Australian Journal of Crop Science

AJCS

AJCS 7(9):1396-1406 (2013) ISSN:1835-2707

Quality of performance of the operation of sugarcane mechanized planting in day and night shifts

Murilo Aparecido Voltarelli, Rouverson Pereira da Silva, David Luciano Rosalen, Cristiano Zerbato and Marcelo Tufaile Cassia

[1]UNESP – Univ Estadual Paulista, Campus de Jaboticabal, SP, Department of Agricultural Engineering, Via de Acesso Prof. Paulo Donato Castellane, s/n, 14884-900, Brazil

***Corresponding author: voltarelli@posgrad.fcav.unesp.br**

Abstract

The sugarcane mechanized planting is becoming increasingly widespread in Brazil due to a higher operability and better working conditions offered to workers compared to other types of planting. Studies related to this topic are insufficient or scarce in Brazil. In this context, the aim of this study was to evaluate the operation quality of sugarcane mechanized planting in two operation shifts, by means of statistical process control. The mechanized planting was held on March 2012 and statistical design was completely randomized with two treatments, totaling 40 replications for the day shift and 40 replications for the night shift. The variables evaluated were: speed, engine rotation, engine oil pressure, water temperature of the engine, effective field capacity and the time consumption hourly and effective fuel. The use of statistical control charts showed that random intrinsic do not cause this process. The tractor alignment error showed outliers in the day and night shifts operations, indicating a possible delay in receiving the signal. The water temperature of the engine and the effective fuel consumption showed lower variability in nighttime operation with average values of 81ºC and 22.66 L ha^{-1}, respectively. The hourly fuel consumption had greater variability and consequently lower quality during the night of the operation, with an average consumption of 25.46 L h^{-1} while the day shift showed 26.86 L h^{-1}.

Keywords: Randomness; control charts; machine performance; *Saccharum* spp.; variability.

Abbreviations: GNSS - Global navigation satellite systems; FWA - Front wheel assist; Kc – Kurtosis coefficient; LCL - Lower control limit; M – Median; Mg – megagram; $\bar{X}$ - average; $\overline{MR}$ – moving range; AD – Anderson-Darling Normality Test (N: Normal distribution; S: Skew distribution); GPS – Global Positioning System; I-MR - Individual and moving range; RTK – Real time kinematic; Sc – Skewness coeficient; σ – Standard deviation; UCL - Upper control limit; UTM - Universal Transverse Mercator; VC – Coefficient of variation.

Introduction

The sugarcane mechanized planting system has proved to be a technique with increasing use in the expansion and renovation of sugarcane plantations, since the sugarcane is a commodity that has extreme importance in the global market of sugar, alcohol and bioelectricity (Chaddad, 2010). This system has a lower operating cost when compared to semi-mechanized planting. The mechanized planting system largely replaces the manpower used in the operation due to greater operability of the mechanized sets that can work for longer periods during the day and nighttime shifts (Khedkar and Kamble, 2008). Associated to such situation, investments in improvements of mechanized field operations in sugarcane planting in daytime and nighttime shifts tend to increase. On the other hand, information about mechanized operations is still insufficient in the sector. Further investigations can improve the management and the quality of the operation. Peloia et al. (2010) explained that the studies in machinery and agricultural mechanization in sugarcane culture are essential to increase the cultivation area, greater operability, as well as cost reduction. These processes are able to achieve a desired quality standard. In addition to the expansion of sugarcane mechanized planting, the use of statistical control in this agricultural operation may prove to be crucial, because it can show a vision of how the process is occurring, indicating possible faults and possible improvements to the operation, with the goal of increasing its quality. So, the management of the operation can be more effective. Recently some authors have used of statistical process control to the area of agricultural machines in order to show the variation in the process, using the variables evaluated as indicators of quality. In these studies, the tool typically used to identify non-random causes or special causes are control charts due to the instability of the process (Montgomery, 2004; Peloia et al., 2010; Cassia et al., 2013).

The performance of sugarcane mechanized planting is affected by performance of the operation shifts (daytime and nighttime). Therefore, this study aimed to evaluate the operational quality of the sugarcane planter set in two operation shifts, by checking the variability of quality indicators, using the tools of the statistical process control.

Results

Analysis of the descriptive statistics

The descriptive statistics (Table 1) shows that for the daytime shift operation the hourly and effective consumption of the fuel showed normal distribution according to the Anderson-Darling test. For daytime operation the variables average

Table 1. Descriptive statistics measure of central tendency (average - $\bar{X}$ and median - M), scatter (standard deviation – σ and coefficient of variation – CV (%)) and the distribution of the dataset being presented by the skewness and kurtosis coefficient for the variables evaluated in sugarcane mechanized planting in daytime shift operation. AD - Anderson-Darling normality test (N: normal distribution; S: Skew distribution).

Variables	$\bar{X}$	σ	M	Sc	Kc	CV	AD
Speed (km h^{-1})	5.30	0.06	5.40	-1.45	3.89	1.20	S
Engine rotation (rpm)	2162	19.01	2170	-1.84	4.21	0.88	S
Engine oil pressure (kPa)	375	11.54	370	0.22	-1.01	3.08	S
Engine water temperature (°C)	82.00	2.49	83.0	-0.53	-0.98	3.03	S
Tractor alignment error (cm)	4.88	9.6	3.00	5.66	34.10	197	S
Hourly consumption (L h^{-1})	26.86	3.89	26.7	1.18	3.39	15.0	N
Effective consumption (L ha^{-1})	23.18	3.46	23.0	1.18	3.14	14.0	N
Field effective capacity (ha h^{-1})	1.15	0.013	1.16	-1.45	3.89	1.20	S

Table 2. Descriptive statistics measure of central tendency (average - $\bar{X}$ and median - M), scatter (standard deviation - σ and coefficient of variation – CV (%)) and the distribution of the dataset being presented by the skewness and kurtosis coefficient for the variables evaluated in sugarcane mechanized planting in nigttime shift operation. AD - Anderson-Darling normality test (N: normal distribution; S: Skew distribution).

Variables	$\bar{X}$	σ	M	Sc	Kc	CV	AD
Speed (km h^{-1})	5.30	0.10	5.30	4.22	22.41	1.89	S
Engine rotation (rpm)	2160	16.80	2160	-0.84	1.07	0.78	S
Engine oil pressure (kPa)	373	14.85	380	-2.44	9.87	3.98	S
Engine water temperature (°C)	81.00	1.55	81.0	-0.48	-0.86	1.91	S
Tractor alignment error (cm)	4.80	14.00	0.20	5.38	29.26	297	S
Hourly consumption (L h^{-1})	25.46	3.65	25.0	-0.66	3.45	14.0	N
Effective consumption (L ha^{-1})	17.91	2.59	17.0	-0.58	3.49	15.0	N
Field effective capacity (ha h^{-1})	1.41	0.026	1.40	4.22	22.41	1.89	S

displacement speed, engine rotation and field effective operational showed negative skewness coefficient and positive kurtosis coefficient, characterizing more elongated distribution curves to the left with the data set grouping above the average and leptokurtic that have greater narrowing, in relation to the normal distribution curve, respectively. On the other hand the engine oil pressure showed positive skewness coefficient and negative kurtosis coefficient characterizing a more elongated distribution curve to the right and flatter (platicurtic). On the other hand, the water temperature of the engine showed more elongated distribution to the left and flatter, in relation to the normal distribution curve, although showed low standard deviations and coefficients of variation. Now, for the variables that are asymmetric by the Anderson-Darling test (alignment error of the tractor, hourly and operational fuel consumption), there is an average greater than the median and a more elongated distribution curve to the right. This means that data are more concentrated below the average, moving away from it and can be verified by the positive skewness and kurtosis coefficients. It may be more evidenced to alignment error of the tractor variable as it has the same high standard deviation and coefficient of variation. The variables like engine rotation, engine oil pressure, and hourly and operational fuel consumption during nighttime operation (Table 2) showed the average lower than the median, indicating that data sets are located above the average, while water temperature of the engine presented data set below the average and may be evidenced by a negative skewness coefficient. The variables such as speed, alignment error of the tractor and field effective capacity showed high skewness and kurtosis coefficients compared to the other variables, although the variables speed and field effective capacity had low standard deviations and coefficients of variation.

Analysis of the operation quality

Indicators of quality of the machine - Tractor

For the displacement speed (Fig. 1a and 1b), daytime and nighttime operations showed points outside the control limits, indicating the occurrence of special causes for individual values and for the process variation (moving range charts). The average forward speed of 5.3 km h^{-1} during daytime and nighttime operations with the concentration of dots revealed by sequential graphical analysis showed mixture patterns and tendency for daytime and tendency for nighttime. The low values of standard deviation resulted in reduced (UCL and LCL); however, for nighttime operation these limits were more distant from the average due to higher speed value caused by the out of control point. In daytime operations, the presence of one point out of control (observation nº 8) led to the instability of the process and variation of it, since the ranges were higher (observations nº 7 and 8), exceeding UCL. This instability can be explained by the fact that the planting operation has started at the head of a contour line, which may have suffered higher soil compaction due to increased traffic by machinery for the same construction and greater number of maneuvers. This causes increasing the power demand of tractor-planter to find higher ground resistance of planter furrow openers. In the nighttime shift, the verification of the unstable process occurred through the existence of one point out of control (observation nº 53), that resulted in higher moving range between the points 52-53 and 53-54. This results in more instability and greater variability, as evidenced in the process variation chart. For the quality indicator of engine rotation in daytime operation, the results showed high variability (Fig. 2a and 2b), occurring in non-random causes, which observed at points outside the control limits (observations nº 8 and 26). This reflects a moving range chart (observations nº 8 and 27). This situation may be

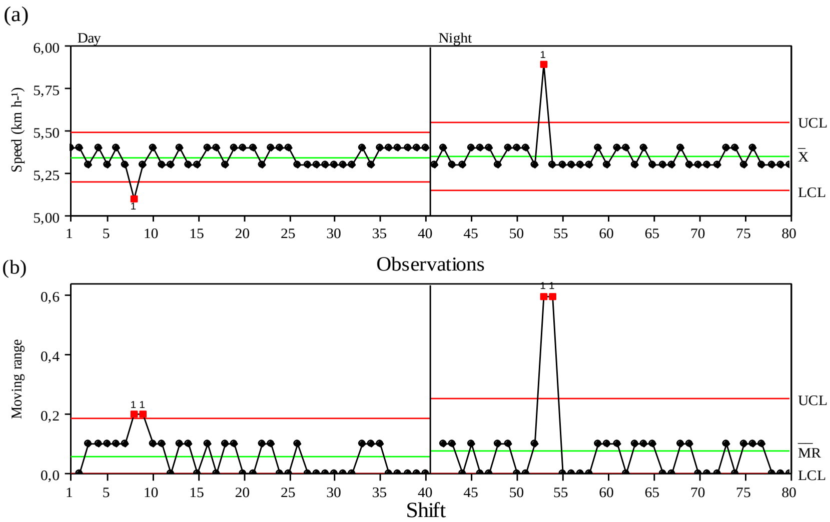

Fig 1. Control charts for quality indicator displacement speed mechanized set tractor planter in planting sugarcane in day and night shifts to operation. (a) Charter of individual values for process monitoring. (b) Charter moving range for monitoring process variability. The limits calculated based: for Upper Control Limit (UCL) mean (μ) plus three times the standard deviation (3σ), and to Lower Control Limit (LCL), average less three times the standard deviation (3σ), when higher than zero. $\bar{x}$: average of individual values. $\overline{MR}$: average of individual moving range (successor less previous observation).

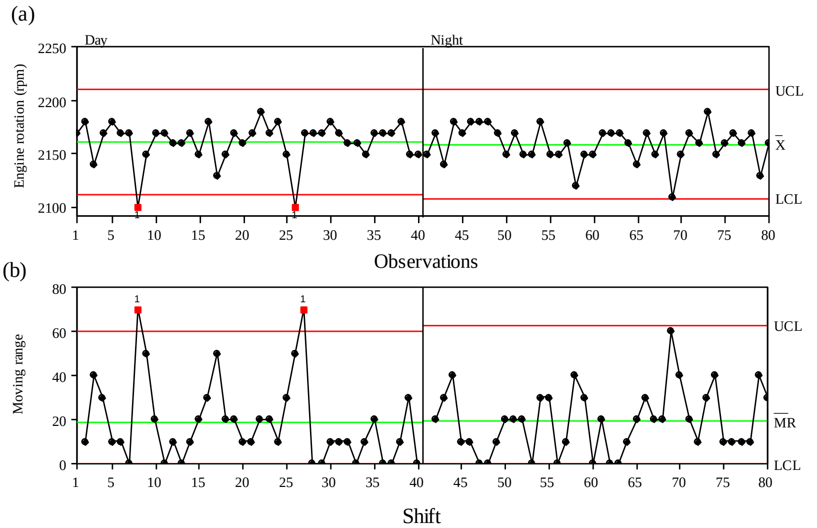

Fig 2. Control charts for quality indicator engine rotation of the tractor to traction the planter sugarcane in day and night shifts to operation. (a) Charter of individual values for process monitoring. (b) Charter moving range for monitoring process variability. The limits calculated based: for Upper Control Limit (UCL) mean (μ) plus three times the standard deviation (3σ), and to Lower Control Limit (LCL), average less three times the standard deviation (3σ), when higher than zero. $\bar{x}$: average of individual values. $\overline{MR}$: average of individual moving range (successor less previous observation).

attributed to the control chart of displacement speed for daytime operation, because in the same period (observation nº 8) there was a reduction of speed that can be associated to the drop of the engine rotation. This indicates that the set tractor-planter actually found more resistance, of the soil at this sampling location, causing it to increase the power demand. Moreover, the next point out of control of the process can be attributed to the resistance of the soil and to the ratoon filling in the planter at the time of planting, but was overcome by the set power, with sharp drop only in the engine rotation. At nighttime operation, the process was stable; the points collected were considered 100% representative of the operation quality, despite the high variability demonstrated in the process variation chart (moving range). This suggested a high value of the standard deviation that reflects in the control limits, distant from the average. For the quality indicator engine oil pressure (Fig. 3a), daytime operation presents grouping patterns and tendency, indicating instability due to the process, which was confirmed by the presence of a point exceeding the UCL in the charts of individual values (observation nº 38) and the process variation charts (observation nº32) (Fig. 3b). This instability can be explained by the fact that the oil filter (filter microscope) cannot filter the whole amount of oil sent by the injection pump or by the fact that the pressure regulating valve of the oil have stopped at the closed position longer than necessary, causing an increase in the pressure. The nighttime operation, despite a higher value of the standard deviation, also showed instability of the process, due to the occurrence of a point out of control with low pressure value (observation nº 69), resulting in two points out of control in the range moving chart (observation nº 69 and 70). The water temperature of the engine (Fig. 4) during the daytime shift showed larger standard deviation than in nighttime operation, which can be evidenced by upper and lower control charts of individual values (Fig. 4a). The process variability was also greater in the moving range chart (Fig. 4b). For daytime operation the individual values chart indicates the grouping pattern for the engine water temperature due to the number of successive observations, which form groups of points in certain areas of the control chart. For the night shift, the grouping pattern and tendency of values can be observed. This quality indicator presented special extrinsic led to the process during the day and nighttime. The variable alignment error of the tractor (Fig. 5a) in daytime and nighttime operation had most of the points around the average; however, the occurrence of grouping and trends of these pattern values were identified, respectively. These indicate the presence of non-random variation in the process. The daytime and nighttime operation shifts showed a single point out of control (observation nº 14 and 64, respectively), reflecting points above the UCL in the moving range charts (observations nº 14 and 15, 64 and 65, respectively) (Fig. 5b). The occurred non-randomness can be justified by these points outside the control limits being considered atypical or discrepant points also known as "outliers". These "outliers" are unusual points that appear distant away from the other observations from the average that could be above or below it. They may be potentially considered as values that do not represent the true behavior of the data set, but have occurred in the process and should be investigated. Considering the "six sigma" factors, the occurrence of these outlier values may be related, possibly due to the measurement and the method used to collect the data. It may have been occurred by delay in receiving the signal by the automatic self-direction system. As this could be attributed to the method used for assessment of this quality indicator, the analyzed value may not correspond to the sampled point.

Quality indicators of the performance of mechanized set - tractor-planter

The field effective capacity was considered to be unstable for the two operation shifts, because it showed the occurrence of trend and mixture for daytime and trend for the nighttime shift, as evidenced by points outside the control limits. The greatest variability was observed in the nighttime operation, once the control limits are furthest from the average and can be evidenced by the variation process charts, although individual values are distributed close to the mean (Fig. 6a and 6b). The quality indicator hourly fuel consumption (Fig. 7a) showed the control limits (UCL and LCL) away from the average (individual value charts), indicating high variability of the process. This was also observed in the moving range charts (process variation) (Fig. 7b). The process was considered unstable as for daytime as for nighttime shift (observations nº 32 and 46, respectively). The occurrence of points outside the control limits indicates the presence of special causes during the operation. The process of instability observed during the day can be explained by the time of transshipment loads of ratoons to the planter. It may have been subjected to a larger load than the tolerable, resulting in higher hourly fuel consumption until the engine rotation was stabilized and the operation returned to the normal. Moreover, nighttime operation showed a point below the LCL, which can possibly be explained by the lower number of billets within the planter, resulting in smaller traction force by the mechanical set and; hence, in a lower hourly fuel consumption. The effective fuel consumption showed similar behavior to the hourly consumption which can be verified by individual value and mobile range charts (Fig. 8a and 8b), respectively. The daytime operation presented a point above the UCL, which may possibly be associated with lower effective performance of the mechanized set being influenced by the minimum value of the displacement speed and/or by the higher hourly fuel consumption. For the nighttime, there was also a point outside the control limits, whose explanation can be the opposite of the previous.

Discussion

The statistical control process is commonly and widely used in the industrial area, verifying defects and quality production of items are being manufactured through of control charts (Chakraborti, 2006; Montgomery, 2004; Ross and Adams, 2012). Application of this philosophy to the agricultural area is new, particularly when it comes to assessing the degree, to which the quality of mechanized agricultural operations are being carried out by monitoring the real-time data (telemetry) of machines and/or mechanized sets. According to Bakir (2012), control charts are essential for the verification of non-random behavior of the process. Jensen et al. (2006) also commented that they are ideal to monitor the variability of the output items in the procedure. Montgomery (2004) described that the main advantage of using statistical process control such as sequential and Shewhart control charts is to improve or maintain the quality of the process through the stability analysis, which is performed by cyclical patterns and individual values, respectively. There are several tasks in control charts such as the presence of special causes of process variability. When the variability raised some analysis and interpretation must be carried out to identify the reasons and situation of instability and eventually eliminate such external influence. So that, the operation meets the quality standards required. Vermatt et al. (2003); Peloia et al. (2010) and Cassia et al. (2013) reported that control charts are essential for checking the quality of mechanized agricultural operations, because check high variation factors extrinsic to the process which diminish the quality.

Analysis of the descriptive statistics

According to Mudholkar and Natarajan (2002), the analysis of data set distribution and variability is interesting to assess the parameters. Montgomery (2004) reported that the normal probability distribution is no longer required for the construction of the charts of statistical process control, as there are situations, where the non-normality does not portray high deviations from a normal distribution. However, this can only be considered when the number of repetition sample is large, but in these cases the normal distribution is not always achieved. It is also observed that the study of the parameters of descriptive statistics serves to give an overview of the behavior of the data sets from a given distribution and especially the variability (Léon et al. 2005). It also can predict what is occurring during certain processes or operations (Kim and White, 2004). For further explanation of the behavior of the data set and its interpretation by the distribution, curves can be found by querying (Bai, 2003).
Bai and Ng (2005) reported an association between the coefficients of skewness and kurtosis to predict the behavior of the data being monitored over time, and can infer the variability in a given sample and parameters.

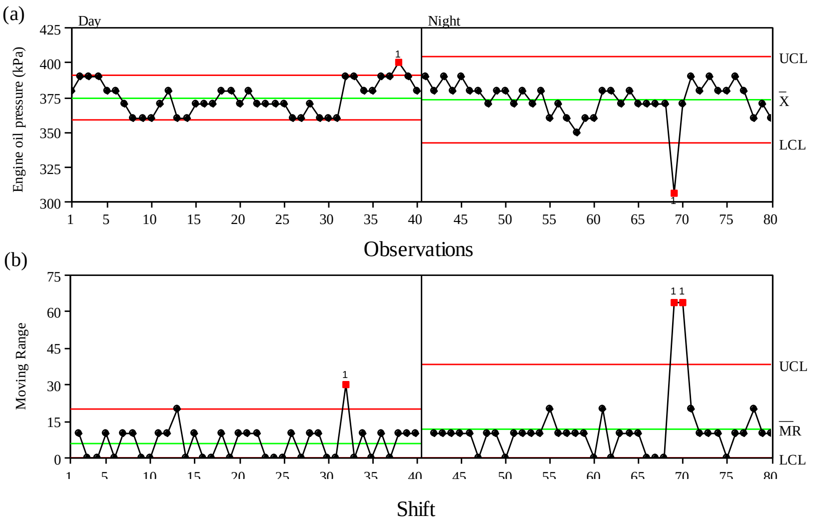

Fig 3. Control charts for quality indicator engine oil pressure the tractor to traction the planter sugarcane in shifts day and night operation. (a) Charter of individual values for process monitoring. (b) Charter moving range for monitoring process variability. The limits calculated based: for Upper Control Limit (UCL) mean (μ) plus three times the standard deviation (3σ), and to Lower Control Limit (LCL), average less three times the standard deviation (3σ), when higher than zero. $\bar{x}$: average of individual values. $\overline{MR}$: average of individual moving range (successor less previous observation).

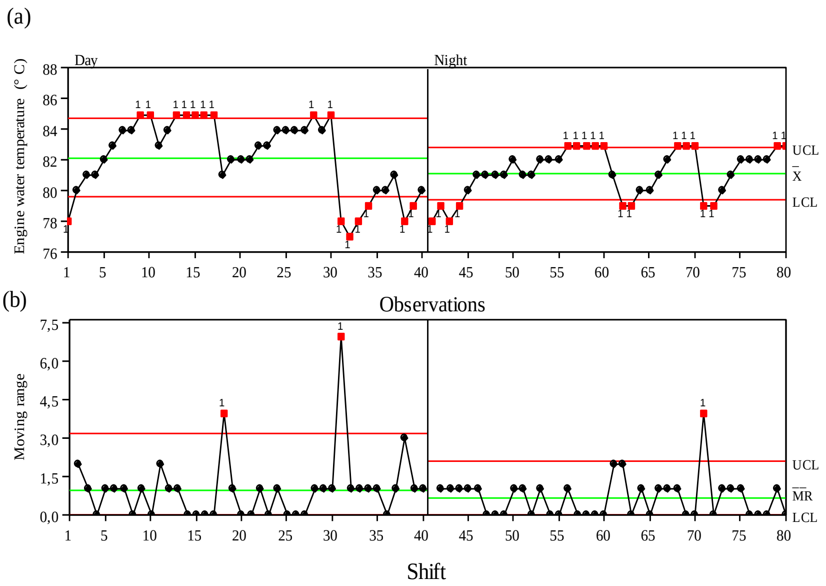

Fig 4. Control charts for indicator quality engine water temperature the tractor to traction the planter sugarcane in day and night shifts operation. (a) Charter of individual values for process monitoring. (b) Charter moving range for monitoring process variability. The limits calculated based: for Upper Control Limit (UCL) mean (μ) plus three times the standard deviation (3σ), and to Lower Control Limit (LCL), average less three times the standard deviation (3σ), when higher than zero. $\bar{x}$: average of individual values. $\overline{MR}$: average of individual moving range (successor less previous observation).

Indicators of quality of the machine - Tractor

For quality indicator displacement speed, the possible explanation for these instabilities can be given by the plot slope at this point, where the machine had a speed gain extrapolating the UCL. Although the process is considered unstable according to the perspective of the statistical process control, it has 97.5% of the points under control, as for daytime as for nighttime operation, showing that the operation of sugarcane mechanized planting depends on this variable and can still obtain high quality. In contrast to this situation, Yadav et al. (2004) reported that the sugarcane planter set had a work speed ranging from 1.77 to 3.27 km h^{-1}.

It decreases the field operational capacity of the mechanized set when compared to this study. The main reason is the tractor used for this operation did not have high engine power with 4x2 traction with the rear axles (Patil et al. 2004; Singh et al. 2011). Moreover, Vishwanathan et al. (2005) and Kichler et al. 2007 reported that the speed of displacement of mechanized set collected in real-time using sensors that are monitored and controlled by computer have small margins of error and can portray the real condition of field. Moreover, it must be observed that the variation in engine rotation between 2100 and 2200 rpm, with an average of 2150 rpm, was maintained very close to

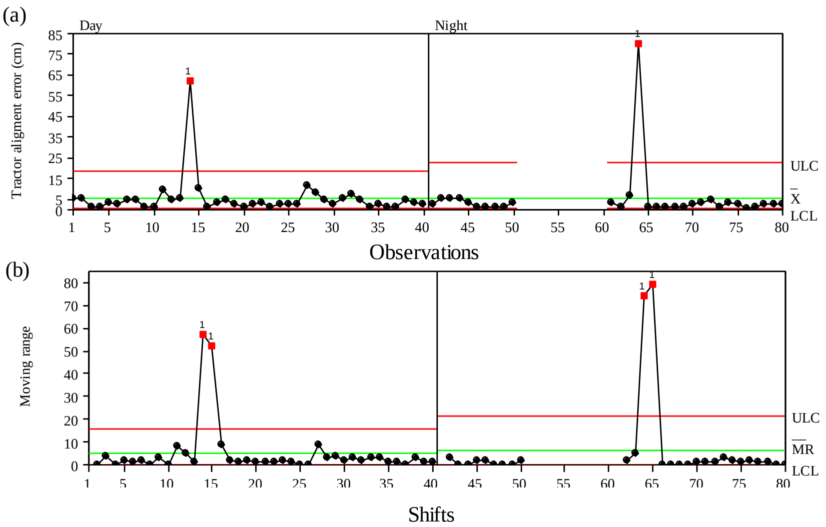

Fig 5. Control charts for quality indicator tractor alignment error to traction the planter sugarcane in shifts day and night operation. (a) Charter of individual values for process monitoring. (b) Charter moving range for monitoring process variability. The limits calculated based: for Upper Control Limit (UCL) mean (μ) plus three times the standard deviation (3σ), and to Lower Control Limit (LCL), average less three times the standard deviation (3σ), when higher than zero. $\bar{x}$: average of individual values. $\overline{MR}$: average of individual moving range (successor less previous observation).

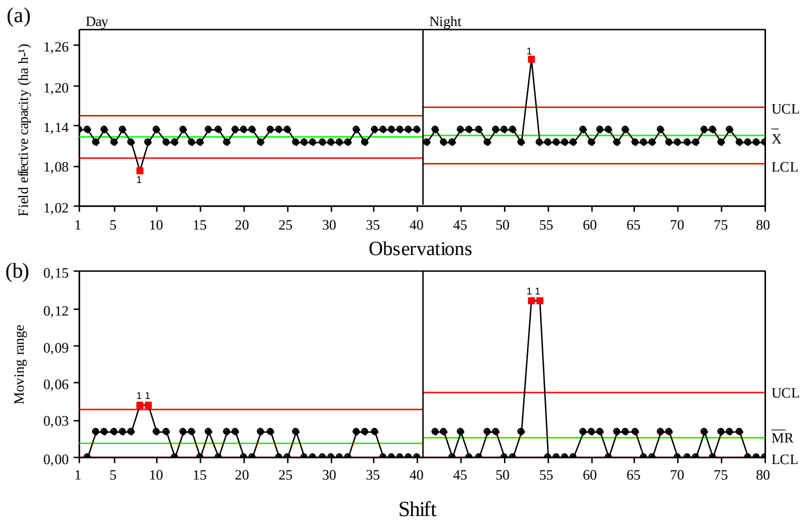

Fig 6. Control charts for quality indicator effective field capacity of all mechanized tractor–planter sugarcane in shifts day and night operation. (a) Charter of individual values for process monitoring. (b) Charter moving range for monitoring process variability. The limits calculated based: for Upper Control Limit (UCL) mean (μ) plus three times the standard deviation (3σ), and to Lower Control Limit (LCL), average less three times the standard deviation (3σ), when higher than zero. $\bar{x}$: average of individual values. $\overline{MR}$: average of individual moving range (successor less previous observation).

the point of rotation of the tractor's maximum power (2200 rpm). At this point, it has the highest hourly fuel consumption and the lowest torque. However, in this situation the planter demands higher power to be tensioned and; thereby, the planter set works close to the ideal operating conditions of the engine. Kim et al. (2011) reported that when the tractors are on their maximum engine speeds, fuel consumption is high and tractor it is working with all its available power. Similar results were found by Ali et al. (1996) studying the characteristic curve of a Cummins engine, due to the variation of engine speed with different proportions of diesel. Rípoli and Rípoli (2010) studied the performance of operation mechanized planting sugarcane in Brazil. Special causes found for the oil pressure of the engine, which may be explained by several reasons such as the large opening time of the pressure regulating valve, preventing the pump to direct the oil flow to the engine, i.e., most of the oil returns to the sump; low oil level in the sump, return tube clogged due to excessive contamination; air intake in the system or even leaking in the injector nozzle that could decrease the viscosity of the oil. Schumacher et al. (1991) explained the importance of preventive maintenance performed on oil filters, hoses and motor tractors; thus, helping to reduce the variations in the pressure of the oil, making it a better engine lubrication. Karra and Fernando (2005) reported that the monitoring of oil pressure as well as temperature are essential parameters for quality lubricant which can directly affect its viscosity. For quality indicator such as water temperature of the engine, these special causes could be explained due to the occurren-ce of one or more of the "six sigma" factors

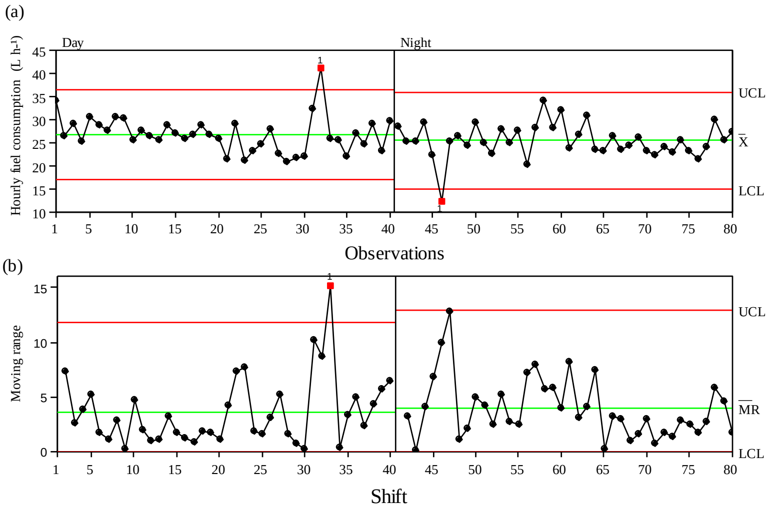

Fig 7. Control charts for quality indicator hourly consumption of fuel of all mechanized tractor–planter sugarcane in shifts day and night operation. (a) Charter of individual values for process monitoring. (b) Charter moving range for monitoring process variability. The limits calculated based: for Upper Control Limit (UCL) mean (μ) plus three times the standard deviation (3σ), and to Lower Control Limit (LCL), average less three times the standard deviation (3σ), when higher than zero. $\bar{x}$: average of individual values. $\overline{MR}$: average of individual moving range (successor less previous observation).

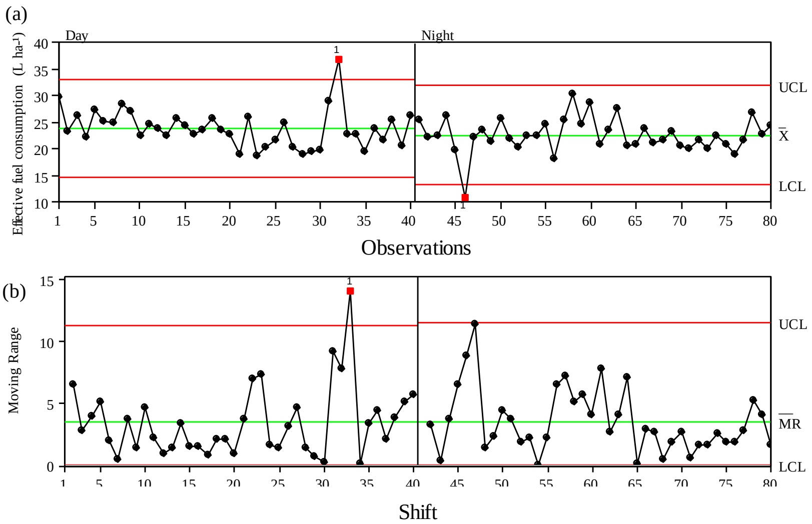

Fig 8. Control charts for the quality indicator of effective fuel consumption of all mechanized tractor–planter sugarcane in in shifts day and night operation. (a) Charter of individual values for process monitoring. (b) Charter moving range for monitoring process variability. The limits calculated based: for Upper Control Limit (UCL) mean (μ) plus three times the standard deviation (3σ), and to Lower Control Limit (LCL), average less three times the standard deviation (3σ), when higher than zero. $\bar{x}$: average of individual values. $\overline{MR}$: average of individual moving range (successor less previous observation).

(material, manpower, method, machine, measurement and environment), but for this situation in specific, points out of the control limits (top and bottom) may indicate the perfect functioning of the cooling system of the engine, because the thermostatic valve opens when the engine temperature is between 85 and 94°C causing the water to go through all the cooling system, making heat dissipation. So, the temperature decrease prevents the damage to the machine operation as explained by Pripps (2004). Bennett (2009) studied diesel engines and found values of temperature water of the engine close to the present study. In the individual values charts it can be observed that temperature increase leads to the opening of the thermostatic valve, and after this opening, the engine cooling is successfully performed promoting temperature drop. Moving range charts also had points outside the control limits that can be justified by the sharp drop of the engine temperature, being the greatest variability found during daytime operation, when the thermostatic valve opened, causing larger variations in the range values. In this context, Grisso et al. 2008 studied different tractors with different powers in different conditions of use of the engine power, and reported that when operating tractor is in its largest range of engine speed and independent power, the average temperature cooling will not exceed 88ºC. This was also confirmed by Shim et al., 2012. The tractor alignment error in nighttime operation showed faults in the reception of the signal (observations n° 49 to 60) which is sent by satellite and received on the mobile antenna (rover) located in the machine. This will be indicated in the individual value and moving range charts by the lack of observation sequence. It is noteworthy that the signal loss can generate possible alignment errors. Thus, represents gross errors in the sugarcane row spacing and, consequently, these errors can jeopardize all other mechanized operations in the crop cycle, particularly harvesting. Despite the loss of signal occurred, the operation during nighttime showed greater variability compared to daytime (process variation chart), a fact that may indicate there is frequent oscillation of the signal received by the mobile antenna during the planting operation in this shift. Baio (2012) suggested that operation quality to be the highest in mechanized sugarcane, using the pilot automatic operation of planting, in which the errors are the smallest as possible. On the other hand, the use of autopilot in agricultural operations to decrease the alignment of the operation is always an interesting topic of study by various researchers, which is not always possible to achieve a maximum accuracy and can cause quality loss in future operations at any stage of any crop cycle (Heraud and Lange 2009). When the autopilot was used in the right and more efficiently way it can bring significant reductions in costs production according the report done by (Batte and Ehsani, 2006). Despite showing average displacement speed of 5.34 and 5.35 km h^{-1} and hourly fuel consumption of 26.86 and 25.46 L h^{-1}, in the daytime and nighttime operation shifts, respectively, the present results differ from those observed by Rípoli and Rípoli (2010). They reported that the average hourly fuel consumption in the operation of sugarcane mechanized planting is approximately 37.80 and 39.60 L h^{-1} for the planters PCP2 and 5000, respectively, when tractors is operating at a speed of approximately 5.0 km h^{-1}. This difference is probably due to the fact that, in that study the authors used tractors with higher engine power of 162 kW, compared to the one used in this experiment. The hourly fuel consumption may vary depending on the number of billets to be deposited inside the planter, because conditions with higher charge can increase fuel consumption of the operation, which is variable with the desired planting density (Matsuoka 2006) when studying the cycle of mechanization in the cultivation of sugarcane. The hourly fuel consumption is high when the tractor does work at high rotation of the engine, either a greater or lesser load and/or with greater or lesser power to the motor (Grisso et al., 2004; Grisso et al., 2008). This prediction becomes very important, because it might reflect production costs and to infer the classification of tractors for each operation accordingly (Gil-Sierra et al., 2007; Shim et al., 2012).

Quality indicators of the performance of mechanized set - tractor-planter

The possible explanation for the points out of control, which resulted unstable characterization of process in the presence of special causes, may be associated to the average displacement speed of the planter set, when the out of control points outside the control limits in our chart are the same in the control chart for the variable displacement speed. Also, most of the factors that constitute the six sigma (material, machine, environment, measurement, method and manpower) could somehow influence the operability of the mechanized set. This situation during the day and night, indicates the effective field capacity of the mechanized set is similar, which may suggest that despite high variations exist throughout the operation of mechanized planting of sugar cane, these did not affect negatively the process as a whole. Kumar and Singh (2012) reported that the machine effective field capacity in sugarcane mechanized planting is only 0.38 ha^{-1} with working speed of 1.8 to 2.5 km h^{-1}. This is a value very lower than the displacement speed of the mechanized set used in this study. However, in this study we used a tractor with 41 kW to pull the planter. On the other hand, results found in this study was confirmed by Ripoli and Ripoli (2007) when evaluating the effective field capacity of five planter of sugarcane in Brazil. They obtained values from 1.54 to 1.64 ha h^{-1}. Moreover, analyzing the process variation charts showed that there is less variability in the daytime operation values due to the effective consumption presents a more homogeneous distribution throughout the operation. The average effective fuel consumption was lower during the nighttime because the planter set showed higher operability when compared to the operation performed during daytime. Ripoli and Ripoli (2007) found values of effective consumption of fuel for mechanized planting of sugarcane very close to the present work, using tractors with power of 136 kw, and this being essential for the performance evaluation of operation of mechanized planting of sugar cane, because it can reflect the improvement in production costs through a proper management (Yadav et al. 2003).

Material and methods

Plant materials and experimental conditions

The experiment was conducted in the municipality of Monte Alto - SP, Brazil, near the geodetic coordinates: Latitude 21°16'42"S and Longitude 48º24'21"O, with an average elevation of 620 meters, an average slope of 6% and Aw climate according to Köeppen classification. The geo-referencing of the area was made with the assistance of a GNSS receiver, Trimble brand, model R6 (centi millimetric positional accuracy) and the coordinates were registered in the UTM (Universal Transverse Mercartor) Cartesian system. The variety used in the operation of mechanized planting of sugarcane was the RB83-5453, developed by Brazilian Universities Network (RIDESA), possessing characteristics such as drought tolerance, early maturity and good productivity. The planting density was 15 gems m^{-1}, featuring an average consumption around 23 Mg ha^{-1} for the two shift operation.

Treatments

The experimental design was completely randomized with two treatments according to the afternoon shift operation delimited from 3:00 to 11:00 pm. This time was chosen to allow assessment of the operation of mechanized planting of the cane-sugar during the daytime (3:30 to 05:30 pm) and night (07:30 to 09:30 pm) without need to change operator; thus, providing better control of the experiment. For this experiment, two mesh samples were established with pre-set 40 replications, with spacing of 50 x 1.5 m apart, with 40 replications for evaluations during the day shift (1- 40) and 40 replications during the night (41 - 80).

Tractor performance

The performance evaluations of the planter set consisted of: displacement speed, engine rotation, engine oil pressure, engine water temperature, and the hourly fuel consumption being all variables collected through the front column monitor (Command Center TM) installed inside the tractor's cabin. The alignment error of the tractor was collected in real time in onboard computer Fmx® Integrated Display. The field effective capacity was calculated according to the methodology described by Liljedahl et al. (1989) and the effective consumption was calculated according to the methodology described by Srivastava et al., (1993).

Soil Condition

Prior to the sugarcane mechanized planting, the area was cultivated with soybean and after harvesting, the sugarcane mechanized planting operation was carried out. The soil periodical preparation (used a harrowing average disc and another leveling) was done before the soybean planting, after sub-soiling at a depth of 0.50 m. The characterization of the amount of straw left by the soybean crop was obtained by collecting ten random points in the area, resulting in 938.03 kg ha^{-1} of dry mass. Ten samples were taken from the soil (0 - 0.20 m) to determine the texture class, giving as result 78% sand, 6% silt and 16% clay and were; therefore, classified as medium texture according to the methodology proposed by Benton (2001). The adjustment of the furrow depth was carried out at 0.30 m, as stipulated by the company. To detect the location, where it was compacted soil was used penetrometer PNT Titan Automation Industrial Ltda, built according to standard ASAE S313.3 (ASABE, 2006). It had a storage capacity of 2048 samples geo-referenced, cell load of 1500 N for measuring the force of penetration resistance, electric motor current continues voltage with 12 V and 24 W of power supplied by the electrical system of the quad bike, which triggers a system and reduction helical thread, to which the load cell is attached to this rod. The equipment had a capacitive-inductive sensor for measuring the depth and acquires data up to 0.55 m deep with penetration speed of 3 cm s-1 and acquisition frequency of 3 Hz. The layer of higher resistance to this soil penetration was in a depth of 0.10 to 0.20 m (3.14 MPa). The characterization of the soil water content was realized by collecting 160 samples, 80 for each period of operation in layers of 0 – 0.15 and 0.15 - 0.30 m according to the methodology recommended by Buol et al. (2011). During daytime and nighttime, soil water content in the layer 0 - 0.15 m was 7.0 and 8.5% and in the depth 0.15 – 0.30 m was 6.5 and 9.0%, respectively.

Tractor and planter characteristics

The sugarcane mechanized planting was carried out in March of 2012 by a planter set, composed of a 4 x 2 FWA tractor, with engine power of 136.0 kW at 2200 rpm, 6 cylinders, with 17:1 compression ratio, front 600/65R28 and rear 710/70R38 wheeling, both R1W, and a chopped sugarcane planter of 2 row with capacity of six tons of seedlings for planting, fertilizer box of 1.300 kg, having a width of 3.60 meters, wheeling 600/50 22.5, with shanks spaced 1.50 m. The tractor operated with the gauge adjusted to 2.70 m and in a working march 1B. During the planting operation there was an application of 400 kg ha^{-1} of fertilizer and 100 L ha^{-1} spray of the insecticide imidacloprid. The set was equipped with an automatic steering hydraulic system of the planting alignment (automatic pilot), composed of onboard computer model Fmx®, GPS receiver model AgGPS (both Trimble), and other accessories. This system uses the kinematic positioning method for real-time (Real Time Kinematic - RTK) with communication rover-based via radio signal reaching horizontal positioning quality around 0.025 m.

Statistical analysis

The general demonstration of the data behavior was made from the descriptive statistical analysis, calculating central tendency measures (average and median), dispersion measures (range, standard deviation and coefficient of variation) and skewness and kurtosis measures. The verification of the normality of the data was conducted by Anderson-Darling test being a measure of closeness of the points and the line estimated in the probability, giving greater stiffness to the analysis (Acock, 2008). All variables were used to construct the control charts, regardless of the normality assumption (Somerville and Montgomery, 1996).

To verify the existence of non-random causes resulting from the process, the standard values of sequential graphics was used as a tool (Hill and Schvaneveldt, 2011). These standard values allow monitoring the process and the identification of the variation type, to which it is subjected throughout time, and may be constituted of grouping, tendency, mixture and oscillation. The verification of the data randomness was realized through the test of 5% probability. If the p-value for the patterns is below 0.05 the null hypothesis of non-randomness is rejected, in favor of the alternative for the standard test. If the p-value is not lower than 0.05 to any of the patterns tested, the data set will only be under the action of random causes. The grouping is represented by groups of points on a chart area that may indicate non-randomness of variation. Tendency represents a sequence of successive increases or decreases in the detected observations when the number of useful observations is successive, increasing or decreasing are higher than seven. The occurrence of trends in a process may warn that it is close to run out of control. It is about a pattern which indicates the absence of points near the centerline. It means the points that are alternated above and below the centerline, showing the existence of two distinct groups of data and lastly oscillation, indicating that a regular pattern is occurring over time and oscillations are detected when the data quickly float above or below the centerline. The analysis of the graphics sequences should be performed in conjunction with control charts for individual values and moving range, to gain greater control and detection of nonconforming items during the assessment of a particular characteristic of the process.

Results were also evaluated by means of statistical process control, using the control chart type I-MR (individual values), which have centerlines (general average) as well as the upper and lower control limits, defined as UCL and LCL. They calculated based on the standard deviation of the variables [for UCL, mean plus three times the standard deviation (eq. 1), and to LCL (eq. 2), average less three times the standard deviation, when higher than zero].

$$UCL = \mu + 3\sigma \quad (1)$$

$$LCL = \mu - 3\sigma \quad (2)$$

Where;

UCL: upper control limits;
LCL: lower control limits;
μ: average general;
σ: standard deviation.
On the other hand, the average moving range (eq. 4) and the upper (eq. 3) and lower (eq. 5) control of these charts were calculated according to:

$$UCL = D_4 \overline{\text{M}}\text{R} \quad (3)$$

$$\overline{\text{M}}\text{R} = \frac{|X_i - X_{i-1}|}{\text{N}} \quad (4)$$

$$LCL = D_3 \overline{\text{M}}\text{R} \quad (5)$$

In which:
UCL: upper control limits;
LCL: lower control limits;
$\overline{MR}$: average moving range;
N: number of observations;
X_i: individual value;
D_3 and D_4: standardized value for the total number of samples that make up (Montgomery, 2004).
These charts were used to identify the non-randomness, caused by some external factor due to the process and as well as evaluate the quality of the operation, using as quality indicators variables previously described (Chakraborti, 2006; Montgomery, 2004).

Conclusions

The operation quality of the sugarcane mechanized planting is stable only for the indicator engine speed during nighttime operation (representing 100% the quality of operation). The displacement speed (mean 5.30 km h^{-1}), engine speed (mean 2610 rpm), engine oil pressure (mean 373 kPa), tractor alignment error (mean 4.80 cm), field effective capacity (means 1.41) and the hourly fuel consumption (mean 25.46 L h^{-1}) showed higher variability during nighttime operation. The engine water temperature (mean 81ºC) and the effective fuel consumption (mean 26.22 L ha^{-1}) showed higher variability during daytime operation and; thus, had lower quality (representing 97.5 and 40% the quality of operation, respectively). The combined use of standard values of sequential graphics and control charts showed efficacy in the detection of special extrinsic causes to the process.

Acknowledgements

The authors thank the National Council for Scientific and Technological Development and Coordination of Improvement of Higher Education Personnel, by grants granted to authors.

References

Acock AC (2008) Descriptive statistics and graphs for one variable. In: Acock AC (ed) A gentle introduction to stata. 1rd edn. Stata Corp. Texas, pp 83-107.
Ali Y, Hanna MA, Borg JE (1996) Effect of alternative diesel Fuels on heat release curves for Cummins N14-410 diesel engine. T ASAE 39(2): 407-414.
Asabe. S313.3 Soil Cone Penetrometer (2006). In: Standars engineering practices data. ASABE American Society of Agricultural and Biological Engineers. ASABE, St. Joseph, p. 903-904.
Bai J (2003) Testing parametric conditional distributions of dynamic models. Rev Econ Stat 85(3):531–549.
Bai J, Ng S (2005) Tests for skewness, kurtosis, and normality for time series data. J Bus Econ Stat 23:49-60.
Baio FHR (2012) Evaluation of an auto-guidance system operating on a sugarcane harvester. Precis Agric 13(1):141-147.
Bakir ST (2012) A Nonparametric shewhart-type quality control chart for monitoring broad changes in a process distribution. Int J Qual Stat Reliab 2012:1-10.
Batte MT, Ehsani MR (2006) The economics of precision guidance with auto-boom control for farmer-owned agricultural sprayers. Comput Electron Agr 53:28-44.
Bennett S (2009) Engine cooling systems. In: Bennett et al. (eds) Modern diesel technology: diesel engines. Cengage Learning, Nova York, pp 139-163.
Buol SW, Southard RJ, Graham RC, McDaniel PA (2011) Morphology and compositions of soils. In: Buol SW, Southard RJ, Graham RC, McDaniel PA (eds) Soil genesis and classification. 6rd edn. Wiley-Blackwell, Oxford, pp 35-88.
Cassia MT, Silva RP, Chioderolli, CA, Noronha RRF, Santos ED (2013) Quality of mechanized coffee harvesting in circular planting system. Cienc Rural 43(1):28-34.
Chaddad FR (2010) UNICA: Challenges to deliver sustainability in the brazilian sugarcane industry. Int Food Agribuss Manage Rev 13: 173-192.
Chakraborti S (2006) Parameter estimation and design considerations in prospective applications of the X chart. J Appl Stat 33(4):439–459.
Gil-Sierra J, Ortiz-Cañavate J, Gil-Quirós V, Casanova-Kindelán J (2007) Energy efficiency in agricultural tractors: a methodology for their classification. Appl Eng Agric 23(2):145-150.
Grisso RD, Kocher MF, Vaughan, DH (2004) Predicting tractor fuel consumption. Appl Eng Agric 20(5):553-561.
Grisso RD, Vaughan DH, Roberson GT (2008) Fuel prediction for specific tractor models. Appl Eng Agric 24(4):423-428.
Heraud JA, Lange AF (2009) Automatic vehicle guidance from horses to GPS: how we got here, and where we are going. Paper presented at the Agricultural Equipment Technology Conference, Louisville, Kentucky, 9-12 February 2009.
Hill SE, Schvaneveldt SJ (2011) Using statistical process control charts to identify the steroids era in major league baseball: An educational exercise. J Stat Educ 19(1):1-19.
Jensen WA, Jones-Farmer LA, Champ CW, Woodall, WH (2006) Effects of parameter estimation on control chart properties: a literature review. J Qual Technol 38(4):349–364.
Jones JB (2001) Soils Analysis. In: Jones JB (ed) Laboratory guide for conducting soil tests and plants analysis, 1rd edn. CRC Press LCL, Florida, pp 11-160.
Karra P, Fernando S (2005) Soyben oil based four-stroke engine crankcase lubricants. Paper presented at the ASAE Annual International Meeting, Tampa Convention Center, Florida, 17 – 20 July 2005.
Khedkar MB, Kamble AK (2008) Evaluation of mechanized planting of sugarcane. Int J Agric Eng 1(2): 136–139.
Kichler CM, Fulton JP, Raper RL, Zech WC, McDonad TP, Brodbeck CJ (2007) Spatially monitoring tractor performance to evaluate energy requirements of variable depth tillage and implement selection. Paper presented at the Paper presented at the ASABE Annual International Meeting, Minneapolis Conventional Center, Minnesota, 17 -20 June 2007.
Kim TH, White H (2004) On more robust of skewness and kurtosis. Financ Res Lett 1:56–73.
Kim SC, Kim KU, Kim DC (2011) Prediction of fuel consumption of agricultural tractors. Appl Eng Agric 27(5):705-709.
Kumar S, Singh BR (2012) Performance feasibility and economic viability of sugarcane planter in western Plane zone of Uttar Pradesh, India. Sugar Tech 14(2):101-108.
Léon, A, Rubio G, Serna G (2005) Autoregressive conditional volatility skewness and kurtosis. Q Rev Econ Financ 45:599–618.
Liljedahl JB, Turnquist PK, Smith DW, Hoki M (1989) Tractor tests and performance. In: Liljedahl JB, Turnquist PK, Smith DW, Hoki M (eds) Tractors and their power units, 4rd edn. Van Nostrand Reinhold, New York, pp 403-438.

Matsuoka M (2006) Sugarcane cultivation and sugar industry in Japan. Sugar Tech 8(1):3-9.

Montgomery, DC (2004) Methods and philosophy of statistical process control. In: Montgomery DC (ed) Introduction to statistical quality control, 6rd edn. Wiley, Arizona, pp 179-213.

Mudholkar GS, Natarajan R (2002) The inverse Gaussian models: analogues of symmetry, skwness and kurtosis. Ann I Stat Math 54(1):138-154.

Patil A, Dave AK, Yadav RNS (2004) Evaluation of sugarcane cutter planter. Sugar Tech 6(3): 121–125.

Peloia PR, Milan M, Romanelli, TL (2010) Capacity of the mechanical harvesting process of sugarcane billets. Sci Agr. 67(6):619-623.

Pripps RN (2004) Air, water, oil cooling and systems. In: Pripps RN (ed) Farm tractor. MBI, Minnesota, pp 77-78.

Rípoli MLC, Rípoli TCC, Casagrandi DV, Ide BY (2007) Evaluation of five sugarcane planters. Paper presented at the ASABE Annual International Meeting, Minneapolis Conventional Center, Minnesota, 17 -20 June 2007.

Rípoli MLC, Rípoli TCC (2010) Evaluation of five sugarcane planters. Eng Agric. 30(6):1110-1122.

Ross GJ, Adams NM (2012) Two nonparametric control charts for detecting arbitrary distribution changes. J Qual Technol 44(2):102–116.

Schumacher LG, Frisby JC, Hires WG (1991) Tractor PTO horsepower, filter maintenance, and tractor engine oil analysis. Appl Eng Agric 7(5):625-629.

Shin CS, Kim UK, Kim KW (2012) Energy efficiency classification of agricultural tractors in Korea. J Biosyst Eng 37(4):215-224.

Singh J, Singh AK, Sharma MP, Singh PR, Srivastava AC (2011) Mechanization of sugarcane cultivation in India. Sugar Tech 13(4):310-314.

Somerville SE, Montgomery DC (1996) Process capability and non-normal distribuitions. Qual Eng 9(2):305-316.

Srivastava AK, Goering CE, Rohrbach RP, Buckmaster DR (1993) Tractor hitching, traction, and testing. In: Srivastava AK, Goering CE, Rohrbach RP, Buckmaster DR (eds) Engineering principles of agricultural machines. ASAE, St. Joseph, pp 139-167.

Vermaat MB, Ion RA, Does RJMM, Klaassen, CAJ (2003) A comparison of Shewhart individuals control charts based on normal, non-parametric, and extreme-value theory. Qual Reliab Eng Int 19(4):337–353.

Vishwanathan O, Weckler PR, Solie JB, Stone MS (2005) Evaluation of ground speed sensing devices under varying ground surface conditions. Paper presented at the ASAE Annual International Meeting, Tampa Convention Center, Florida, 17 – 20 July.

Yadav RNS, Yadav S, Terja RK (2003) Labour saving and cost reduction machinery for sugarcane cultivation. Sugar Tech 5(1):7-10.

Yadav RNS, Chaudhuri D, Sharma MP, Singh PR, Kamthe SD, Tajuddin A (2004) Evaluation, refinement and development of tractor operated sugarcane cutter planters. Sugar Tech 6(1):5-14.