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INFLUÊNCIA DO ÂNGULO DE CORTE E DA VELOCIDADE DE COLHEITA NOS DANOS CAUSADOS PELAS FACAS DA COLHEDORA NA CULTURA DA CANA-DE-AÇÚCAR

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RESUMO: Este estudo teve como objetivo avaliar os danos causados durante o corte basal da cana-de-açúcar, alterando as características operacionais, tais como a velocidade de deslocamento durante a operação e o ângulo de ataque do corte de base em laboratório, utilizando o DECCA (Dispositivo de Ensaio de Corte Basal da Cana-de-Açúcar), desenvolvido pela equipe do NEMPA (Núcleo de Ensaio de Máquinas e Pneus Agroflorestais) para utilização em laboratório, que reproduz a ação do cortador de base sobre os colmos da cultura. A amostra de pesquisa foi formada a partir de um total de 432 observações referentes à 9 combinações de três velocidades de deslocamento do dispositivo (3, 5 e 7 km h⁻¹) e três ângulos de ataque do corte de base (12°, 15° e 18°), sendo que, para cada combinação foram coletadas e analisadas 48 unidades amostrais (3x3x48 = 432 observações) devidamente classificadas qualitativamente conforme metodologia proposta por Toledo, Silva e Furlani (2013). Os resultados obtidos nesta investigação, detectaram a influência dessas combinações sobre a ocorrência de danos extremos às soqueiras de cana-de-açúcar. Sendo que, a análise isolada de cada uma das variáveis sinalizou que, a velocidade de deslocamento do sistema de corte não é estatisticamente significativa para a expressão dos danos e, por outro lado, observou-se que a angulação utilizada para corte exerceu influência significativa sobre os danos extremos.

Palavras-chave: dispositivo eletromecânico, perda invisível, corte basal.

INFLUENCE OF CUTTING ANGLE AND HARVEST SPEED ON DAMAGE CAUSED BY HARVESTER KNIVES IN SUGARCANE CROP

ABSTRACT: The objective of this study was to evaluate the damage caused during the basal cut of sugarcane, changing the operative characteristics, such as the displacement speed during the operation and the attack angle of the base cut in the laboratory, using DECCA (Sugarcane Basal Cut Test). Device, developed by the NEMPA equipment (Agroforestry Machines and Tires Testing Nucleus) for use in the laboratory, which maps the action of the base cutter on the tops of the crop. The research sample was formed from a total of 432 observations that refer to 9 combinations of three displacement speeds of the device (3, 5 and 7 km h⁻¹) and three base cutting angles of attack (12°, 15 ° and 18 °), and for each combination, 48 units of study were collected and analyzed (3x3x48 = 432 observations) duly classified qualitatively based on the methodology proposed by Toledo, Silva e Furlani (2013). The results obtained in this investigation detected the influence of these combinations on the occurrence of extreme damage to sugarcane ratoons. The isolated analysis of each of the variables indicated that the displacement speed of the cutting system is not statistically significant for the

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expression of damage and, on the other hand, it was observed that the angle used for cutting exerted a significant influence on extreme damage.

Keywords: electromechanically device, invisible loss, basal cut.

1 INTRODUCTION

Sugarcane (*Saccharum* sp.) is a plant of Asian origin that is highly important for the trade balance of Brazilian agribusiness. According to data from the National Supply Company (CANA-DE-AÇUCAR, 2020), Brazil is the world's largest producer of this crop.

Despite the great importance of this crop, some obstacles still reduce its productive potential, with the quality of the mechanized harvesting operation being one of the main factors (VOLTARELLI *et al.*, 2018), since this harvesting process is characterized as a practice that is increasingly adopted owing to the almost total replacement of manual harvesting, owing to legal requirements aimed at reducing environmental impact.

The mechanical harvesting system consists of cutting the tip, passing it through the toppling roller, feeder roller, base cutting, feeder and conveyor rollers, choppers, primary extractor, slat elevator and secondary extractor, making it difficult to avoid qualitative and quantitative material losses in this process.

Mechanized harvesting generates potential losses, mainly due to the condition of the cutting equipment, the harvester model used, the speed of the extractors, and the size at which the stalk is cut. Furthermore, soil compaction caused by machine traffic during harvesting operations at times when the soil moisture content is not adequate also leads to reduced productivity in future cycles (MARQUES FILHO *et al.*, 2022) and, along with mechanical damage to the plant, affects the

profitability and viability of the crop, resulting in lower productivity and longevity of the sugarcane field (SEVERIANO *et al.*, 2010).

The quality of mechanized sugarcane harvesting is affected by the disturbance of the stubble caused by the harvesting mechanism (VOLTARELLI *et al.*, 2017). Lima *et al.* (2015) noted that mechanized harvesting can increase the rate of damage to stalks, also harming the regrowth of sugarcane fields.

Similarly, Martins *et al.* (2019) reported that, when used improperly, mechanized sugarcane harvesting can cause major problems for producers because of the high cost of purchasing this equipment and the high cost of maintenance and fuel consumption.

In this context, this research aimed to evaluate the performance of sugarcane basal cutting, which is based on combinations of three harvesting device travel speeds and three base cutting angles, using an electromechanical device in a laboratory with controlled operating conditions.

2 MATERIALS AND METHODS

The tests were carried out at the Agricultural and Forestry Machinery and Tire Testing Center (NEMPA), which belongs to the Faculty of Agronomic Sciences of São Paulo State University (UNESP).

The sugarcane used in the trials was collected from a sugarcane field located in the municipality of Lençóis Paulista – SP, with the following geographic coordinates: latitude 22°38'29" S and longitude 48°41'53" W (Figure 1).

Figure 1 of sugarcane stalk harvesting .

Source: Moura, 2019.

For the cutting tests, the sugarcane basal cutting test device (DECCA), designed and built by the NEMPA team, was used to simulate, in a controlled environment, the mechanized cutting operation of sugarcane harvesting. The device was assembled via a base box from a 1998 CNH-6600 sugarcane harvester, which was coupled to a 7.3 kW induction motor with a working speed of 600 rpm.

The assembly was mounted on a metal structure measuring 1530 mm wide, 2200 mm long, and 1480 mm high, on 25.4 mm angle irons, mounted on the ground with the apex

pointing upward, in the form of rails, 15 m long, with 100 mm diameter steel wheels, making it possible to simulate the movement of the sugarcane harvester, along with the activation of the base cutter.

Between the rails, metal tubes with a diameter of 50 mm and a thickness of 2 mm, 200 mm long, were fixed to the floor, serving as support for the sugarcane stalks and simulating the plant in the field. The device cut the sugarcane stalk at a height of 230 mm from the floor, that is, 30 mm above the tube (Figure 2).

Figure 2. Sugarcane basal cutting test device (DECCA) attached to a tractor .



Source: Moura, 2019.

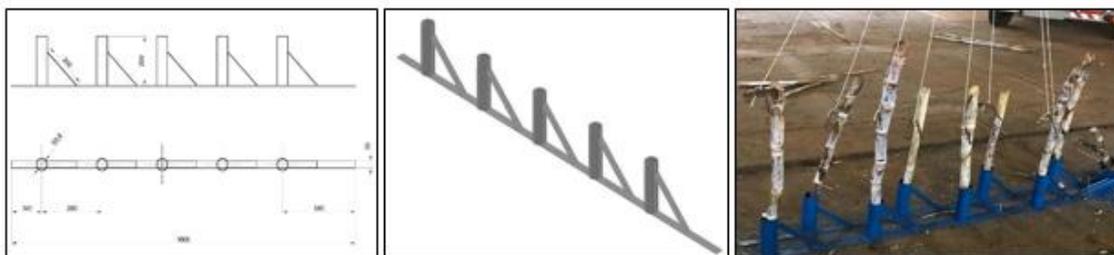
For the tests, the conventional base cutting system of sugarcane harvesters was adopted, with 5 new cutting knives coupled to each of the two discs with a diameter of 560 mm and a distance between the disc axes of 650 mm. A conventional model with 6 holes, four sides and a thickness of 4.75 mm was used according to the manufacturer's instructions.

In base cutting tests with DECCA, the damage caused by base cutting to sugarcane stalks was evaluated under different operating conditions. Three device travel speeds (3, 5 and

7 km h⁻¹) and three base cutting attack angles (12°, 15° and 18°) were selected.

The tests were carried out with multiple tube systems containing aligned stalks, simulating the arrangement of plants in rows in the field. The simulation of row-based stalks, without the interference of lodged stalks, served to treat the position of the stalks as covariates in the tests, isolating characteristics and sources of variation that would interfere with the quality of the cut in a field situation (Figure 3).

Figure 3 Technical drawing of the support for the culms and their fixation during testing in a controlled environment.



Source: Moura, 2019.

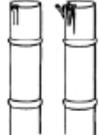
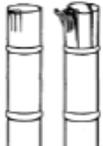
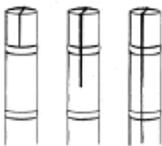
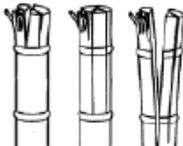
Five hundred kilograms of clean sugarcane stalks, variety SP80-1816, were

used. These stalks were harvested from the Bocaina farm, located in the municipality of

Lençóis Paulista, São Paulo, in a first-cut sugarcane field aged 12 months. The sugarcane stalks, measuring between 400 and 500 mm in length, were selected and placed inside the support via a wedge. After being tied and properly identified, the stalks were subjected to the cutting process via the DECCA device.

For the assessment of cut quality, the stalks after cutting were classified on the basis of the methodology proposed by Toledo, Silva and Furlani (2013) as follows: no damage (SD), stalks with partial damage (DP) and stalks with extreme damage (DE), as described in Figure 4.

Figure 4 of sugarcane stalks.

Classificação	Limite inferior	Limite superior
Sem danos (SD)		
Danos parciais (DP)		
Danos Extremos (ED)		

Source: Adapted from Toledo, Silva and Furlani, 2013.

The research sample was formed from a total of 432 observations related to 9 combinations of three device displacement speeds (3, 5 and 7 km h⁻¹) and three base cut attack angles (12°, 15° and 18°). For each combination, 48 sample units were collected and analyzed (3x3x48 = 432 observations) duly classified qualitatively on the basis of the methodology proposed by Toledo, Silva and Furlani (2013).

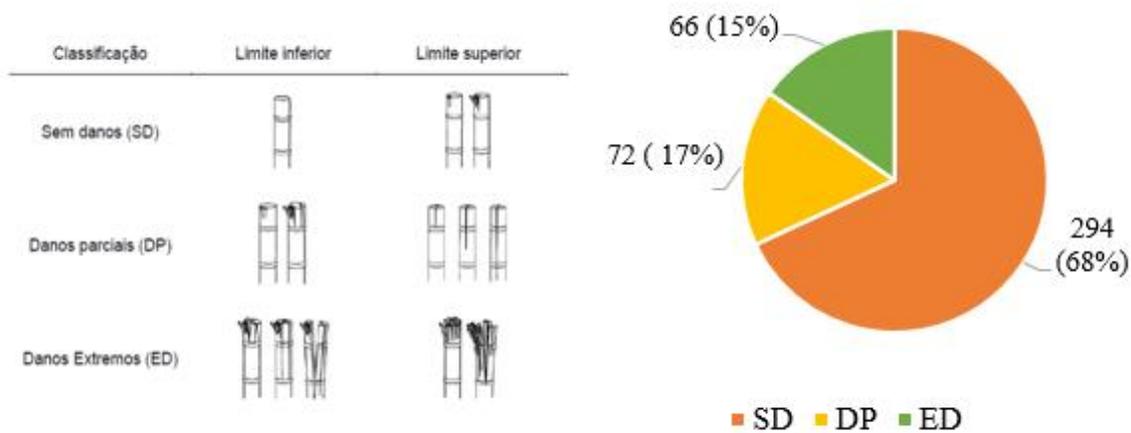
The chi-square test was applied to evaluate the degree of damage caused to the stalks according to the different treatments to which they were subjected through combinations of different harvesting speeds and blade inclinations used for base cutting. Both the descriptive statistical analysis and the

statistical tests were performed via electronic spreadsheets.

3 RESULTS AND DISCUSSION

On the basis of the 432 observations comprising the sample of this research, regardless of the 9 combinations of three device travel speeds (3, 5 and 7 km h⁻¹) and three base cut attack angles (12°, 15° and 18°), 32% of the sample units presented some type of damage to the stubble (DP+ED = 15%+17% = 32%), according to the qualitative classification proposed by Toledo, Silva and Furlani (2013), as shown in the descriptive summary presented in Figure 5.

Figure 5 Analysis of the absolute frequency (units) and relative frequency (percentages) of damage caused to the stubble.



Source: Prepared on the basis of research data.

With respect to the analysis of the occurrence of damage caused to the stubble based on the applied methodology, for each type of damage (SD, DP, ED), the expected occurrence frequency was calculated by dividing the total number of observations (SD= 294; DP= 72; ED=66) by the total number of combinations of displacement speeds (3) and base cut attack angles (3), resulting in 9 combinations (3x3).

This methodology assumes the average frequency for each type of damage to be the expected frequency, where the respective observed totals are divided by the total number of possible combinations (9 combinations), thus allowing an assessment of how much the actually observed occurrence deviates from the respective expected average.

The adoption of these 3 expected average quantities, according to each type of damage to the stubble analyzed (SD, DP, ED), evaluated in this research with the aid of the chi-square test, is justified by considering that if there were no statistically significant difference between the combinations of travel speed and cutting angle, all real observations would tend toward that expected average quantity, whose probability of occurrence would be equally distributed, attributing such occurrences to chance and not as a function of one or more combinations between travel speed and cutting angle.

In this sense, for a significance level of 95%, if the parameter value (p value) of the chi-square test statistic is greater than or equal to

0.05 (p value ≥ 0.05), the null hypothesis (H_0) assumes the possibility that all observation totals identified from each combination of speed and angle are statistically equal to their respective expected mean values, discarding the possibility that these combinations (speed *versus* cutting angle) influence the type of damage to the stubble qualitatively analyzed on the basis of the methodology proposed by Toledo, Silva and Furlani (2013).

Conversely, for a significance level of 95%, if the parameter value (p value) of the chi-square test statistic is less than 0.05 (p value < 0.05), the null hypothesis (H_0) is rejected, and consequently, it is assumed that at least one of the total observations identified from each combination of speed and cutting angle is significantly different from the respective expected average value; therefore, the possibility of evidence that those combinations influence the type of damage to the stubble qualitatively analyzed according to the applied methodology is admitted.

As already shown in Figure 5, the total of 294 occurrences observed for the SD (undamaged) stubble data followed the distribution described in Table 1, according to those 9 combinations of speed and cutting angle, with the expected average quantity for each combination showing a frequency of 33 occurrences.

According to the information summarized in Table 1, based on the tests carried out in this research, no evidence was found that any combination of device travel

speeds and base cutting angles influenced the test observations, in which no damage to the stubble (SD) was observed, according to the

qualitative evaluation methodology proposed by Toledo, Silva and Furlani (2013).

Table 1 Damage caused to SD-type stubble (no damage)

Combinations		Frequency of occurrence	
Speed displacement (km h ⁻¹)	Base cut attack angles (degrees)	Observed (unit)	Expected (unit)
3	12	24	33
3	15	33	33
3	18	41	33
5	12	30	33
5	15	33	33
5	18	40	33
7	12	27	33
7	15	29	33
7	18	37	33

chi-square test statistic for the data above is 8.21, with a p value of 0.4130.

$$(a) \text{ Expected frequency} = \frac{\sum \text{observações}}{\text{quantidade de combinações}} = \frac{294}{9} = 32.67 \cong 33$$

Source: Prepared on the basis of research data.

When analyzing the distributions of the total of 42 occurrences observed for the DP (partial damage) type stubble data, according to the 9 combinations of speed and cutting angle considered in this study and taking into account the respective average quantity expected for each combination (7 occurrences per

combination), no evidence of influence of the combination of travel speed and cutting angle on the observations regarding partial damage caused to the stubble (DP) was detected, as demonstrated by the information contained in Table 2.

Table 2 Damage caused to DP-type stubble (partial damage)

Combinations		Frequency of occurrence	
Speed displacement (km h ⁻¹)	Base cut attack angles (degrees)	Observed (unit)	Expected (unit)
3	12	12	8
3	15	10	8
3	18	6	8
5	12	8	8
5	15	10	8
5	18	6	8
7	12	8	8
7	15	5	8
7	18	7	8

chi-square test statistic for the data above is 5.25, with a p value of 0.7306.

$$(a) \text{ Expected frequency} = \frac{\sum \text{observações}}{\text{quantidade de combinações}} = \frac{72}{9} = 8$$

Source: Prepared on the basis of research data.

Unlike the two classes of stubble damage already analyzed (SD and DP), the distribution of observations for occurrences of

extreme stubble damage (ED) showed evidence of influence from the combination of speed and cutting angle, as summarized in Table 3.

Table 3 Damage caused to the stubble of type ED (extreme damage)

Combinations		Frequency of occurrence	
Displacement speed (km h ⁻¹)	Base cut attack angles (degrees)	Observed (unit)	Expected (unit)
3	12	12	8.00
3	15	5	8.00
3	18	1	8.00
5	12	10	8.00
5	15	5	8.00
5	18	2	8.00
7	12	13	8.00
7	15	14	8.00
7	18	4	8.00

chi-square test statistic for the data above is 25.00, with a p value of 0.0016.

$$(a) \text{ Expected frequency} = \frac{\sum \text{observações}}{\text{quantidade de combinações}} = \frac{66}{9} = 7.33 \cong 8$$

Source: Prepared on the basis of research data.

In this sense, what stands out regarding the occurrence of extreme damage caused to the stubble is the variability in the number of occurrences observed, as detailed in Table 3. Unlike the two previous damage classes (SD and DP), the frequency distribution of occurrences related to extreme damage (ED) showed greater variability from one combination of speed and cutting angle to another.

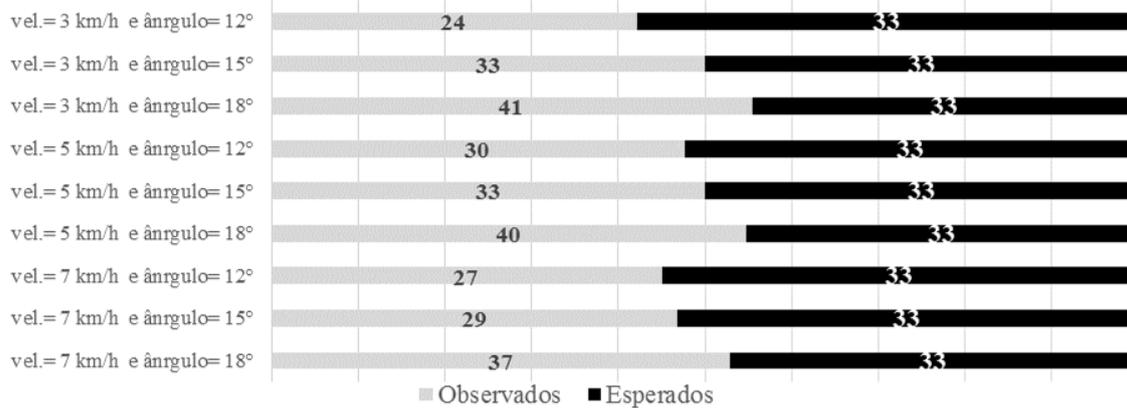
According to Martins *et al.* (2019), the quality of the basal cut of sugarcane is extremely important for the productivity and longevity of the sugarcane field in subsequent years, so these factors are decisive for the economic viability of the crop. In addition to being captured by the chi-square test, the influence of the variability in question (different combinations of travel speed with cutting angles) on the observed occurrences of ED-type damage (extreme damage to the

stubble), the graphical analysis presented in Figure 6 shows that the combinations of speed = 3 km h⁻¹ and cutting angle = 12°, speed = 5 km h⁻¹ and cutting angle = 12°, speed = 7 km h⁻¹ and cutting angle = 12°, and speed = 7 km h⁻¹ and cutting angle = 15°, produced the greatest amounts of extreme damage to the stubble, i.e., 12, 10, 13, and 14 observations, respectively.

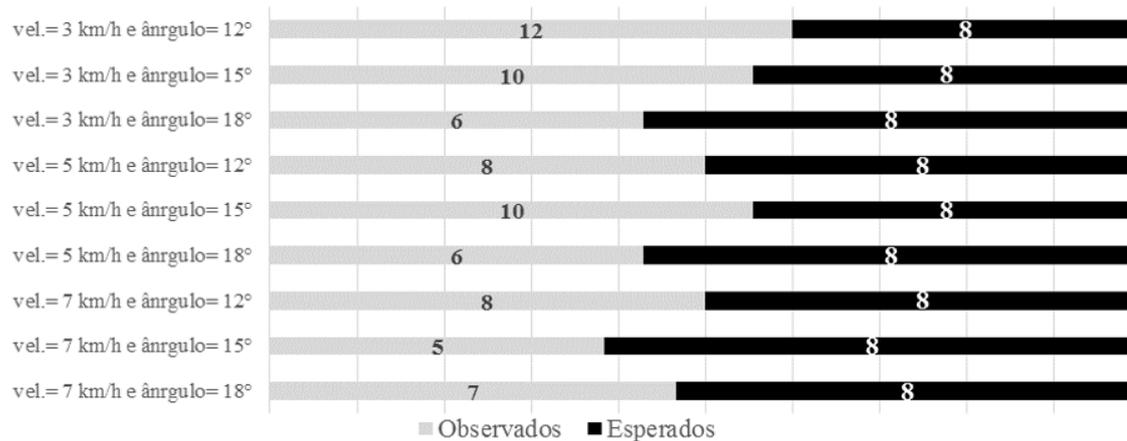
cutting angle = 12°, and speed = 7 km h⁻¹ and cutting angle = 15°, produced the greatest amounts of extreme damage to the stubble, i.e., 12, 10, 13, and 14 observations, respectively.

Figure 6 Comparative analysis of the damage caused to the stubble.

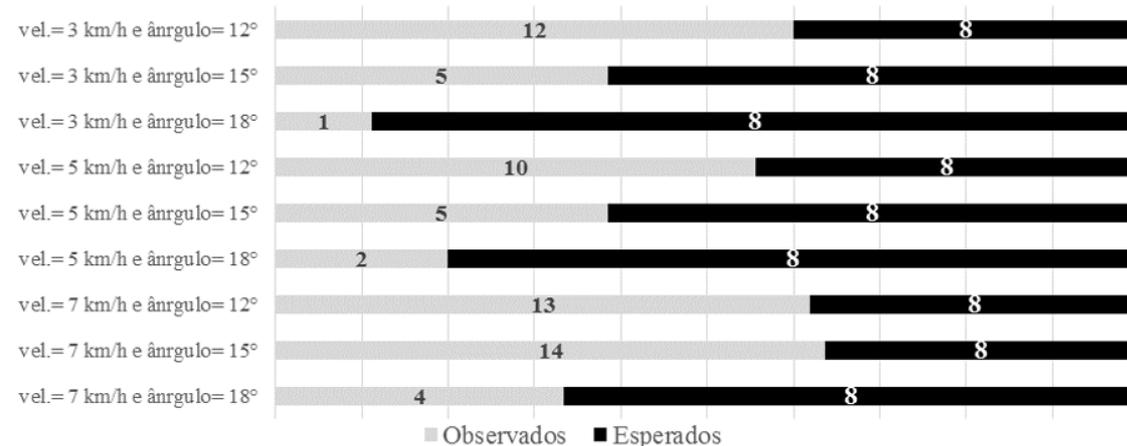
Danos causados à soqueira do tipo SD (sem danos)



Danos causados à soqueira do tipo DP (danos parciais)



Danos causados à soqueira do tipo ED (danos extremos)



Source: Prepared on the basis of research data.

On the basis of the graphical analysis presented in Figure 6 and according to the chi-square test results described in Table 3, both pieces of information presented for interpretation regarding the occurrences observed throughout the tests for the damage caused to the stubble of the ED type (extreme damage) do not allow establishing a cause-and-effect relationship between combinations (speed and angle) and occurrences of damage. In other words, there is some influence of the combinations of displacement speed and base cutting angle on the quantities of extreme damage (ED) occurrences observed, unlike what occurred with the two damage categories initially analyzed (SD and DP).

Although it is not empirically possible to dissociate the variables travel speed (km h^{-1}) and angles of attack of the base cut (degrees), isolated analysis of the observations relating to each of those variables indicated the existence of evidence that travel speed does not significantly influence any of the three types of stubble damage analyzed in this research (SD: chi-square test statistic = 0.51 with p value = 0.7748; DP: chi-square test statistic = 1.33, with p value = 0.5134; ED: chi-square test statistic = 5.551, with p value = 0.0625).

In mechanized sugarcane harvesting, the basal cut of the stalks, even when new blades are used, can damage and disturb the sugarcane stubble (CASSIA *et al.*, 2014; SILVA *et al.*, 2020; VOLTARELLI *et al.*, 2018; VOLTARELLI *et al.*, 2015), even to the point of complete removal from the soil.

Stubble plants that have suffered extreme damage may exhibit delayed regrowth and reduced agronomic vigor. Momin *et al.* (2017), in evaluating different basal cutting tools in sugarcane, with a harvester working at 6.3 km h^{-1} , reported that the frequency of undamaged stalks exceeded 83%, 11.3% partially damaged, and 5.65% extremely damaged in a continuous cutting system with a serrated tool. Silva *et al.* (2020) reported that after the third hour of use, rigid knives negatively influenced crop performance during the following harvest.

Bernache *et al.* (2020) reported an increase in the damage index caused by wear on cutting tools but reported no relationship with

crop regrowth. In the present study, the blades used did not wear; however, Cassia *et al.* (2014) and Reis *et al.* (2015) obtained high coefficients of variation in the evaluation of base cutting systems in sugarcane in field trials and indicated the strong influence of the soil and operator on the results.

On the other hand, regarding the angles of attack of the base cut, there was evidence that the angle used for cutting may influence damage to the stubble of the SD type (chi-square test statistic = 7.12, with p value = 0.0284) and the ED type (chi-square test statistic = 18.09, with p value = 0.0001). However, there was no evidence that the angle used for cutting may influence damage to stubble of the DP type (chi-square test statistic = 1.75, with p value = 0.4169).

The results obtained through a controlled system in the laboratory allow for the isolation of variables that negatively affect field results, such as the presence of soil in the basal cutting mechanisms. This fact contributes to the findings of Li *et al.* (2013), who developed studies on sugarcane cutting and loading using prototypes. The authors stated that the testing and development costs of these models are lower and offer greater control over the processes.

4 CONCLUSION

The influence of the combination of the translational speed of the basal cutting mechanism and the angle of inclination of the rotating trays significantly affected the occurrence of extreme damage to the sugarcane stubble.

The isolated analysis of each of the variables indicated that the speed of movement of the cutting system is not statistically significant for the expression of damage; however, the angle used for cutting significantly influences the degree of extreme damage.

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