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TIMES OF EFFICIENCY AND QUALITY OF SOYBEAN CROP MECHANICAL OPERATION IN GEOMETRY FUNCTIONS OF PLOTS

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ABSTRACT: The knowledge of the operational quality of soybean harvester provides useful information to management in order to obtain the maximum performance of all available resources, with minimal expenses. The aimed of this study was to evaluate the quality of mechanized soybean harvesting operation in different formats of plots through statistical process control. Treatments were established from the formats of existing plots in the area (irregular, trapezoidal and rectangular). The activities carried out during the harvest were monitored (harvesting, unloading, handling, maneuvering and climate charts) and through these activities were made the calculation of capacity and harvesting operation efficiencies. In the determination of total losses were used 4 circular frames of 0.33 m² each, the grain losses were considered below and above these frames. The statistical analysis was by means of statistical process control opting for the use of the type CUSUM charts. The rectangular plot showed greater management efficiency and harvesting efficiency. The trapezoidal shape facilitated the maneuvers relative to others. The rectangular plot has better quality of operation in relation to others. The CUSUM control chart showed to be effective in preventing instability and maintenance of process quality.

KEYWORDS: grain harvester, CUSUM, machine performance, *Glycine max* (L.) Merrill.

INTRODUCTION

According to ASAE standard D497.6 (2009), time field efficiency or efficiency is defined as the ratio between the time effectively used and the total time available, when considering only the operations performed in cultivated field. This efficiency is related to the unused total working width of the machine, with the operator's habits, time and maneuvering characteristics of the area (ARALDI et al., 2013).

Considering that the shape of the blocks is of great importance for increasing time efficiency, the ideal plot shape is rectangular, being influenced by the width of the platform and the length and width of the blocks (WHITNEY, 1988). Also according to the author an ideal situation, the maneuvering time would be the minimum possible, which maximize the efficiency of the operation level and the harvester remain most of the time removing the production area, however, in practice this ideal condition is difficult to occur.

Among the factors that affect the operational capacity of the combine harvest, the scroll speed is one of the crucial point, as they increase or decrease the speed of harvest, influences the permissible capacity of the combine to process the mass harvested, so this decision should also take into account the acceptable loss levels for each region or production unit to meet its quality standards (CUNHA & ZANDBERGEN, 2007; MAGALHÃES et al., 2007).

Associated with the greatest potential for exploration of soybean harvesters, greater efficiency or lower levels of losses during harvest, regardless of the field format, VOLTARELLI et al. (2015) state that the use of statistical control applied to the monitoring of crop losses process may prove to be important because it can show a vision of how the process is taking place, indicating possible faults and possible improvements for future operations to the order to increase the quality of it.

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Some authors have made the use of statistical process control, using quality indicators for monitoring of mechanized agricultural operations. In these works, the tool typically used to identify non-random causes or special causes arising from instability of the process are the individual values of control charts (CHIODEROLI et al., 2012; COMPAGNON et al., 2012; CASSIA et al., 2013; SILVA et al., 2013; VOLTARELLI et al., 2013; ZERBATO et al., 2013; VOLTARELLI et al., 2014).

As alternatives control charts of individual values, there is the control chart of the cumulative sums (CUSUM) type V-mask, suitable for monitoring processes subject to small and persistent changes (FOLLADOR, 2012). This chart, the decision on the status of the process is based on the accumulated information of several previous samples, not only the last of them, it is possible to signal more quickly small misadjustment, and identify the time when there is a change (MONTGOMERY, 2009). We also emphasize that the CUSUM has a higher stringency in relation to the letters of individual values for detecting variations in the process and can also be applied to analysis of other statistical variables, beyond the middle such as range and standard deviation of subgroup (MUKHERJEE et al., 2013).

Assuming that the efficiency of time and losses of mechanized harvesting of soybean can reduce the quality of this process, the aim of this study was to evaluate the efficiency and quality of the operation of mechanized harvesting of soybeans due to the geometry of the plots, by controlling statistical process.

MATERIAL AND METHODS

The experiment was conducted in the municipality of Conceição das Alagoas - MG, in the dependences of the São Sebastião farm, located near the geodetic coordinates 19º47'40 "S and 48º08'54" W, with average altitude of 801 m, and the weather classified according to Köppen - Geiger as Aw. The soil of the experimental area was classified as eutrophic ultisol Red-yellow with medium texture (EMBRAPA, 2013).

It was evaluated in the same area, three plots of different shapes and characteristics (Table 1).

TABLE 1. Characteristics of the evaluated plots formats and their respective areas.

Shape	Irregular	Trapezoidal	Rectangular	Slope (%)
Area (ha)	5.14	4.82	6.97	3.0
Length (m)	400	617	480	3.0
Width (m)	107	97	153	3.0

All plots were sown with the cultivar BMX Turbo RR spacing of 0.50 m between rows and 22 seeds m^{-1}. Harvest was done by a combine harvester, model MF 5650 Advanced, 2010 with approximately 700 hours of work, with nominal power of 130 kW (175 hp), equipped with cutting deck 5.00 m wide and track system tangential type. The areas were classified as mild relief, in which the harvest was carried out on the same day.

To evaluate the performance of the combine was monitored times, movements and operating efficiency in each plot. Data was collected with the help of field notebook, clipboard and stopwatch throughout operation. The monitoring activities during harvest were divided as follows: Total time of harvest, the designated time at which the machine is intended to perform mechanical harvesting operation (Harvest Time); Time spent on bedside maneuvers (maneuver time); Demanded time for the machine moves up to the points of discharge and perform the unloading of grain, until his return to harvesting activity (Discharge time); Time needed for unforeseen resolution, such as repairs and / or bushings (Time for maintenance); and the time devoted to stops due to adverse weather conditions, until the return of the harvesting operation in plot (Time Climate stops).

With the data, we calculated the variables related to the operation (time spent during the operation and the length / width of the field) and the efficiency of operation (field efficiency) as ASABE EP 496.3 (2009) standards and efficiency time and capabilities as MIALHE (1974).

The effective field capacity was calculated according to the methodology described by MIALHE (1974) [eq. (1)]:

$$Efc = \frac{A}{Tho} \quad (1)$$

On what,

Efc: Effective field capacity (ha h^{-1});

A: area of the field (ha), and

Tho: harvesting operation time (h).

The operational field capacity was calculated according to the methodology described by MIALHE (1996) [eq. (2)]:

$$Ofc = \frac{A}{Tho + Td + Ts + Tm + Tcs} \quad (2)$$

On what,

Ofc: operational Field capacity (ha h^{-1});

Td: discharge time (h);

Ts: maintenance or stop time (h);

Tm: maneuver time (h), and

Tcs: climatic stop time (h).

To calculate the harvest efficiency (Eh), field efficiency (Ef) and management efficiency (Em) we used the methodology described by ASABE EP 496.3 (2009) standards according to eqs (3), (4) and (5):

$$Eh\ (\%) = \left\{\frac{Tho + Tm}{Tho + Td + Ts + Tm + Tcs}\right\} \times 100 \quad (3)$$

On what,

Eh (%): Harvest efficiency.

$$Ef\ (\%) = \left\{\frac{Ofc}{Efc}\right\} \times 100 \quad (4)$$

On what,

Ef (%) Field efficiency (%).

$$Em\ (\%) = \left\{\frac{Tho + Td + Tm}{Tho + Td + Ts + Tm + Tcs}\right\} \times 100 \quad (5)$$

On what,

Em (%): Management efficiency (%).

The harvest time (Th) discharge time (Td) and maintenance or stop time (Ts) were calculated according to the methodology described by MIALHE (1996) according to eqs (6), (7) and (8), respectively.

$$Th\ (\%) = \left\{\frac{Tho}{Tho+Td+Ts+Tm+Tcs}\right\} \times 100 \quad (6)$$

$$Td\ (\%) = \left\{\frac{Td}{Tho+Td+Ts+Tm+Tcs}\right\} \times 100 \quad (7)$$

$$Ts\ (\%) = \left\{\frac{Ts}{Tho+Td+Ts+Tm+Tcs}\right\} \times 100 \quad (8)$$

For the calculation of maneuver time, we used the formula according to the methodology of ASABE EP 496.3 (2009), maneuver, [eq. (9)]:

$$Tm\ (\%) = \left\{\frac{Tm}{Tho+Td+Ts+Tm+Tcs}\right\} \times 100 \quad (9)$$

Also, using the methodology described by MIALHE (1974) determined the ratio length/width (L / W) of each plot (equation 10).

$$L/W = \frac{L}{W} \quad (10)$$

On what,

L / W: ratio length / width of plots;

L: Average lengths of each plots (m), and

W: Average width of each plots (m).

Monitoring the combine harvester was accompanied from the beginning to the end of the operation; the total loss was quantified at regular intervals until the end of the harvest in each plot. It was used circular frames made with hoops of 0.33 m², sealed with shading screen resembling with sieves, we use three hoops of the same size, which together had a total area of approximately 1.00 m². The hoops were launched soon after the passage of the harvester platform at predetermined points, so that two hoops were willing outside of the tracing of wheel sets of the harvester (left and right) and a third was launched between the rear axle (middle). We collected all the grains and pods present inside and below the hoops after the passage of the harvester.

The losses in mechanical harvesting of soybeans were defined as follows: the summation of the grains and pods found above and below the screen portraying as total losses. Eight samples were collected per plot every 20 minutes at random times throughout the harvest period, based on standards of Statistical Process Control (SPC). The characterization of the loss of water content was effected by means of a digital meter model G600, by collecting 10 samples in the morning and 10 in the afternoon, with a mean of 12.7% day for all formats plots evaluated.

The SPC tool used to monitor the loss was the control chart (CUSUM). This statistical method accumulates samples of the information mulling also a process that is; the samples have the same weight. The procedure is based on the successive collecting samples of size n, which is obtained statistics accumulated sum.

The accumulated sum technique can be applied both in the construction of CUSUM chart for individual observations and for sample observations of the average rational subgroup. For individual observations, the statistic used is the accumulated sum of the deviations of each individual value regarding the measure given the hypothesis being tested. In the case of size samples (n > 1) this statistic is the accumulated sum of the deviations from the sample mean with respect to the nominal value. In this sense, the control charts CUSUM kind V mask, proposed by BARNARD (1959) was drafted by eqs (11) and (12):

$$C_i = \sum_{j=1}^{i} y_j \tag{11}$$

$$C_i = y_i + C_{i-1} \tag{12}$$

On what:

y_i is the standardized observation $y_i = (x_i - \mu_0)/\sigma$.

The decision procedure is to place the V mask in the control chart the cumulative sum with the point 0 about the last value of C_i and line 0P parallel to the horizontal. When all the previous cumulative sums, C_1, ..., C_i are located within the two arms of the mask, the process is under control. However, if any of the cumulative sums is located outside the mask's arms, the process is considered out of control. On actual use, the V mask should be applied to each new point on the CUSUM chart, when it is graphed, and it is assumed that the arms of the mask extend back toward of the source.

The performance of the V mask is determined by the distance d and the angle θ, the decision interval h and the slope (slope) k of the mask arms.

$$k = A \times \tan\theta \tag{13}$$

$$h = A \times d \times \tan(\theta) \tag{14}$$

In these two equations, A is the horizontal distance in tracing of the V mask between successive points in terms of unit distance on the vertical scale.

Thus, the limit of losses (LE) was recommended by the production unit being evaluated in 60 kg ha^{-1} (EMBRAPA, 2002). Because of the calculation basis used in the CUSUM control chart, V mask model, is possible the occurrence of samples with negative values, however this situation is not considered bad, since all values in the case of this study, which are below the limit set as a goal (60 kg ha^{-1}), they will be considered better results, as losses are below the maximum limit accepted by the production unit.

RESULTS AND DISCUSSION

Table 2 shows the results of operating performance quality indicators on mechanical harvest of soybeans. In trapezoidal plot, the effective field capacity (Efc) and the operating field capacity (Ofc) showed similar values, 1.55 and 1.42 ha h^{-1}, respectively. This fact is related with the lowest total time spent (harvesting, maneuver, discharge, problem and climate stop) at the plot in this format over the other.

On the other hand, harvest efficiency (Eh) for plots 1, 2 and 3 were 76.33, 68.00 and 82.63%, respectively. In that sense, it is noted that plot 3 presents a rectangular shape, showed the greatest time spent in harvesting operation, thereby increasing its efficiency. In plot 2 (trapezoidal), there was a lower value for this variable, which could be explained by the greater climatic stop time (25%), due to the rain.

TABLE 2. Analysis of time, movement and efficiency of mechanical harvesting of soybeans in different plots.

Variables	Format plots		
	Irregular (1)	Trapezoidal (2)	Rectangular (3)
Efc (ha h^{-1})	2.57	1.55	2.89
Ofc (ha h^{-1})	1.35	1.42	1.33
Eh (%)	76.33	68.00	82.63
Ef (%)	52.50	91.61	46.02
Em (%)	87.33	73.33	88.42
Th (%)	41.54	38.95	44.47
Td (%)	11.00	5.33	5.79
Ts (%)	6.00	1.67	2.37
Tcs (%)	6.67	25.00	9.21
Tm (%)	34.80	29.05	38.17
L / W	3.74	6.36	3.14

Efc=effective field capacity; Ofc=operational field capacity; Eh= harvest efficiency; Ef= field efficiency; Em= management efficiency; Th= harvest time; Td= discharge time; Ts= maintenance or stop time; Tcs= Time climatic stop; Tm= maneuver time; L/W= length and width.

PITTA et al. (2014) reported that to carry out the monitoring of the efficiency of agricultural machinery in the field using the Controller Area Network (CAN) has enabled the management of operations, since times were collected through broadsides computers providing greater accuracy in analysis data. This result compared to the present study, based on the average technological level of the property, it is not useful for management and monitoring of the harvest, since the collection of information through chronometer and manual annotations obtains satisfactory results.

For field efficiency (Ef), which is the relationship between the two capacities (effective and operational), it is observed that plot 2 showed higher (91.61%), followed by plots 1 (52.60%) and 3 (46.02%). This situation can be explained by the proximity of Efc and Ofc values of the trapezoidal plot, making this next ratio of 100%. Note that for the other evaluated plots (irregular and rectangular) harvesting efficiency values were very near as well as their operational capacity values.

The management efficiency (Em) suggests the impact of downtime on the harvesting operation, which can be seen the best result for plot 3 (88.42%) followed by plot 1 (87.33%) and plot 2 (73.33%). These results are due to mainly to climatic stop time (Tcs), whereas plot 2 (trapezoidal) even with the lowest results in other variables (Ts, Td and Tm), had climatic stop time (Tcs) very high (25%), making the Em lower than the other stands evaluated.

Watching the harvest time (Th), it was found in the rectangular plot the highest value compared to other plots; due to this plot format facilitate the logistics of mechanized soybean harvesting, providing longer shots for the operation.

When comparing the three plots in relation to the discharge time (Td) and the maintenance or stop time (Ts), noted that plot 1 showed the highest values 11 and 6% respectively. A possible explanation is the plot has an irregular shape, which made it difficult to access a bulk carrier tank to the machine for unloading of soybeans and several times the platform angle of attack was damaged; often causing accumulation of straw between the harvester mechanisms that is the "bushings".

ARALDI et al. (2013) studying the time efficiency in mechanical harvesting of rice in various conditions, using combined harvesters, reported an average time of discharge 10.8%, this value being near of found for this study in relation to irregular plot and higher than the other models of plots.

To maneuver time (Tm), it is noted that plot 3 (rectangular) showed the highest value (38.17%). This may be related to the presence of a vinasse channel, which hampered the continued displacement of the harvester, increasing the need for maneuvers. In this condition, it can be observed that the plot of trapezoidal shape, favored the maneuvers in relation to the others. Such results can be explained by their high length / width (L / W = 6.36) which reduces the number of operations per area harvested and therefore the operational capacity of the combiner.

Based on statistical process control for total losses, irregular plot presented process stability throughout the evaluation period, with all points between the upper and lower lines of the V mask (Figure 1).

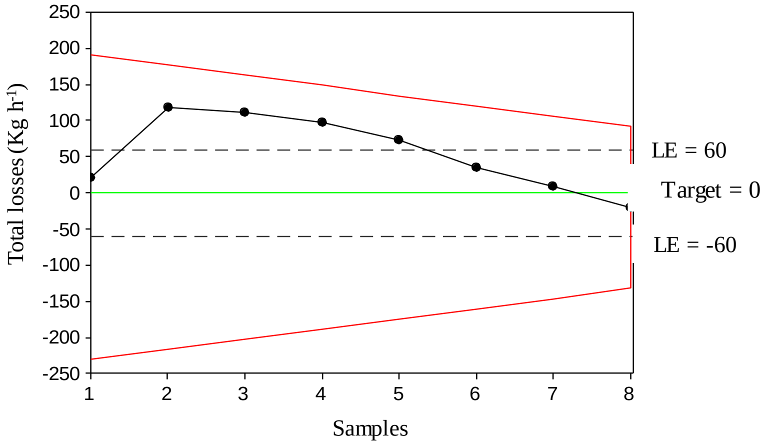

FIGURE 1. CUSUM control charts for total losses in the soybean mechanical harvesting in the irregular plot format.

It can be observed that only three points (sample 1, 7 and 8) possessed sample values near zero by means of cumulative sum, that is, smaller loss values. This presents a favorable condition for the mechanical harvesting process of soybean, due to the amount smaller of losses occurring at harvest compared to the limit set for the operation (LE = 60 kg ha^{-1}). Moreover, 50% of the points which are above the established limit of losses represent larger amounts of losses, but showing process stability.

MACHADO et al. (2012) evaluated the losses in mechanical harvesting of soybean, reported that loss to be at an acceptable level, the harvester shall operate at a speed of 7 km h^{-1} associating the drawing machine rotation so as to minimize the total losses. These results can be considered opposites to the present study, since the average speed is 5 km h^{-1} which also confers losses within the limits set by the producing unit.

The use of CUSUM chart gives greater rigor to the analysis of the process because of its calculation base. Further LEIRAS et al. (2007) point out that when it comes to small samples is preferable to its choice instead of the letters of Shewhart. However, the interpretation of it has importance in order to elucidate the process in the best possible way to identify whether or not there was the occurrence of external factors influencing the quality of the operation.

According to GRAHAM et al. (2014) the use of CUSUM control charts of tabular type was effective for detection and rapid election of special causes acting in the course of a process and can be more accurate than letters of individual values because of their algorithm based calculation. This may be different from the results of this study, since the charts V mask type did no detect special cause, and this may be due to their lower stringency when compared to CUSUM tabular which does not point to an inefficiency of the monitoring process.

Figure 2 shows the stability of the process to the total losses in the trapezoidal plot. Because all points are between the upper and lower lines of the V mask which can portray the absence of special causes acting in the course of mechanical harvesting of soybean process.

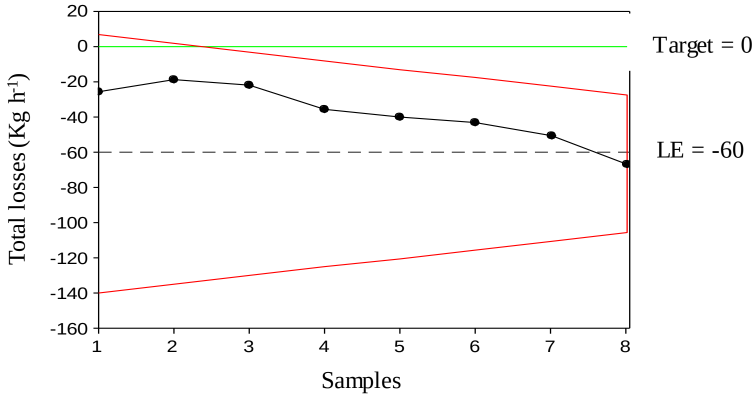

FIGURE 2. CUSUM control charts for total losses in the soybean mechanical harvesting in the trapezoidal plot format.

On the other hand, when observing the behavior of the values of the cumulative sum along the harvesting process, there is a tendency of loss values decrease over time from the number of sample 3. This result can be effective in decision making for assiduous monitoring of the process, since the CUSUM control chart identifies small variations in the middle of a process, which are absorbed by other models of cards (CRUZ et al., 2014).

The total losses in mechanical harvesting of soybeans to the rectangular plot showed instability of the process because there is a point (sample 1) above the top line of the control V mask (Figure 3). However, this value of the cumulative sum may prove to be favorable harvesting since it has the least amount of losses, being set below the control limit.

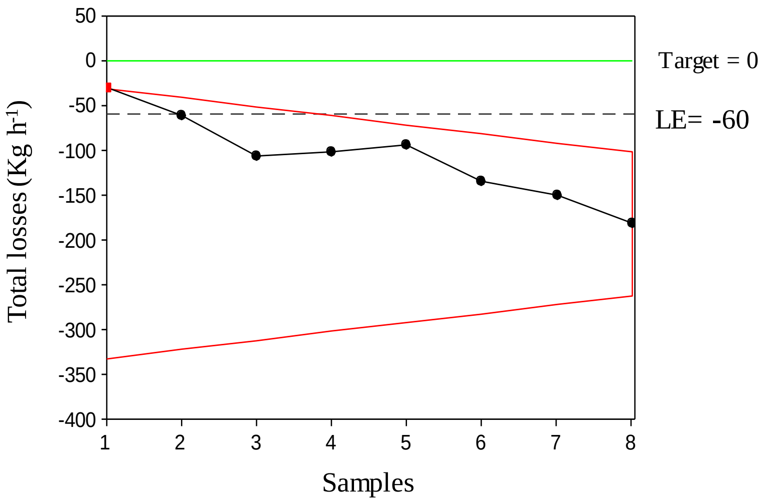

FIGURE 3. CUSUM control charts for total losses in the soybean mechanical harvesting in the rectangular plot format.

It is also observed that there are 87.5% of the sampling points within the limits of the V mask, a condition which portrays the losses in mechanical harvesting of soybean meeting the production unit quality standards, it is not necessary the adequacy of the process as a whole, so there is reduced variation of loss levels.

WALTER (2013) by comparing the control charts of individual values with the CUSUM tabular model, reports that the charts of the cumulative sums is a good option for monitoring processes having greater strictness in detecting any special causes or process instability. These results, in part, may be similar to those shown by this study, since the use of CUSUM V mask process presented stability, depicting only the presence of random variation in the course of the soybean harvest.

Furthermore, note that since the start of collection of the samples there was a trend of loss values decrease along harvesting process, the situation is beneficial to the operation, as reflected in increased level of its quality. This situation is similar to that described by MONTGOMERY (2009) which states that the reduction of variability is inversely proportional to increase the quality of operations or processes to be performed.

CONCLUSIONS

The trapezoidal shape of the plot showed better efficiency, less time spent on bedside maneuver, while the time spent on rectangular plot was larger on bedside maneuvers, management and harvest efficiencies.

The trapezoidal plot showed lower variability of total losses, with higher quality process. The total losses for the rectangular plot presented instability process, however the data is mostly below the limit.

The CUSUM control chart is suitable for monitoring the soybean harvest process, it acted as a management tool to avoid interference in the process quality, since it indicates faster small misadjustment, as well as accurately identifies the moment in which it occurs.

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