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Quality monitoring of billets distribution in mechanised sugarcane planting

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Abstract

The mechanised farming operations, especially sugarcane mechanised planting, have diverse sources of variation that may harm the agronomic performance of the crop and destabilise the process, causing failure to meet operational goals. Accordingly, this study aimed to assess the quality of sugarcane mechanised planting in two operating shifts, on the left and right furrows, using statistical quality control tools. Mechanised planting was conducted in a farming area in the municipality of Monte Alto, São Paulo (SP), Brazil. The statistical design used was completely randomised, with plots subdivided in space, wherein 80 sampling points (replicates) were recorded during the day and night shifts, divided into 40 replicates on the left furrow and 40 replicates on the right furrow. The quality variables and/or indicators assessed regarding the performance of the mechanised set were the number of billets m^{-1}, total number of shoots m^{-1}, number of viable shoots m^{-1}, percentage of viable shoots, and billets consumption (Mg ha^{-1}), for both furrows and operating shifts. The combined use of run charts and control charts has become essential to monitor the mechanised planting process more stringently, leading to greater reliability in decision-making and thereby improving future operations. The operation quality of mechanised sugarcane planting is affected by day and night shifts and is lower during the night period for all quality indicators, especially the left furrow.

Keywords: operating shifts; quality control; *Saccharum* spp.; variability; agricultural mechanized.

Abbreviations: AD_ value of the Anderson-Darling normality test; LCL_ lower control limit; LSL_ lower specification limit; m_mass of billets within the furrow; $\overline{MR}$_ moving-range mean; Nb_number of billets; NNS_number of non-viable shoots; NVS_number of viable shoots m^{-1}; Pd _planting density; BC_billets consumption; UCL_ upper control limit; USL_upper specification limit; $\bar{X}$_individual-value mean; σ_standard deviation; % VS_percentage of viable shoots.

Introduction

Brazil has approximately 8.8 million hectares of sugarcane, and the semi-mechanised system (mechanical furrowing, manual distribution and placement of buds, and mechanical furrow closing) is the most widely used planting system. Labour costs and shortages have increased due to social and environmental policies, indicating the necessity of fully mechanising this operation (Rípoli and Rípoli, 2010; Barros and Milan, 2010). Accordingly, most sugarcane planting operations are labour intensive; therefore, there is an urgent need to introduce the use of machines termed planters, which complete all crop management practices within a single operation (furrowing, fertilisation, distribution of buds, application of agricultural pesticides, and furrow closing and compaction) to increase the sustainability and overall productivity of the sugarcane plantation (Voltarelli et al., 2013). Mechanised planting reduces time, labour, and loss of water content of chopped cane billets at planting, and may promote higher sprouting rates (Kumar and Singh, 2012). Such considerations corroborate the findings by Coleti and Stupiello (2006), who reported that sugarcane-planting operations are essential to the success of the crop cycle, and management decisions at this stage have consequences throughout the useful life of the crop. The most important factor for a good final plant stand is planting quality, which should provide a uniform distribution of sugarcane billets, and this is a key indicator of the operation quality of mechanised planting (Carlin et al., 2004). Inadequate planting methods, incorrect adjustment of the distribution of shoots in furrows, as well as the lack of modern equipment and, especially, management and monitoring of the quality of this mechanised operation are the main causes of low productivity (Khedkar and Kamble et al., 2008). Agricultural operations may affect the quality of this process and compromise its continuity when performed outside the quality standards established by the mechanised planting operation managers. Quality control should be conducted using a set of procedures that promote services and results, meeting the requirements of machines and processes (Campos et al., 2008). Accordingly, a key objective of any production process is to increase productivity and reduce costs. The use of inspection methods from the beginning of the production chain is essential to assess the final product and ensure it maintains the specified standards and, therefore, the success of the process (Toledo et al., 2008). To minimise the costs resulting from mechanised agricultural operations, the use of statistical quality control tools becomes essential to monitor the process, detect eventual special causes of variations, and, finally, create an improvement plan to eliminate the effect of factors extrinsic to the process, which will consequently increase the quality of operations by reducing their variability

(Voltarelli, 2013). Considering the above factors and assuming that the operation quality of mechanised sugarcane planting may be affected by the work shifts and that this variability affects the crop growth, this study aimed to monitor the quality of the mechanised sugarcane planting process during two work shifts (day and night) using statistical quality control.

Results

Descriptive statistical analysis

The data corresponding to the number of billets, total number of shoots, number of viable shoots, percentage of viable shoots, and billets consumption in the right furrow during both the daytime and night-time shifts exhibited a normal frequency distribution (Table 1). The data corresponding to the number of billets; total number of shoots; and number of billets, total number of shoots m^{-1}, and number of viable shoots m^{-1} in the left furrow in both the daytime and night-time shifts were non-normally distributed. This asymmetry was observed because of successive occurrences of equal and/or repeated values, thereby precluding a probability distribution fitting. However, this finding does not necessarily mean that the mechanised planting operation is being conducted in an unsatisfactory manner but that a different type of analysis is required for these data.

Analysis of run charts and control charts

No patterns of non-natural causes or non-random sources were found for the quality indicators number of billets m^{-1} and billets consumption (Mg ha^{-1}) during the daytime shift in both furrows (left and right; Table 2), or for the total number of shoots in the right furrow. However, the data corresponding to the quality indicators number of billets m^{-1}, total number of shoots m^{-1} and billets consumption Mg ha^{-1} also exhibited a natural or random pattern in the night-time shift, according to the standard deviation values (Table 3).

This lack of patterns may indicate that the data have a given homogeneous distribution of values around the mean, regardless of the situation found for the control charts, causing no harm to the process because this random variation is common to the process. Additionally, no fluctuation pattern value was detected in any quality indicator related to planting, increasing the likelihood that the data randomly concentrate around the centreline. The data corresponding to the quality indicators number of billets m^{-1}, total number of shoots m^{-1}, and billets consumption Mg ha^{-1} exhibited a natural or random pattern in the night-time shift, according to the standard probability values (Table 3).

The quality indicator percentage of viable shoots exhibited a clustering pattern of data points outside the control limits. However, if their clusters were mostly near the value of the upper control limit, there would be a higher percentage of viable shoots m^{-1}, which would consequently increase the overall mean of the parameter and maybe considered a risk-reducing factor for sprouting failures. The quality indicator number of billets m^{-1} in the daytime shift indicated that the process is outside the control limits in both the left and right furrows, both for the individual-value and moving-range control charts (Fig 1a and 1b). An analysis of this same variable in the night-time shift also revealed the occurrence of process instability (but only in the left furrow), whilst the right furrow remained inside the control limits according to the individual-value and moving-range control charts. Conversely, the process variability was mostly similar for both planting furrows in the daytime shift and higher in the left than in the right furrow in the night-time shift. Non-assignable causes occurring extrinsically to the process may account for this variation, which should be detected and subsequently removed to ensure the process reaches the expected quality.

The analysis of the individual-value and moving-range control charts (Fig 2a and 2b) revealed that the total number of shoots m^{-1} in the right furrow was only affected by common causes during the night-time shift, with all data points inside the upper and lower control limits (Fig 2a).

Another key issue to be analysed was the presence of non-common causes of variation process exclusively in the moving-range chart of the right furrow in the daytime shift (Fig 2b). When this situation occurs, regardless of the pattern observed in the individual-value control chart, the process in considered unstable given the wide range at this point (observation no. 72). The solution to this problem is the continuous monitoring of the process to decrease the variation because the variability would be potentially lower if this data point did not exist.

The individual-value control charts for the number of viable shoots m^{-1} (Fig 3a) show that both the daytime and night-time shifts have patterns of non-assignable causes of variation, in the right and left furrows, which may be observed in Tables 1 and 2, respectively, with points extrapolating the upper control limit, except for the left furrow in the daytime shift. This finding is also expressed in the high variability between observations, which implies process instability based on the moving-range charts (Fig 3b). Conversely, the daytime shift only exhibited one data point above the upper control limit on the moving-range chart of the left furrow, which deems the process unstable, given the high variability between observations no. 20 and 21 in the individuals values control chart. Additionally, a clustering pattern was observed when the data points were near the mean and the LSL. The process only stayed within the UCL and LCL control limits in the night-time shift in the right furrow, confirming that the process is under control.

The quality indicator percentage of viable shoots exhibited process stability only in the left furrow and in the daytime shift (Fig 4a and 4b), which is explained by the high standard deviation value expressing a high dispersion of values. A clustering pattern was also observed for this operating shift for both furrows (Table 1), which was evidenced by the proximity of the observations in the individual-value control charts. Furthermore, process non-randomness was only diagnosed for the right furrow, which was represented by a trend pattern resulting from successive increases and decreases in the data points over time.

For the planting process during the night-time shift, the presence of special causes of variation extrinsic to the process was observed from the data points falling outside the lower control limit in the individual-value control chart, and a clustering pattern was also observed in both furrows (Table 2). Furthermore, the moving-range control chart for the process was also compromised by instability given the high magnitude of variation in the values.

For billets consumption Mg ha^{-1}, the process may be only considered stable in the right furrow of the night-time shift (Fig 5a), which is explained by the lower observation variation values found over time, indicating clustering near the mean. Similar to the variable number of billets m^{-1}, billets consumption follows a specific ratio according to the number of billets, with the same data points outside the upper control limit in both charts. The variability in the daytime shift for

Table 1. Descriptive statistics regarding the variables number of billets (NB), total number of shoots (TNS), number of viable shoots (NVS), % viable shoots (VS), and billets consumption (SC) assessed following mechanised sugarcane planting during daytime and night-time shifts.

Variable	Mean		σ		Range		CV (%)		AD	
	LF	RF	LF	RF	LF	RF	LF	RF	LF	RF
Daytime shift										
NS m^{-1}	16.3	15.0	5.1	4.7	21.7	22.2	31.3	31.4	0.943^{A}	0.373^{N}
TNS m^{-1}	38.4	35.7	11.1	10.3	49.2	41.5	28.9	28.9	0.770^{A}	0.354^{N}
NVS m^{-1}	23.9	23.3	6.9	7.8	28.5	31.0	29.1	33.4	0.697^{N}	0.203^{N}
VS (%)	62.8	64.9	8.5	8.7	32.5	34.7	13.5	13.5	0.328^{N}	0.4750^{N}
BC (Mg ha^{-1})	24.9	23.1	7.8	8.2	33.2	22.1	31.3	35.3	0.315^{N}	0.373^{N}
Night-time shift										
NS m^{-1}	15.2	15.1	6.0	4.5	31.2	17.0	39.7	30.2	1.197^{A}	0.344^{N}
TNS m^{-1}	35.6	34.3	15.0	9.8	80.7	41.5	42.2	28.7	1.084^{A}	0.196^{N}
NVS m^{-1}	23.8	22.8	11.3	8.1	59.7	35.0	47.1	35.5	1.141^{A}	0.383^{N}
VS (%)	66.0	65.8	3.3	9.8	42.9	44.4	14.1	14.9	0.330^{N}	0.467^{N}
BC (Mg ha^{-1})	23.2	23.2	9.2	7.0	47.7	25.9	39.7	30.2	0.321^{N}	0.349^{N}

σ – Standard deviation; CV – Coefficient of variation; AD – Value of the Anderson-Darling normality test (N: Normal distribution – $p > 0.05$; A: Non-normal distribution – $p \leq 0.05$); RF: Right furrow; LF: Left furrow.

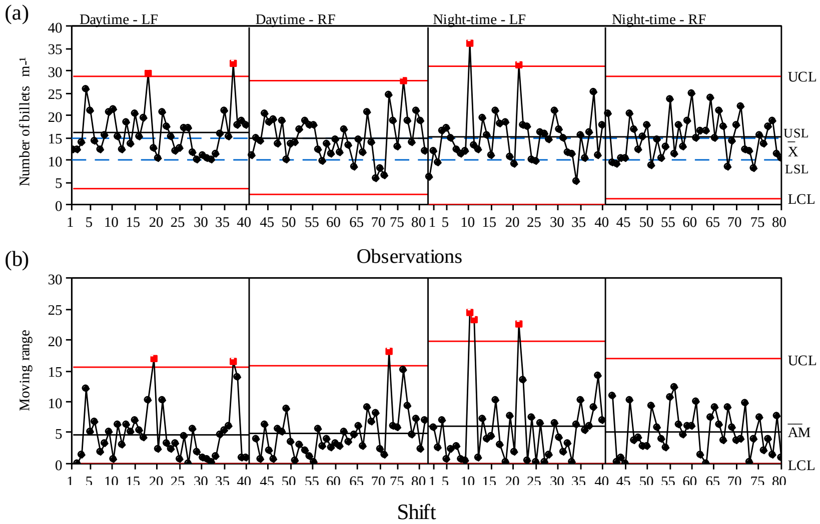

Fig 1. Control charts for the number of billets distributed by the planter during the mechanised sugarcane planting operation. (a) Individual-value control chart. RF: Right furrow; LF: Left furrow. (b) Moving-range chart. UCL: Upper control limit. LCL: Lower control limit. USL: Upper specification limit. LSL: Lower specification limit. X̄: Individual-value mean. M̄R: Moving-range mean.

both the left and right furrows was very similar (Fig 5b), and it was also similar to the right furrow in the night-time shift. The difference in variation between the left and right furrows during the night-time shift may be explained based on observations no. 10 and 21 found in the individual-value control chart of the left furrow, which had high values, thereby increasing the variation among values, expressed in the instability observed in the moving-range control chart.

Discussion

Descriptive statistics

The analysis of the pattern of a dataset of specific operation assessment parameters when combined with descriptive statistics parameters provides an overview of the distribution of results for a specific variable, which enables assessing the sample variability and, ultimately, detecting any unsatisfactory situations (Léon et al., 2005). The analysis of the percentage of viable shoots shows that the coefficient of variation was considered moderate according to Pimentel-Gomes and Garcia (2002), whereas it was considered high and/or very high for the other variables assessed, in both operating shifts. The variability existing in all variables analysed may be explained by the high dataset dispersion, which may also be observed by the range and standard deviations of the left and right furrows, in both operating shifts. Comparing the mean viable-shoot values assessed in the planting furrows (65%) with the means assessed following the passage and distribution performed by the sugarcane planter, a mean decrease of approximately 20% occurred in both the daytime and night-time shifts compared with the buds located in the upper part of the planter. This sharp reduction observed in the percentage of viable shoots following mechanised planting expressed the high variation existing in the measurement of mechanical damage caused to buds during the mechanised steps involved in the sugarcane production cycle (harvest, loading, transport, billets unloading through overflow within the planter, and the friction existing inside the planter caused by the billet conveyor belt, and other frictions, until the billets reach the planting furrows). Furthermore, the possible negative effects caused by weather and plant physiological conditions, among others, may not be easily detected when assessments are

Table 2. Standard probability values of run charts regarding the quality indicators assessed in the mechanised sugarcane planting operating during the daytime shift.

Daytime shift					
Quality indicators	Furrows	Patterns			
		C**	M	T	O
Number of billets m^{-1}	Left	0.17^{ns}	0.82^{ns}	0.10^{ns}	0.90^{ns}
	Right	0.50^{ns}	0.50^{ns}	0.92^{ns}	0.08^{ns}
Total number of shoots m^{-1}	Left	0.37^{ns}	0.62^{ns}	0.02*	0.98^{ns}
	Right	0.73^{ns}	0.26^{ns}	0.92^{ns}	0.08^{ns}
Number of viable shoots m^{-1}	Left	0.06^{ns}	0.94^{ns}	0.02*	0.98^{ns}
	Right	0.00*	0.99^{ns}	0.18^{ns}	0.81^{ns}
Viable shoots (%)	Left	0.01*	0.98^{ns}	0.44^{ns}	0.55^{ns}
	Right	0.00*	0.99^{ns}	0.02*	0.98^{ns}
Billets consumption of (Mg ha^{-1})	Left	0.17^{ns}	0.82^{ns}	0.10^{ns}	0.90^{ns}
	Right	0.50^{ns}	0.50^{ns}	0.92^{ns}	0.08^{ns}

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

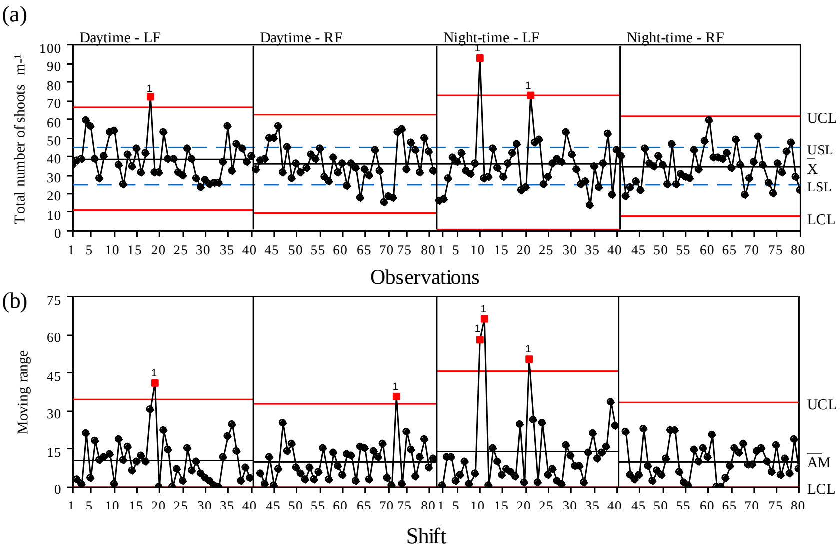

Fig 2. Control charts for the total number of shoots distributed by the planter during the mechanised sugarcane planting operation. (a) Individual-value control chart. RF: Right furrow; LF: Left furrow. (b) Moving-range chart. UCL: Upper control limit. LCL: Lower control limit. USL: Upper specification limit. LSL: Lower specification limit. $\bar{X}$: Individual-value mean. $\overline{M}$R: Moving-range mean.

Table 3. Standard probability values of run charts regarding the quality indicators assessed in the mechanised sugarcane planting operation during the night-time shift.

Night-time shift					
Quality indicators	Furrows	Patterns			
		C**	M	T	F
Number of billets m^{-1}	Left	0.38^{ns}	0.62^{ns}	0.10^{ns}	0.90^{ns}
	Right	0.63^{ns}	0.36^{ns}	0.60^{ns}	0.39^{ns}
Total number of shoots m^{-1}	Left	0.06^{ns}	0.94^{ns}	0.30^{ns}	0.69^{ns}
	Right	0.37^{ns}	0.62^{ns}	0.30^{ns}	0.69^{ns}
Number of viable shoots m^{-1}	Left	0.06^{ns}	0.94^{ns}	0.04*	0.95^{ns}
	Right	0.06^{ns}	0.94^{ns}	0.30^{ns}	0.69^{ns}
Viable shoots (%)	Left	0.00*	1.00^{ns}	0.73^{ns}	0.26^{ns}
	Right	0.02*	0.97^{ns}	0.18^{ns}	0.81^{ns}
Billets consumption (Mg ha^{-1})	Left	0.38^{ns}	0.62^{ns}	0.10^{ns}	0.90^{ns}
	Right	0.63^{ns}	0.36^{ns}	0.60^{ns}	0.39^{ns}

**C – Clustering; M – Mixture; T – Trend; F – Fluctuation; *Non-randomness standard values detected using the probability test at $p < 0.05$; ^{ns}randomness standard values detected using the probability test at $p > 0.05$.

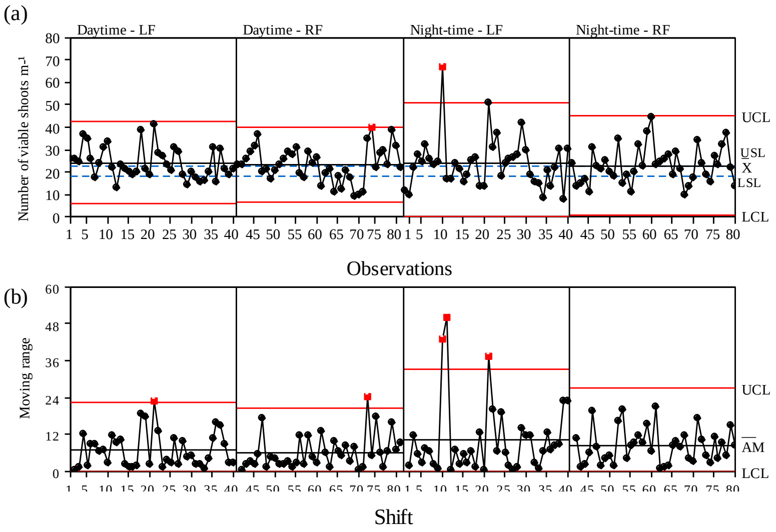

Fig 3. Control charts for the number of viable shoots distributed by the planter during the mechanised sugarcane planting operation. (a) Individual-value control chart. RF: Right furrow; LF: Left furrow. (b) Moving-range chart. UCL: Upper control limit. LCL: Lower control limit. USL: Upper specification limit. LSL: Lower specification limit. $\bar{X}$: Individual-value mean. $\overline{M}$R: Moving-range mean.

performed, which may also contribute to increasing billets consumption (Mg ha^{-1}). This phenomenon also leads to high operating production costs and a marked decrease in the percentage of viable shoots that reach the planting furrows.

Quality analysis

Run charts

According to the National Healthcare Services (NHS) Scotland (2012), the analysis of runs may follow different norms and guidelines to detect standard values, which are therefore fitted to each situation (in this case, mechanised operations), by setting their sequence of points that will be the limits of production when assessing non-randomness.
The total number of shoots and viable shoots values exhibited the trend pattern, both in the left furrows. These parameters are somewhat directly related to each other, with one variable affecting the other. The trend pattern decreased mildly over time as observed from the slight decrease in the number of shoots throughout the process. Cassia (2013) also noted the occurrence of a trend and clustering of their quality indicators, when using run charts to detect non-randomness patterns resulting from the mechanised coffee harvesting process in circular planting, as in the present study.The analysis of run charts is critical for determining the external sources of variation, although the necessity to examine the reasons why they occur is even greater (NHS Scotland, 2012a).

Control charts

Noronha (2012) reported mean billet rates approximately 50% lower than the present study (15 billets m^{-1}) when studying mechanised sugarcane planting. This situation strongly contrasts with the present study and may adversely affect the initial crop tillering, given the potential damage to shoots. The sources of variations extrinsic to the process should be attributed to the so-called “6 M’s” factors (manpower, material, raw material, environment, machine, method, and measurement). In this case, we may associate the fact that the planter operator (manpower), who controls the billet conveyor belt settings, lost control of those settings at certain time points, which resulted in points above the upper control limits, with higher numbers of billets m^{-1}, in addition to the fact that the machine lacks a buds metering mechanism specific for distributing billets into the planting furrows. The lack of this mechanism, combined with the highly random arrangement of billets within the planter and their size, causes them to be collected and directed to furrows through conveyor belt rotation in different amounts, and this casual event may have occurred at said data points outside the control limits. Silva et al. (2011) studied the technological standards of precision agriculture in the state of São Paulo and noted that sensors are typically seldom used in the sugarcane sector, that the use of these resources would enable reaching improved productivity rates and reduced production costs, and that the operations would be performed with higher quality. Likewise, the presence of a metering sensor able to quantify the distribution of billets in mechanised planting, according to the conveyor belt rotation settings, would be a valuable solution to decrease the distribution variability over the working hours, regardless of operating shift, which would potentially reduce the external sources of error caused by operator fatigue over time. The process of distribution of billets mostly maintained a cluster of values above the USL. This directly affects the operation that the planter operator is conducting, which in this case is above the specifications and may cause increased billets consumption Mg ha^{-1}. The specification limits (USL and LSL) are used in the individual-value control charts to demonstrate how the process performs over time, and whether it requires modification to enable it to reach the quality demanded by managers. Similarly to the situation described above regarding the number of billets, some data points above the control limits recorded for the total number of shoots in the left furrow, both in the daytime and night-time shifts, are the same for both variables. These points show a non-random trend pattern (Table 1) in the individual-value and moving-range control charts of the daytime shift (observations no. 10 and 21), given the ascending and descending sequences of

Table 4. Specification control limits used in the mechanised sugarcane planting operation during daytime and night-time shifts.

Quality indicators	Lower specification limit (LSL)	Upper specification limit (USL)
Number of billets m^{-1}	10	15
Total number of shoots m^{-1}	25	45
Number of viable shoots m^{-1}	18	23
Viable shoots (%)	60	90
Billets consumption (Mg ha^{-1})	13	25

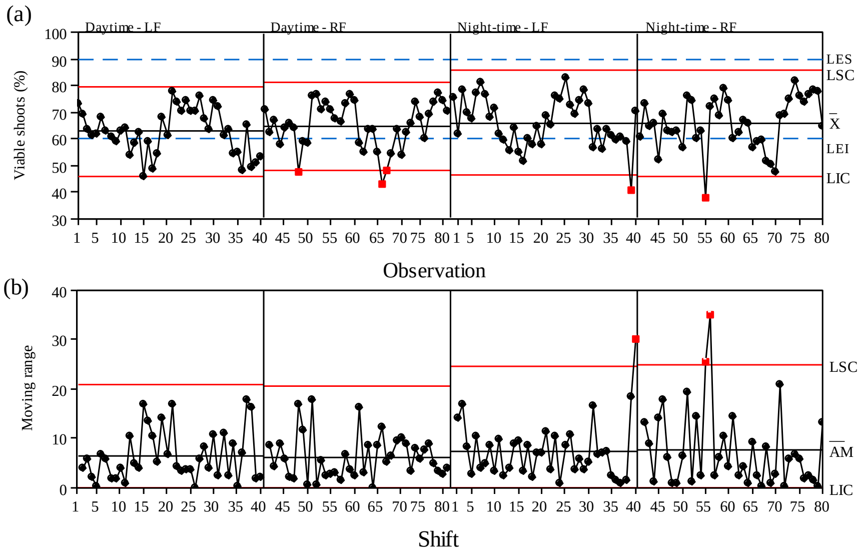

Fig 4. Control charts for the percentage of viable shoots distributed by the planter during the mechanised sugarcane planting operation. (a) Individual-value control chart. RF: Right furrow; LF: Left furrow. (b) Moving-range chart. UCL: Upper control limit. LCL: Lower control limit. USL: Upper specification limit. LSL: Lower specification limit. $\bar{X}$: Individual-value mean. $\overline{MR}$: Moving-range mean.

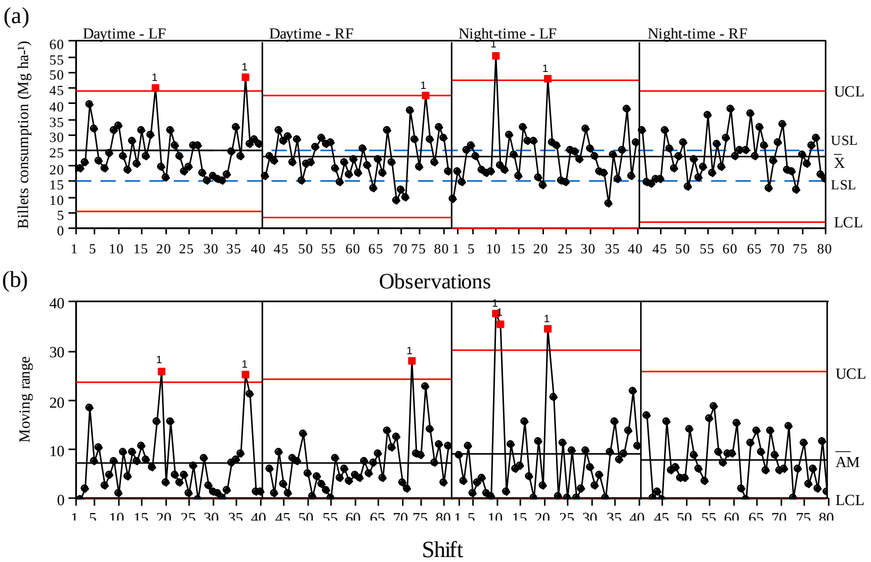

Fig 5. Control charts for billets consumption during mechanised sugarcane planting. (a) Individual-value control chart. RF: Right furrow; SE: Left furrow. (b) Moving-range chart. UCL: Upper control limit. LCL: Lower control limit. USL: Upper specification limit. LSL: Lower specification limit. $\bar{X}$: Individual-value mean. $\overline{MR}$: Moving-range mean.

points (left furrow), which express the variation of special causes occurring in the process. Regarding the night-time shift (observations no. 10, 21 and 10, and 11 and 21, respectively), this observation may be explained by the direct effect of the number of billets distributed in the planting furrows on the total number of shoots m^{-1} because these variables are somewhat correlated (Cebim, 2007), Therefore, potential increases in the distribution of billets may affect the total number of shoots in plating furrows. In general, there is a high clustering of points within the specification limits (USL and LSL), with approximately 73.8% of the daytime shift data points and 65.0% of the night-time shift data points and a difference of approximately 8% of the data points outside the specific limits between shifts, which expressed the decreased quality of the night-time operation, given the higher number of data points outside the specification limits during this shift. The quality of sugarcane planting with buds derived from mechanised harvest may be reduced due to the number of shoots allocated to planting furrows, with no significant response in productivity. This situation may occur in the present study if the continuous monitoring of planting is not performed judiciously because some values are above the USL. The variability due to the process for this variable was typically higher in the night-time shift than in the daytime shift. This finding suggests that the process quality may have experienced a marked decrease in this operating shift. It should be emphasised that the analysis of the USL and LSL in the control charts is not fully accurate regarding the process capacity and is only a means of presenting the dataset pattern throughout the process. Montgomery (2004) reports that capacity analysis should be performed based on other statistical patterns to generate a greater accuracy and understanding of the magnitude of the process. Based on tests conducted by modelling sugarcane row dividers in mechanised harvesting, Zhang et al. (2009) reported that the angle of stalks to be lifted by this system and directed to the cutting mechanism should not be lower than 15º to prevent damage to the stalks and, consequently, to the shoots, which would decrease their viability, possibly affecting the initial crop growth. Other authors have also examined the subject in more detail (Song et al., 2010; Xie et al., 2011). The mechanised planting night-time shift mostly exhibited higher variability in the number of viable shoots, which consequently decreased the quality, with the existing sources of variability defined according to the so-called "6 M" factors (manpower, material, raw material, environment, machine, method, and measurement). A possible explanation for this increased variability is the machine factor, which most likely negatively affected (through damage caused to shoots) the number of viable shoots due to the mechanised harvesting of buds. This factor is also associated with the other types of damage and/or frictions caused by loading and transporting the buds to the planting area, although the observations are mostly above the specification control limits. Lai et al. (2010) studied simulations of terrain irregularities at the time of mechanised harvest and reported that the higher the machine vibration frequency, the greater will be the impacts caused to sugarcane shoots by the base cutting mechanism, which subsequently accelerates their deterioration. This situation may partly explain the points extrapolating the control limits in the present study because the variability of mechanised sugarcane harvest is greater during the night-time shift (Noronha, 2012). By using simulations, Lai et al. (2010) noted that a new base-cutting support mechanism concept providing a higher quality operation must be used to generate lower rates of damage to buds in mechanised harvesting. The authors also reported that mechanised harvesting is the leading cause of decreased percentage of viable shoots assigned to sugarcane planting operations. All data points outside the lower control limit, both in the individual-value and process-variation (moving-range) control charts are also proportional to the variable number of viable shoots and, therefore, their smaller values affect the percentage of viable shoots, which is confirmed by the higher variability found in the night-time shift (Fig 5b). This variation may also be associated with mechanised harvesting of buds, resulting from the wear-and-tear of blades of the base-cutting mechanism, terrain fluctuations, operator's inability to control the machine, poor visibility of the harvester operator during the operation, and billets loading and transport to the planting area. When studying the damage caused to sugarcane buds at the time of action of the harvesters extraction mechanism using high-speed photography, Mou et al. (2012) reported that the results from the models constructed indicate the existence of damage to plants as assessed by the leaf water content. The lower this content, the easier the leaf-plant separation will be, which may consequently cause greater damage to shoots because they are left unprotected, and inversely, a greater amount of leaves may disrupt sprouting. Lin et al. (2012) studied control and automation methods based on the engineering of sugarcane harvesters and proposed a new detrashing system to remove excess straw for potentially better shoot sprouting conditions, carefully avoiding as much as possible the decrease in the percentage of viable shoots derived from harvesting. The authors reported that the smaller the damage to shoots at harvest, the higher the sugarcane plantation quality will be because the cycle of operations involving planting also leads to a decreased percentage of shoots until their allocation to planting furrows.When conducting simulations of mechanised sugarcane planting and billets harvesting logistics and management, Yu et al. (2007) reported that predicting possible problems that may occur during the cycles of operations is essential to avoid a lack of buds for used during planting because the scheduling of all available machinery directly affects the operational field capacity of mechanised planting. The control charts are interpreted in a different way, if these two observations were eliminated or if they were below the upper control limit, it is possible that the variability between the two operating shifts regarding the number of viable shoots as well as the number of billets m^{-1} and the total number of shoots m^{-1} could be approximately similar. Such proximity of the variability existing between these variables in both operating shifts was expected because the variables depend exclusively on the fixed settings of the planter billet conveyor belt (machine factor) and conveyor belt control by the planter operator (manpower factor).

Salassi et al. (2004) studied mechanised and semi-mechanised sugarcane planting using billets and whole cane, respectively, in the state of Louisiana, USA, and reported that the volume of billets used may be up to four times higher than the use of whole cane, which certainly is a factor affecting production costs.

Materials and Methods

Plant and soil materials and experimental conditions

The experiment was conducted in the municipality of Monte Alto (SP), Brazil, in the vicinity of geodetic coordinates: 21º16'42" S latitude and 48º24'21" W longitude, with a mean altitude of 620 m, 6% mean slope and Aw climate according to the Köppen climate classification.

The field was cultivated with soybean prior to mechanised sugarcane planting. Periodic tillage (using medium harrowing followed by levelling harrowing) was conducted before soybean sowing, after subsoiling at a 0.50 m depth. After the mechanical harvesting of soybeans the amount was estimated straw left from the soybean crop was assessed by sampling ten random points and was determined to be 938.03 kg ha^{-1} dry mass. And then, was realized the mechanised sugarcane planting.

Soil samples were collected (0 – 0.20 m) to assess the texture class, and the following results were obtained: 78% sand, 6% silt, and 16% clay. The soil was thus classified as medium texture soil. The methods described by ASABE (2006) and by Buol et al. (2011) were used to characterise the soil mechanical resistance to penetration and the soil water content, respectively, wherein 80 points were sampled to assess the soil resistance, including 40 points for each operating shift, and 160 samples were collected to assess the soil water content, including 80 for each operating shift, at the 0 -0.15 and 0.15 - 0.30 m layers. The layer of higher resistance to this soil penetration was at a depth of 0.10 to 0.20 m (3.14 MPa), and the soil water content in the layer (0 - 0.15 m) was 7.0 (daytime) and 8.5% (night-time) and in the depth (0.15 – 0.30 m) was 6.5 (daytime) and 9.0% (night-time), respectively.

Tractor and planter characteristics

Mechanised sugarcane planting was performed from 03.27.2012 to 03.31.2012 using a tractor-planter set consisting of the following: 1) a 4 x 2 FWA tractor, having a 6-cylinder engine with 134.0 kW engine power at 2.200 rpm, with a 17:1 compression ratio, 600/65R28 front tires and 710/70R38 back tires, both R1 W and 2) a 2-row chopped sugarcane planter, with a capacity of six tons of buds for planting, a 1.300 Mg fertiliser box, with a 3.60 m width, 600/50 22.5 tires, and shanks spaced 1.50 m apart.

The tractor was operated with the gauge adjusted to 2.70 m and in work gear 1B. The sugarcane variety planted was RB83 – 5054, which is a variety suited to mechanised harvest and appropriate for medium fertility soils. The set was equipped with an automatic steering hydraulic system for planting alignment (autopilot), consisting of an Fmx® onboard computer (Trimble), a AgGPS Global Positioning System (GPS) receiver (Trimble), and other accessories.

Experimental design

The experimental design was completely randomised with plots subdivided into subplots and the treatments applied in the evening shift (3:00 PM to 11:00 PM) to allow assessing the operation during the daytime (3:00 PM to 6:00 PM) and night-time (7:00 to 10:00 PM) shifts without having to replace the operator, thus providing better experimental control conditions. Two pre-defined sampling grids spaced 50 x 1.5 m apart were set up, in which 80 replicates for the day shift and 80 for the night shift were tallied, including 40 replicates in the left furrow and 40 in the right furrow, totalling 160 replicates.

Quality indicators

The total number of billets, shoots, and viable shoots were tallied after mechanised planting (furrow opening, billets placement, and furrow closing) by direct count within 4 m in the evaluated furrow as described in Voltarelli (2013). For the counts, the furrows were dug using a hoe, which was handled carefully to avoid injuring the billets. A single rater counted the number of billets (units) in each replicate to ensure greater experimental control. The total number of shoots and number of viable shoots were tallied using the same billets. Again, a single rater tallied the total number of shoots and the number of viable shoots (units) for each replicate.

Viable shoots were defined as those that had not been attacked by pests or diseases or had not been damaged during the mechanised harvest, billets transport to the planting area, billets unloading into the planter hopper, and subsequent allocation to planting furrows, adapted according to the methodology Robotham and Chappell (2002).

The percentage of viable shoots was assessed using the following equation:

$$\% VS = \left(\frac{NVS}{NNS}\right) x\ 100 \qquad (1)$$

Wherein:
% VS: percentage of viable shoots;
NVS: number of viable shoots m^{-1};
NNS: number of non-viable shoots m^{-1};
100: conversion factor.

Billets consumption in each planting furrow (Equation 2), left and right, and operating shift, daytime and night-time, was estimated based on the values assessed by biometric analysis of the buds (mass of billets), data on the number of billets m^{-1} furrow, and the spacing used in the mechanised planting (Janine, 2007).

$$BC = \frac{m\ x\ Nb\ x\ Pd}{1000} \qquad (2)$$

Wherein:
BC: billets consumption (Mg ha^{-1});
m: mass of billets in the furrow (m kg $billet^{-1}$);
Nb: number of billets (billets m^{-1});
Pd: planting density (m ha^{-1});
1000: conversion factor of kg ha^{-1} into Mg ha^{-1}.

Statistical analysis

Statistical descriptive

The descriptive statistics were performed for the overall monitoring of the data set by measures of central tendency (mean) and dispersion (standard deviation, coefficient of variation, and amplitude). Verification of the normality of the data was conducted using the Anderson-Darling test, which is a measure of closeness of the points and the line estimated in the probability, giving greater stiffness to the analysis (Acock, 2008).

Non-random patterns (run charts)

Run charts are plots of data over time used to assess the randomness or non-randomness of processes in which the reduction of viability is sought. These charts allow identifying the possible presence of special-cause variation, especially when control charts are diagnosed as stable, with all points falling within the control limits (Werkema, 2006).

This type of chart is an ordered sequence of data, with a central horizontal axis representing the mean or most often the median. Run charts allow monitoring the process to identify the type of variation it is subjected to over time through the combined analysis of sensitive chart parameters according to the standard deviations of the mean (NHS Scotland, 2013).

At least 15 sample points are optimally required when designing a run chart. This enables identifying the occurrence of non-random causes of variation in the process and identifying the existing pattern, which may be classified as a trend (sequence of successive increases or decreases in the observations), fluctuation (existence of a regular pattern occurring over time), mixture (lack of points near the centreline), and clustering (groups of points in a given area of the run chart) (NHS Scotland, 2013).

The assessment of possible data randomness was performed using the probability test at 5%. The null hypothesis of non-randomness was rejected in favour of the alternative hypothesis for the pattern tested when the p-value was lower than 0.05 (Minitab, 2007).

The occurrence of these patterns may suggest that the process is close to extrapolating the control limits, i.e., becoming "unstable", or that the process is already unstable, failing to meet the quality standards when the control charts are stable. However, this type of analysis should be complemented with an assessment of the control charts to determine the performance of the quality indicators with greater accuracy. This test is unilateral, and the trend and fluctuation patterns are calculated from observations falling on a single side of the centreline, while the clustering and mixture patterns are calculated from observations falling on both sides of the centreline.

Control charts

The control charts used were individual-value and moving-range (I-MR) control charts, which have centrelines (overall mean and mean range) and upper and lower control limits (defined as UCL and LCL), calculated based on the standard deviation of the variables (the mean plus three times the standard deviation for the UCL and the mean minus three times the deviation (when greater than zero) for the LCL) (Montgomery, 2009). According to the same author the process is considered unstable when any of the points exceed the upper and lower control limits (red dots) is stable when all the points are between these limits (black dots). These charts were used to identify the non-randomness caused by a factor external to the process (when control charts show the unstable process) and to assess the operational quality using the variables described above as quality indicators (Montgomery, 2009).

Individual-value control charts should be implemented to monitor the variables that affect the quality of items or process produced over time (Minitab, 2007). Accordingly, a certain variable may be monitored through successive samples that may be collected during specific periods of time from production batches (in real time) and from batches of raw materials, among others (i.e., they are variables with measurable characteristics of a particular process that may be considered continuous variables) (Werkema, 2006).

The use of moving-range charts aims to detect the variability existing in the process resulting from the individual-value control chart. In the moving-range charts, the values are the difference between two consecutive points, in absolute values. When the difference between the points exceeds the control limits, the process potentially has special causes of variation affecting its quality. Moving-range charts express the variation existing within the sample at a given time point (Montgomery, 2009).

The combined use of moving-range and individual-value control charts is critical to monitor and understand the possible special causes of variation affecting the process to minimise this variation, leading to increased quality (Minitab, 2007).

Specification limits, also known as engineering limits, are parameters based on technical recommendations or agricultural criteria, which may provide higher quality and economic standards for any process. These parameters are reported in the literature or are common values for the quality indicators assessed (Table 2).

The specification control limits were established with the assistance of the operations managers (farm supervisor and manager) and other staff members (tractor driver, planter operator, and post-planting quality raters in each operating shift) by brainstorming so that the final operation quality value would be 90% from the viewpoint of this production unit. This value would be used to assess the capability of the daytime and night-time shifts of the mechanised sugarcane planting operation.

A unit value was established for all quality indicators assessed, and an individual value was also considered to perform this analysis, for both planting furrows. A total sample of 40 points and/or replicates was used for each evaluation furrow and shift. This number was chosen given the practical importance, in this planting system, of having high quality billets in both planting furrows (Table 4).

Conclusion

The combined use of run charts and control charts has become essential to monitor the mechanised planting process more stringently, leading to greater reliability in decision-making and thereby improving future operations. The operational quality of mechanised sugarcane planting is affected by daytime and night-time shifts and is lower during the night-time shift for all quality indicators, especially in the left furrow. The design of an improvement plan has become essential to the mechanised sugarcane planting operation when seeking to increase the operational quality and to reach the process goals of most quality indicators over time.

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