, preserving its regrowth potential and allowing for more vigorous leaf development.

Internode number at 90 DAC was similar between the two harvest seasons and also between the harvester speeds, regardless of the season (Figure 5C). From 180 DAC onwards, the internode number was greater in the rainy season than in the dry season, regardless of the harvesting speed of the harvester. In turn, regardless of the harvest season, the internode number recorded for the speed of 5 km h^{-1}, at 360 DAC, was lower than those recorded for the speeds of 2, 3 and 4 km h^{-1}.

Internode length at 90 DAC was greater in the rainy season than in the dry season, regardless of the harvester's harvesting speed (Figure 5D). In turn, the internode length recorded in the dry season at 180 DAC was greater than that recorded in the rainy season, also regardless of the harvester's harvesting speed. The internode length values recorded for speeds of 4 and 5 km h^{-1} in the dry season, at 270 DAC, were greater than those recorded in the rainy season. A significant difference in internode length was only recorded as a function of the harvester's harvesting speed at 360 DAC, when the internode length values recorded for the speeds of 5 and 6 km h^{-1} were greater than those recorded for the speed of 4 km h^{-1}, regardless of the harvest season.

No significant difference was recorded for leaf area at 90 DAC; however, from 180 DAC onwards, leaf area was greater in the dry season than in the rainy season, regardless of the harvester's harvesting speed (Figure 5E). At 270 DAC, the leaf area values recorded for the speed of 5 km h^{-1} were higher than those recorded for the speed of 4 km h^{-1}, regardless of the harvest season.

No significant difference was recorded in sugarcane quality attributes (industrial variables) as a function of harvester speed in the rainy season (Table 2).

These results can be justified because genetic effects are predominant for the responses expressed in yield traits (culm height and diameter, number of internodes and culms per meter and culm yield) and sugarcane quality, even with the influence of crop ratoons, cultivation, and the studied genotype (Dutra Filho et al., 2014). Thus, the absence of influence of the factors studied on brix and other industrial variables is associated with the physiological process of sucrose accumulation, which reaches its maximum point when the plant has limited resources for its growth, whether due to lack of nutrients, water or climatic conditions (Julius et al., 2017).

Conclusions

1. Sugarcane harvested in the dry season has better vegetative performance throughout the ratoon cycle.
2. The harvester speed of 5 km h^{-1} increases the leaf area and culm diameter of ratoon sugarcane.
3. Different harvesting speeds did not significantly affect the industrial quality of sugarcane, regardless of the harvest season.
4. It is concluded that a speed of 5 km h^{-1} proves to be technically viable for sugarcane harvesting. This operation does not compromise the industrial quality of the product and, combined with increased operational efficiency (larger area harvested per unit of time), is the most advantageous configuration. Additionally, agronomic development variables, such as leaf area and culm diameter, were favored under this condition.

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Literature Cited

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. D. M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

Ashagre, S. Y.; Khan, A. Q. Determining optimum period of withholding irrigation for inducing maturity of sugarcane (*Saccharum* spp. hybrid) in Southern Ethiopia. Journal of Applied Biotechnology & Bioengineering, v.7, p.16-25, 2020. https://doi.org/10.15406/jabb.2020.07.00211

Borges, B. M.; Strauss, M.; Camelo, P. A.; Sohi, S. P.; Franco, H. C. Re-use of sugarcane residue as a novel biochar fertiliser-Increased phosphorus use efficiency and plant yield. Journal of Cleaner Production, v.262, e121406, 2020. https://doi.org/10.1016/j.jclepro.2020.121406

Castro, S. G. Q.; Graziano M. P. S.; Coutinho J. F. H.; Mutton, M. Â. Harvesting systems, soil cultivation, and nitrogen rate associated with sugarcane yield. Bioenergy Research, v.11, p.583-591, 2018. https://doi.org/10.1007/s12155-018-9917-0

Cherubin, M. R.; Carvalho, J. L. N.; Cerri, C. E. P.; Nogueira, L. A. H.; Souza, G. M.; Cantarella, H. Land use and management effects on sustainable sugarcane-derived bioenergy. Land, v.10, p.1-24, 2021. https://doi.org/10.3390/land10010072

CONSECANA - Conselho dos Produtores de Cana-de-açúcar, Açúcar, Álcool do Estado de São Paulo. Manual de instruções. Piracicaba: Consecana, 112p. 2006.

Coonan, E. C.; Richardson, A. E.; Kirkby, C. A.; Kirkegaard, J. A.; Amidy, M. R.; Strong, C. L. Soil fertility and nutrients mediate soil carbon dynamics following residue incorporation. Nutrient Cycling in Agroecosystems, v.116, p.205-221, 2020. https://doi.org/10.1007/s10705-019-10037-w

Dahab, M. H.; Abdalla, O. A. Evaluation of mechanized field operations energies for production of sugar cane crop: Kenana sugar company as case study. Journal of Energy Research and Reviews, v.14, p.1-8, 2023. https://doi.org/10.9734/JENRR/2023/v14i2278

Dutra Filho, J.; Calsa Junior, T; Simões Neto, D. S. Phenotype adaptability and stability of sugarcane genotypes in the sugarcane belt of the State of Pernambuco, Brazil. Genetics and Molecular Research, v.13, p.6865-6877, 2014. http://dx.doi.org/10.4238/2014.August.29.8

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. Sistema Brasileiro de Classificação de Solos, 5.ed. Embrapa, Rio de Janeiro, Brazil, 2018, 356p.

Gomathi, R.; Gururaja Rao, P. N.; Chandran, K.; Selvi, A. Adaptive responses of sugarcane to waterlogging stress: An over view. Sugar Tech, v.17, p.325-338, 2015. https://doi.org/10.1007/s12355-014-0319-0

Hermann, E. R.; Câmara, G. M. S. Um método para estimar a área foliar da cana-de-açúcar. STAB-Açúcar e Álcool e Subprodutos, v.17, p.32-34, 1999. Available at: <https://repositorio.usp.br/item/001053660>. Accessed on: Sep. 2025.

Julius, B. T.; Leach, K. A.; Tran, T. M.; Mertz, R. A.; Braun, D. M. Sugar transporters in plants: new insights and discoveries. Plant and Cell Physiology, v.58, p.1442-1460, 2017. https://doi.org/10.1093/pcp/pcx090

Manhães, C. M. C.; Garcia, R. F.; Correa Júnior, D.; Francelino, F. M. A.; Francelino, H. O.; Santos, C. M. F. G. Evaluation of visible losses and damage to the ratoon cane in the mechanized harvesting of sugarcane for different displacement speeds. American Journal of Plant Sciences, v.5, p.2956-2964, 2014. https://doi.org/10.4236/ajps.2014.520312

Marchiori, P. E.; Machado, E. C.; Sales, C. R.; Espinoza-Núñez, E.; Magalhães Filho, J. R.; Souza, G. M.; Pires, R. C. M.; Ribeiro, R. V. Physiological plasticity is important for maintaining sugarcane growth under water deficit. Frontiers in Plant Science, v.8, e2148, 2017. https://doi.org/10.3389/fpls.2017.02148

Marques Filho, A. C.; Martins, M. B.; Santana, L. S.; Lopes, A. G. C.; Lustosa Sobrinho, R.; Souza, E. F. C.; Okla, M. K.; Alaraidh, I. A. Effect of soil compaction caused by manual and mechanized harvesting management on sugarcane yield. Sugar Tech, v.27, p.1351–1361, 2025. https://doi.org/10.1007/s12355-025-01571-9

Martins, M. B.; Marques Filho, A. C.; Drudi, F. S.; Bortolheiro, F. P. A. P.; Vendruscolo, E. P.; Esperancini, M. S. T. Economic efficiency of mechanized harvesting of sugarcane at different operating speeds. Sugar Tech, v.23, p.428-432, 2021. https://doi.org/10.1007/s12355-020-00910-2

Martins, M. B.; Testa, J. V. P.; Drudi, F. S.; Sandi, J.; Ramos, C. R. G.; Lanças, K. P. Interference of speed at cutting height and damage to rootstock in mechanical harvesting of sugarcane. Australian Journal of Crop Science, v.13, p.1305-1308, 2019. https://doi.org/10.21475/ajcs.19.13.08.p1713

Mohanraj, K.; Hemaprabha, G.; Vasantha, S. Biomass yield, dry matter partitioning and physiology of commercial and Erianthus introgressed sugarcane clones under contrasting water regimes. Agricultural Water Management, v.255, e107035, 2021. https://doi.org/10.1016/j.agwat.2021.107035

Pelloso, M. F.; Pelloso, B. F.; Lima, A. A.; Ortiz, A. H. T. Influence of harvester and rotation of the primary extractor speed in the agroindustrial performance of sugarcane. Sugar Tech, v.23, p.692-696, 2021. https://doi.org/10.1007/s12355-020-00944-6

R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, 2020. Available at: <https://www.r-project.org/>. Accessed on: Mar. 2022.

Resende, R. S.; Fernandes, M. F.; Silva, S. M. Sugarcane yield, ratooning, and water response in cropping environments with contrasting water supply gradient. Agronomy Journal, v.117, e70153, 2025. https://doi.org/10.1002/agj2.70153

Ripoli T. C. C.; Ripoli M. L. C. Biomassa de cana-de-açúcar: colheita, energia e ambiente. 2.ed. Piracicaba: ESALQ, 2009. 333p.

Rossi Neto, J.; Souza, Z. M.; Kölln, O. T.; Carvalho, J. L. N.; Ferreira, D. A.; Castioni, G. A. F.; Franco, H. C. J. The arrangement and spacing of sugarcane planting influence root distribution and crop yield. Bioenergy Research, v.11, p.291-304, 2018. https://doi.org/10.1007/s12155-018-9896-1

Saavedra-Díaz, C.; Trujillo-Montenegro, J. H.; Jaimes, H. A.; Londoño, A.; Villareal, F. A. S.; López, L. O.; Valens, C. A. V.; López-Gerena, J.; Riascos, J. J.; Quevedo, Y. M.; Aguilar, F. S. Genetic association analysis in sugarcane (*Saccharum* spp.) for sucrose accumulation in humid environments in Colombia. BMC Plant Biology, v.24, p.570, 2024. https://doi.org/10.1186/s12870-024-05233-y

Silva, M. J.; O.; Neves, L. D.; Correa, M. H.; Souza, C. H. Quality indexes and performance in mechanized harvesting of sugarcane at a burnt cane and green cane. Sugar Tech, v.23, p.499-507, 2021. https://doi.org/10.1007/s12355-021-00957-9

Silva, R. C.; Oliveira, T. C.; Figueiredo, Z. N.; Caldeira, D. A. S. Perdas visíveis na colheita mecanizada de cana-de-açúcar. Revista Engenharia na Agricultura, v.23, p.71-77, 2015.

Smit, M. A.; Singels, A. The response of sugarcane canopy development to water stress. Field Crops Research, v.98, p.91-97, 2006. https://doi.org/10.1016/j.fcr.2005.12.009

Soil Survey Staff. Keys to Soil Taxonomy. 13.ed. USDA - Natural Resources Conservation Service, 2022. 401p. Available at: <https://www.nrcs.usda.gov/resources/guides-and-instructions/keys-to-soil-taxonomy>. Accessed on: Jan. 2025.

Tolera, B.; Gedebo, A.; Tena, E. Genetic variability, character association and path analysis in sugarcane genotypes. Archives of Agronomy and Soil Science, v.70, p.1-15, 2024. https://doi.org/10.1080/03650340.2024.2331036

Verma, K. K.; Song, X. P.; Verma, C. L.; Chen, Z. L.; Rajput, V. D.; Wu, K. C.; Liao, F.; Chen, G. L.; Li, Y. R. Functional relationship between photosynthetic leaf gas exchange in response to silicon application and water stress mitigation in sugarcane. Biological Research, v.54, p.1-11, 2021. https://doi.org/10.1186/s40659-021-00338-2

Vianna, M. S.; Sentelhas, P. C. Performance of DSSAT CSM-CANEGRO under operational conditions and its use in determining the 'Saving irrigation' impact on sugarcane crop. Sugar Tech, v.18, p.75-86, 2016. https://doi.org/10.1007/s12355-015-0367-0

Xavier, W. D.; Silva, D. C.; Costa, R. B.; Ribeiro, D. O.; Sousa, V. S.; Silva, J. V. S. Losses in the mechanized harvesting of sugarcane as of speed function of two harvester models in Tropical Savanna Environment. Australian Journal of Crop Science, v.14, p.675–682, 2020. https://doi.org/10.21475/ajcs.20.14.04.p2338

Zhou, B.; Ma, S.; Li, W.; Peng, C.; Li, W. Study on sugarcane cutting and damage mechanism during harvesting by sugarcane chopper harvester sugar. Biosystems Engineering, v.243, p.1-12, 2024. https://doi.org/10.1016/j.biosystemseng.2024.04.019

Zhu, Y.; Gong, H. Beneficial effects of silicon on salt and drought tolerance in plants. Agronomy for Sustainable Development, v.34, p.455-472, 2014. https://doi.org/10.1007/s13593-013-0194-1