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STUBBLE DAMAGE AND UNSETTLING INDEXES FOR DIFFERENT CUTTING AND LOADING SYSTEMS

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ABSTRACT: Simultaneous mechanical cutting and loading of sugarcane may trample the remaining stumbles in the harvested area, thus increasing the damage and unsettling indexes of the stubs remaining in the ground after the harvest, which, in the end, can hamper sugarcane regrowth. To this end, this work aimed to evaluate how cutting and loading systems affect sugarcane ratoon using statistical process control. The experiment was conducted in an agricultural area in Frutal, MG, in June 2014. Mechanical harvesting was conducted at a 1.1 m s-1(4.0 km h-1) average working speed and 1.50m spacing. The statistical design used was completely randomized, based on the concepts of quality control, in which the data were collected during harvesting time. The study treatments were as follows, basal cut, and mechanical sets A, B, C and D according to equipment gauge width. The stubble damage and unsettling indexes were the parameters used to determine the quality of the process under study. Set D with the widest gauge is the best option for mechanical harvesting, loading and transporting sugarcane since it has significantly lower sugarcane stubble damage and unsettling indices compared to sets A, B, and C.

Keywords: agricultural mechanization, control charts, mechanical harvest, stubble trampling, variability.

RESUMO: O corte mecânico e carregamento simultâneo da cana-de-açúcar pode atropelar a palha remanescente na área colhida, aumentando os índices de danos e abalos das socas que permanecem no solo após a colheita, o que, ao final, pode dificultar a rebrota da cana-de-açúcar. Para tanto, o objetivo deste trabalho foi avaliar como os sistemas de corte e carregamento que afetam a soca de cana-de-açúcar por meio do controle estatístico do processo. O experimento foi conduzido em uma área agrícola em Frutal, MG, em junho de 2014. A colheita mecanizada foi realizada a uma velocidade média de trabalho de 1,1m s-1 (4,0 km h-1) e espaçamento de 1,50m. O delineamento estatístico utilizado foi inteiramente casualizado, em que os dados foram coletados na época da colheita. Os tratamentos estudados foram o corte basal e os conjuntos mecânicos A, B, C e D de acordo com a largura de bitola do equipamento. Dessa forma, conclui-se que o Conjunto D com a bitola mais larga é a melhor opção para colheita mecânica, carregamento e transporte da cana-de-

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açúcar, pois apresenta danos significativamente mais baixos à palha da cana-de-açúcar, além dos índices de abalos, quando comparados aos conjuntos A, B e C.

Palavras-chave: mecanização agrícola, cartas de controle, colheita mecanizada, pisoteio de soqueira, variabilidade.

1 INTRODUCTION

The mechanical harvesting system of raw sugarcane consists of a harvester coupled to extraction vehicles, such as the side tipper trailer, pulled by either tractor or truck. The damages this system cause to the field and sugarcane stubble may result from the operator carelessness (loss of alignment), hindering the uniform handling of the machines; bad terrain conditions such as slope, field size, soil moisture content, harvesting speed, and especially the loading systems, among others (VOLTARELLI et al., 2017; GÍRIO et al., 2019; REIS et al., 2015).

The intense traffic of sugarcane harvesters and loading systems in areas without proper systematic planning may result in trampling of the previously collected sugarcane rows causing loss of vigor, failure, and low plant development and population in the subsequent harvests due to stubble damage (PAIXÃO et al., 2020; COMPAGNON et al., 2017).

The statistical process control (SPC) tools have been used to monitor mechanical operations in agriculture. There are reports in the literature of using SPC to identify and manage process inadequacies and to create an efficient action plan to improve the quality of the processes (TAVARES et al., 2018a; OLIVEIRA et al., 2018) such as the mechanical planting of sugarcane Orlando Junior (2018), Alcântara et al. (2017); mechanical sowing of peanuts Zerbato et al. (2019) and, finally, mechanical transplanting of coffee plants Oliveira et al. (2020) and Tavares et al. (2018b).

Among CEP tools are sequential graphs used to monitor processes and identify patterns of variation such as grouping, trend, and sway, while the best interpretation is used when individual control indicators. The chart is nothing more than an ordered sequence of data with a centralized horizontal axis (NATIONAL HEALTHCARE SERVICES SCOTLAND, 2017; PAIXÃO et al., 2019a; VOLTARELLI et al., 2015).

However, individual control charts should be implemented to monitor the variables that influence the quality of items and/or processes performed over time (VOLTARELLI et al., 2018) .During process monitoring, the presence of outliers, data points that vary around the average out of control over time, shows that the process is out of statistical control, requiring verification of the special causes affecting the process, so that the overall quality of the process can improve (MONTGOMERY, 2009).

In addition, the individual control chart can be complemented by the moving range chart, which can detect the process variability resulting from the individual value charts. According to Montgomery (2009), the use of moving scale with graphics is essential to monitor, understand and try minimizing special causes.

A capable process produces products or services that conform to specifications. Assuming that process performance is predictable, it is possible to predict the ability of the process to produce items within specifications (limits) and the number of items outside these limits. Capacity indices (Cp and Cpk) are dimensionless values that can be used to compare the capacities of different processes. In the literature, many professionals consider 1.33 the minimum acceptable value for the process capacity index (Cp) (BONILLA, 1994).

According to Bonilla (1994), when the value of the specified target is used to analyze process capability, another index is generated, Cpm (capability index relative to the target). This index refers to the variation from the target and the average values inside the specification limits, which should be compared to Cp and Cpk indexes to infer process centralization and capability.

To this end, assuming that the different loading systems can increase the trampling of sugarcane stubbles due to different gauge sizes, this work aimed at applying statistical process control to determine the damage and unsettling indexes to sugarcane stumbles resulting from the different harvesting and loading systems used.

2 MATERIAL AND METHODS

The experiment was conducted in the agricultural area of a sugarcane mill located in Frutal, MG, Brazil, near 20º01'29"S and 48º56'25"W, with average altitude of 516 m and slope of about 3%. The predominant climate is Aw according to the Köeppen classification.

The soil of the experimental area is classified as 72% sand, 5% silt, and 23% clay, on average. The soil moisture was determined in 20 random samples, 4 for each treatment (close to the stubbles), in the 0.00–0.15m layer according to the methodology recommended by Embrapa (2017). The average moisture content of the soil was 14%.

The size of the sugarcane plantation was measured using a standard rectangle triangle in 20, 38 and 42% of laying, bedded and erect stalks, respectively. The RB85-5453 sugarcane variety was in the first cut, while area average productivity was 92.91 Mg ha^{-1}.

The Model 3520 harvester had 6090T PowerTech (Tier III) engine of 9.0 liters and 251 kW (342 hp), was equipped with the *FieldCruise* system to control engine rotation and conveyor belt speed, with 1.88 m gauge and 0.46 m width. These harvesters were manually operated and worked at average speed of 1.1 m s^{-1}(4.0 km h^{-1}).

The harvester had 2480 lift-hours and harvested the sugarcane rows spaced 1.50 m during the daytime. The basal cutting mechanism knives consisted of uncoated flat knife with 4 cutting faces and 6 holes, with approximately 3 hours use period.

The loading systems consisted of a truck-pulled side tipper trailer, moving alongside the harvester, in which the harvested sugarcane was loaded and subsequently transported to the industrial unit. Table 1 sows the dimensions of the loading system (the truck-side tipper assembly) with 2.25 m front gauge. The truck that pulled the side tipper trailer had 1.90 m front and rear gauge.

Table 1. Dimensional characteristics of set A.

Characteristics/Dimensions (m)	Set A
Front gauge	2.25
External distance	2.55
Rear gauge	2.00
External distance	2.60
Distance between axles (truck tire - 1st side tipper tire)	4.90
Distance between axles (truck tire – 2nd side tipper tire)	6.20
Length of the side tipper trailer	7.20

Table 2 presents the dimensions of the smaller loading system (truck-side tipper set) with a 1.90 m side trailer gauge. The truck that pulled the vehicle had 1.90 m front and rear gauge.

Table 2. Dimensional characteristics of set B.

Characteristics/Dimensions (m)	Set B
Front gauge	1.90
External truck gauge	2.80
Distance between axles (truck tire - 1st side tipper tire)	3.70
Distance between axles (truck tire – 2nd side tipper tire)	5.10
Total distance	14.00
Length of the side tipper trailer	11.00

Table 3 shows the dimensions of the loading system (tractor- side trailer assembly) with 1.90 m front gauge, smaller than set A, but the same size as set B. The tractor pulling the side tipper trailer had 1.90 m front and rear gauge.

Table 3. Dimensional characteristics of set C.

Characteristics/Dimensions (m)	Set C
Length between the axles	3.00
Tractor front gauge	1.60
Tractor rear gauge	1.90
Side tipper trailer gauge	1.50

Table 4 shows the dimensions of the tractor-side trailer set with 2.90 m gauge, which was the ideal to avoid the slightest trampling of sugarcane stubbles. The tractor that pulled the side trailer had 2.90 m front and rear gauge.

Table 4. Dimensional characteristics of set D.

Characteristics/Dimensions (m)	Set D
Length between the axles	2.45
Tractor front gauge	2.60
External distance	3.05
Tractor rear gauge	2.90
External distance	3.44
Side tipper trailer gauge	2.90
External distance	3.40
Distance between axles of the side tipper	1.40
Lateral distance between axles of the side tipper	5.00
Length of the side tipper	12.80
Distance from the drawbar to the chassis	1.50

The experimental design was completely randomized, following the quality control methodology. At the end of the evaluation period, 100 random samples were collected in total, of which 20 samples for the basal cut treatment and 20 samples for each tractor-loading sets A, B, C, and D (at random times), during one working day shift of 8 hours, for each variable analyzed. The machine operator was the same during the evaluation days to represent better the experimental conditions.

Stubble damage was classified into three classes with different weights assigned as follows, no damage (SD = 0), peripheral damage (DP = 0.33) and fragmented (DF = 1.00). After that, the damage index was determined by assigning weights to each class according to equation 1 adapted from Voltarelli et al. (2017):

$$ID = \frac{PSD\ nSD + PDP\ nDP + PFR\ nFR}{N} \quad (1)$$

Where:
ID: Stubble damage index;
P_{SD}: weight assigned to undamaged stubbles (0.00);
n_{SD}: number of undamaged stubbles;
P_{DP}: weight attributed to stubbles with peripheral damage (0.33);
n_{DP}: number of stubbles with peripheral damage;
P_{FR}: weight assigned to fragmented stubbles (1.00);
NFS: number of fragmented stubbles;
N: total number of ratoons/stalks in the stubbles.

The evaluator manually checked stubble mobility in the ground to evaluate unsettling/unsettling indexes. The high, average and low stubble mobility was classified as strong ($0.67 \leq IA < 1.0$), average ($0.34 \leq IA < 0.66$) and weak ($0.00 \leq IA < 0.33$), respectively, and weights were assigned (FF = 1.00, MR = 0.33 and AF= 0.00) as well. Therefore, the greater the stubble mobility, the higher is the stubble unsettling. Equation 2 presents the calculation of the unsettling index:

$$IA = \frac{Pff\ nff + Pam\ \ nam + Paf\ naf}{N} \quad (2)$$

Where,
IA: Stubble unsettling index;
Pff: weight attributed to strongly unsettled stubbles (1.00);
Nff: number of highly mobile stubbles;
Pam: weight attributed to average unsettled stubbles (0.33);
Nam: number of average mobile stubbles;
Paf: weight attributed to weakly unsettled stubbles (0.00);
Naf: number of slightly mobile stubbles, and;
N: total number of stubbles/stalks in the ratoon.

The damage and unsettling indices represent in a single value, the classification attributed to stubbles with stalks that have no damage, peripheral damage and fragmented stubble, as well as weak, medium and strong unsettling/unsettling. The index closer to 1.00 indicates greater damage and/or unsettling caused the stubble. Conversely, the index closer to 0.00 indicates less damage and unsettled stumbles while zero indicates no damage and unsettling.

For more experimental control, a single evaluator performed all evaluations in a 0.25 m² sample area. The basal cut samples were collected immediately after the harvester cut the plants. However, the trampling effect of the A, B, C, and D sets on the remaining stubble was determined on samples collected after five sugarcane rows were harvested.

To evaluate the damage and unsettling indexes, the management team of the production unit established standards and quality targets as shown in Table 5.

Table 5. Quality standards required by the production unit.

Quality indicator	LSL	Target	USL
Damage index	0.15	0.50	0.66
Unsettling index	0.15	0.50	0.66

USL: Upper Specification Limit; LSL: Lower Specification Limit

The data overall behavior was determined by an initial descriptive statistics analysis. The data were assumed to be independent, uninfluenced by the sampling place and its relative positions. Finally, the overall behavior of the data was determined by measuring/calculating the central tendency (mean) and dispersion (standard deviation and coefficient of variation).

Pimentel-Gomes and Garcia (2002) classified the coefficient of variation of a sample distribution as high (>30%); high (between 21 and 30%); medium (11 to 20%) and low (<10%). However, stated that the asymmetry coefficient (Cs) indicates the distance between the variable and the central value.

The data normality was checked by the Anderson-Darling test, which measures the proximity of the points and the estimated probability line, conferring greater rigidity to the analysis (PAIXÃO et al., 2020). Regardless of the normality assumption, due to the high number of samples, the control charts can be used to analyze process quality and reduce its variability, according to Paixão et al. (2020).

The single-factor analysis of variance was performed using F test, at 1%, to verify whether the means were significantly different, and when significant, the means were compared by Tukey test at 5%. When necessary, the data were transformed by the function y=ln(x).

The overall mean and the upper and lower control limits allow to infer whether the data variation is due to nonrandom causes in the process (special causes), and are calculated based on the standard deviation of the quality indicators, as shown in eq. 3, 4 and 5, respectively, for the individual value chart:

$$UCL = \overline{X} + 3\sigma \quad (3)$$

$$\overline{X} = \frac{(X1+X2+X3+\cdots Xn)}{N} \quad (4)$$

$$LCL = \overline{X} - 3\sigma \quad (5)$$

Where,
UCL = Upper control limit;
LCL = Lower control limit;
$\overline{X}$ = Overall mean;
N = total sample number;
σ= standard deviation;
X1, X2...= sample value.

The mean-moving range and upper and lower control limits are calculated by the moving range chart as shown in equations 6, 7 and 8:

$$UCL = D_4\,MR \quad (6)$$

$$\bar{M}R = \frac{|X_i - X_{i-1}|}{N} \quad (7)$$

$$LCL = D_3\,MR \quad (8)$$

Where,
UCL = Upper control limit;
LCL = Lower control limit;
MR = mean overall moving range;
N = Total sample number;
i= Number for individual value;

D3 and D4 = Tabulated values depending on the individual values or subclusters. Here, for individual values D3 was set at zero and D4, approximately 3.2670.01 (Montgomery, 2009).

Notably, the specific limits (upper and lower) placed in some of the individual value charts do not correlate with the control limit values, which are determined based on the standard deviation. The spec limits were used only for general demonstration of process behavior over time, considering the limits established by the production unit.

The presence of special causes is detected every time an outlier, point outside the control limits are observed in individual value or moving range charts. The point was then highlighted on the control chart, with the respective test numbers (Type I error). Outliers indicate non-random data variation, due to causes extrinsic to the process, and that such variation should be investigated, detected and later corrected. The absence of outliers in the control chart shows that there is no evident error in the process, and the lack of special variation indicates that the process is under control, being affected only by random factors.

The capability indexes Cp and Cpk (potential and real, respectively) were obtained using the standard deviation of the process within the subclusters (subcluster), being indicative of the inherent process variation, calculated according to equations 9, 10 and 11:

$$Cp = \frac{(UCL-LCL)}{6\sigma_{potential}} \quad (9)$$

Minimum Cpk (CPL, CPU)

$$Cpm = mim(USL; LSL)$$

$$Cpm = \frac{USL-LSL}{6.\sqrt{\frac{\sum_{i=1}^{n}(X_i-target)^2}{n-1}}}$$

$$Cpm = \frac{minimum[(USL-target),(target-LSL)]}{\frac{6}{2}.\sqrt{\frac{\sum_{i=1}^{n}(X_i-target)^2}{n-1}}}$$

Where:
Cpm = Capability index with respect to target;
USL: Upper Spec Limit;
LSL: Lower Spec Limit;
X_i = variable value for observation i;
n = number of observations.

$$\mathrm{CPL} = \frac{(\bar{\mathrm{X}}-\mathrm{LSC})}{3\sigma_{\mathrm{potential}}} \quad (10)$$

$$\mathrm{CPU} = \frac{(\bar{\mathrm{X}}-\mathrm{USL})}{3\sigma_{\mathrm{potential}}} \quad (11)$$

Where:
Cp = potential capability index;
Cpk = average minimum potential capability index;
CPL = potential capability index in relation to the lower spec limit;
CPU = potential capability index in relation to the upper spec limit;
USL: Upper Specific Limit;
LSL: Lower Specific Limit;
Dp or $\sigma_{\text{potential}}$ = Estimate of the potential standard deviation using the average moving range (subcluster = 1), in this case, between the specification limits;
$\bar{X}$ = average variable.

The Cpm index is the ratio between the spec limit amplitudes and the square root of the square of the average deviations from the target, considering the distance between process and spec averages, by measuring the centering of the process (eq. 12 and 13).

$$\text{If the target} = \frac{USL+LCL}{2} \quad (12)$$

$$\text{If the target} = \frac{UCL+LCL}{2} \quad (13)$$

A capability index of 1.33 was adopted as reference, that is, the minimum acceptable value capable of predicting whether the process could produce satisfactory results. A higher index shows that the process could produce acceptable results and within the specified limits (PAIXÃO et al., 2019b). The reference capability index is set at a higher value to increase the rigor of the analysis. However, this resource should be used when continuous process improvement does not affect the production costs of the operation since cost is also a quality indicator of the overall process.

The indexes contain information about the process average and limits, showing current process performance, within the subclusters and overall, respectively, by considering process average in relation to the specified limits, unlike the Cp and Pp indexes.

When the Cp and Cpk indexes are close, the process is centered between the specified limits, not considering the average displacement but considering the average displacement with respect to the specified and/or target nominal value, respectively. The latter can evaluate whether the process reaches the specified goals. If Cp is significantly greater than Cpk, the process is not centered between these limits.

The Cpm index is calculated only when a target is determined. This index examines the magnitude of the process and the process average variation in relation to the target, comparing it to the specified limit intervals and is sensitive to the average displacement in relation to the specifications. The higher the Cpm value, the more capable is the process.

The potential variation of the subcluster, in this case subcluster = 1, corresponds to the inherent process variation, while the general variation corresponds to the total process variations due to inherent (random) and non-inherent (special) causes of the given process.

3 RESULTS AND DISCUSSION

The basal cutting (damage index) and tractor-loading trailer sets A (damage index) and C (damage and unsettling indexes) treatments (Table 6) cannot be described by the normal probability density function according to the Anderson-Darling test results. The AD test results show values above zero, indicating that the dataset is distant from the estimated line.

Table 6. Descriptive statistics for the damage and unsettling indexes.

Treatment	Quality indicator	Average	σ	CV (%)	AD	p-Value
Basal Cutting	Damage index	0.44	0.17	38.68	0.88	0.01[A]
	Unsettling index	0.20	0.17	84.91	0.69	0.06[N]
Set A	Damage index	0.91	0.10	11.57	1.33	<0.005[A]
	Unsettling index	0.54	0.22	41.06	0.35	0.43[N]
Set B	Damage index	0.85	0.17	19.98	1.83	<0.005[A]
	Unsettling index	0.61	0.27	44.32	0.78	0.03[A]
Set C	Damage index	0.74	0.20	27.24	0.60	0.10[N]
	Unsettling index	0.55	0.29	53.05	0.37	0.37[N]
Set D	Damage index	0.41	0.13	32.49	0.54	0.13[N]
	Unsettling index	0.28	0.22	78.53	0.43	0.26[N]

σ – Standard deviation; CV (%) – Coefficient of variation; AD – Anderson-Darling normality test (N: normal distribution – $p > 0.05$; A: non-normal distribution – $p < 0.05$).

The standard deviation varied little among the quality indicators, while the lowest and highest values were observed for the sets A (damage index) and C (unsettling index), respectively. However, except for the damage index for sets A and B (moderate), coefficients of variation were high, showing high data variability over the sampling period (PIMENTEL-GOMES; GARCIA, 2002).

Figure 1 shows that set D had the lowest damage and unsettling indexes and did not differ from the basal cut treatment. Therefore, the extended gauge (3 m) of the tractor-side tipper trailer set favors sugarcane mechanical harvesting, indicating benefits to the sugarcane, following the basal cut.

Figure 1. Analysis of variance of damage and unsettling indexes in the mechanical harvesting of sugarcane.

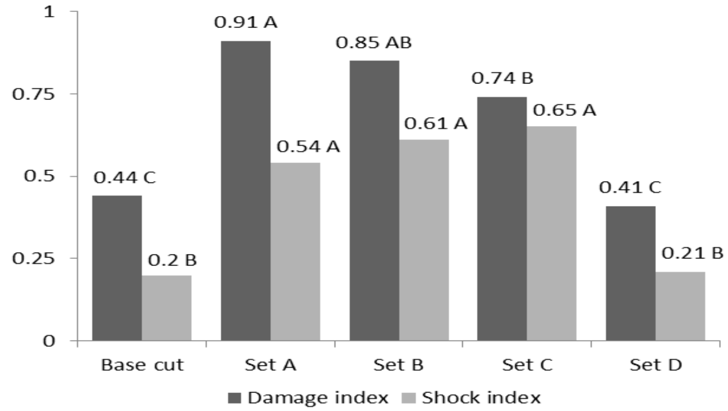


Table 7 shows the standard randomness values for damage and unsettling indexes for all treatments, verified by the clustering, mixing, trend and oscillation patterns. These results indicate that the process is potentially unaffected by external special causes over time, showing that sugarcane cutting and loading can be high-quality processes.

Table 7. Probability standard values for the tractor-side trailer sets in the mechanical harvesting of sugarcane.

Treatment	Quality indicator	C	M	T	O
Basal Cutting	Damage index	0.01^{*}	0.98^{ns}	0.28^{ns}	0.71^{ns}
	Unsettling index	0.82^{ns}	0.17^{ns}	0.28^{ns}	0.71^{ns}
Set A	Damage index	0.51^{ns}	0.48^{ns}	0.28^{ns}	0.71^{ns}
	Unsettling index	0.33^{ns}	0.66^{ns}	0.50^{ns}	0.50^{ns}
Set B	Damage index	0.91^{ns}	0.08^{ns}	0.71^{ns}	0.28^{ns}
	Unsettling index	0.32^{ns}	0.67^{ns}	0.28^{ns}	0.71^{ns}
Set C	Damage index	0.03^{*}	0.96^{ns}	0.13^{ns}	0.86^{ns}
	Unsettling index	0.17^{ns}	0.82^{ns}	0.50^{ns}	0.50^{ns}
Set D	Damage index	0.32^{ns}	0.67^{ns}	0.50^{ns}	0.50^{ns}
	Unsettling index	0.32^{ns}	0.67^{ns}	0.71^{ns}	0.28^{ns}

**A – Clustering; M – Mixture; T – Trend; O – Oscillation. * Non-randomness standard values detected by the probability test at $p<0.05$; ^{ns} randomness values detected by the probability test at $p>0.05$.

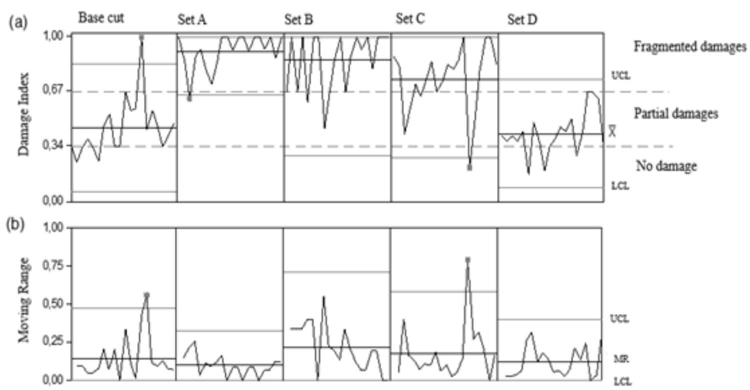
However, the damage index for the basal cut and set C treatments had non-randomness standard values for clustering. Therefore, if the detected clustering has a low damage index, it favors basal cut and trampling of the stubble.

Voltarelli et al. (2017) reported that the analysis of the sequential charts can be complemented by the control charts since the point distribution or repetitions could be the same for the two tests throughout the process. The authors also reported that the difference is that the sequential charts detect non-randomness patterns using the probability test (p <0.05), as a function of the standard deviation from the mean, using the statistical parameters of the normal distribution as calculation basis (for p-value). However, the control charts check process stability only as a function of the standard deviation from the mean.

Paixão (2015) studied patterns of randomness in the mechanical harvesting of soybean and observed the clustering pattern throughout the operation. This clustering pattern results from the fact that the samples were concentrated in specific areas of the charts, showing that the process might have been affected by special causes.

The control charts (Figure 2) show that the basal cut, and sets A and C treatments had points above and below the control limits, indicating an unstable process affected by factors extrinsic to sugarcane mechanical harvesting. To this end, the non-randomness patterns (Table 7) detected in these treatments (clustering), reliably indicated that external factors are influencing the operation and increasing process variability, thus requiring closer monitoring of the process.

Figure 2. Damage Index of the different sets in the mechanical harvesting of sugarcane.



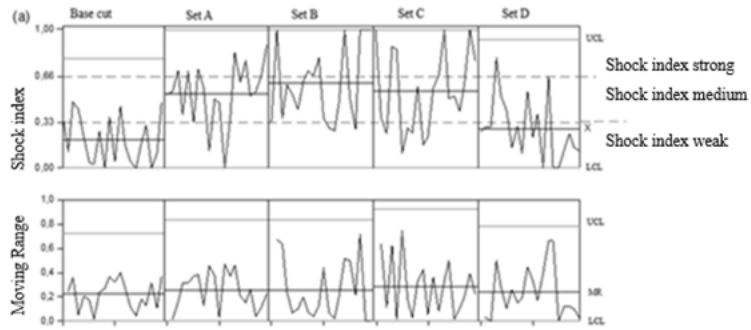
The external factors affecting the process are known as the 6 M's (machine, manpower, mother nature/environment, material, method, and measurement). The sets A and C were considered inadequate (the material factor) since the high stubble damage index was due to the width of the tractor-side tipper set. However, the instability of the basal cutting process was probably related to working speed (machine factor), a machine operator (manpower factor), wearing out of the knives (association between manpower and machine factors), size of sugarcane plantation (raw material), and uneven terrain (environment).

Furthermore, the wider gauge of set D improved process stability, decreasing dataset variability (moving range control chart). This result may indicate that the wide gauge of the tractor-trailer set reduced the damage index of stubbles/ratoons, improving sugarcane regrowth.

Voltarelli et al. (2017), investigated how knife models (smooth and serrated) and disks (with and without inclination) affect the quality of sugarcane basal cut and reported lower variability of damage index for the serrated knife coupled with the normal cutting disc. This set had the lowest percentage of non-damaged ratoons/stubbles; however, in this work, the harvester had smooth knives and disks without inclination.

The control charts (Figure 3) show that all sets, A, B, C, and D, favored process stability since the data points were within the UCL (upper control limit) and LCL (lower control limit).

Figure 3. Unsettling index of different sets used in the mechanical harvesting of sugarcane.



This result demonstrates that the unsettling caused by the basal cut and the different sets used did not cause great damage to the stubbles/ratoons.

Also, Set D with the extended gauge resulted in a stable process with the lowest unsettling index average, showing that an extended gauge can reduce unsettling index further improving sugarcane regrowth.

Bernache et al. (2020) reported that the wearing out of the knives of the cutting mechanism and the high working speed of the harvester also increased the unsettling/unsettling index, but this fact was not observed in this study since the harvester working speed was constantly monitored.

The values obtained for damage and unsettling indexes show that the process did not reach the target (Cpk, Cpm <1.33), similar behavior was observed for the Cpm and Cp values. The dataset for set D has a higher percentage within the USL and LSL interval for both quality indicators, which is also shown by the fact that Cp> Cpk for all evaluated situations (Table 8).

Table 8. Process capability, damage and unsettling indexes for all treatments.

Treatment	**Quality indicator**	**Cpk***	**Cp***	**Cpm***	**Cpk**	
					% <LSL	**% >USL**
Base cut	Unsettling index	0.35	0.56	0.15	0	0
Set A	Unsettling index	0.18	0.49	0.24	0	35
Set B	Unsettling index	0.14	0.44	0.18	0	35
Set D	Damage index	0.76	1.01	0.33	0	10
	Unsettling index	0.44	0.52	0.17	0	10

Cpk: real capacity; Cp: potential process capability; Cpm: capability in relation to the target; LCL: lower spec limit; UCL: upper spec limit; *Classification according to Bonilla (1994).

The sets A and B had 35% of the data above the established upper limit and, therefore, the quality control requirements for a successful process were not fulfilled in these two cases. However, the basal cutting dataset was between the established limits the first time but, over time, the real and potential capability indexes yielded values of Cp and Cpk <1.33, respectively.

Voltarelli et al. (2018) evaluated the cutting height and damage index to the ropes and reported oscillations outside the specification levels, concluding that the process could be improved. Likewise, a similar behavior is observed for the stubble damage and unsettling indexes, and since limits and targets established by the producing unit were not reached, the process capability did not achieve its full potential as well.

4 CONCLUSION

Set D equipped with the extended gauge is the best harvesting/loading/transportation option for mechanical harvesting of sugarcane since it has a significantly lower damage and unsettling rates of the stubbles/ratoons than the others.

In conclusion, the loading system affects the quality of the mechanical harvesting of sugarcane, which is higher for the set with extended gauge.

The damage and unsettling indices of sugarcane stubble were not within the limits established by the production unit since the process capability indices were also below the target.

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