

INFLUENCE OF THE SAMPLE AREA IN THE VARIABILITY OF LOSSES IN THE MECHANICAL HARVESTING OF SOYBEANS

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ABSTRACT: The mechanical harvesting is an important stage in the production process of soybeans and, in this process; the loss of a significant number of grains is common. Despite the existence of mechanisms to monitor these losses, it is still essential to use sampling methods to quantify them. Assuming that the size of the sample area affects the reliability and variability between samples in quantifying losses, this paper aimed to analyze the variability and feasibility of using different sizes of sample area (1, 2 and 3 m²) in quantifying losses in the mechanical harvesting of soybeans. Were sampled 36 sites and the cutting losses, losses by other mechanisms of the combine and total losses were evaluated, as well as the water content in seeds, straw distribution and crop productivity. Data were subjected to statistical analysis (descriptive statistics and analysis of variance) and Statistical Control Process (SCP). The coefficients of variation were similar for the three frames available. Combine losses showed stable behavior, whereas cutting losses and total losses showed unstable behavior. The frame size did not affect the quantification and variability of losses in the mechanical harvesting of soybeans, thus a frame of 1 m² can be used for determining losses.

KEYWORDS: Statistical Control Process, Control Charts, Combine.

INFLUÊNCIA DA ÁREA AMOSTRAL NA VARIABILIDADE DAS PERDAS NA COLHEITA MECANIZADA DE SOJA

RESUMO: A colheita mecanizada é uma fase importante no processo produtivo da soja, sendo comum, neste processo, a perda de quantidade significativa de grãos. Apesar da existência de mecanismos para monitorar essas perdas, ainda é fundamental o uso de métodos de amostragem para a quantificação das mesmas. Pressupondo-se que o tamanho da área amostral afeta a confiabilidade e a variabilidade entre as amostras na quantificação das perdas, este trabalho teve como objetivo analisar a variabilidade e a viabilidade do uso de diferentes tamanhos de área amostral (1, 2 e 3 m²) na quantificação de perdas na colheita mecanizada de soja. Foram amostrados 36 pontos e avaliadas as perdas provocadas pelo corte das plantas, pelos demais mecanismos da colhedora e totais, o teor de água das sementes, a distribuição de palha e a produtividade da lavoura. Os dados foram submetidos à análise estatística (estatística descritiva e análise de variância) e ao Controle Estatístico de Processo (CEP). Os coeficientes de variação foram semelhantes para as três armações avaliadas. As perdas na máquina apresentaram comportamento estável, enquanto as perdas no corte das plantas e totais apresentaram comportamento instável. O tamanho da armação não interferiu na quantificação e na variabilidade das perdas na colheita mecanizada de soja, podendo ser usada armação de 1 m² para a determinação das perdas.

PALAVRAS-CHAVE: controle estatístico de processo, cartas de controle, colhedora.

INTRODUCTION

The cultivation of soybean (*Glycine max* L. Merrill) is one of the most important in the scenario of Brazilian agriculture, with an estimate of 24.63 million hectares of crop area in the

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Recebido pelo Conselho Editorial em: 9-3-2012

Aprovado pelo Conselho Editorial em: 15-9-2013

harvest of 2011/12, with a total production of 71.7 million tons (CONAB, 2012). Mechanized harvesting is an important stage in the production process, and production losses are a very common occurrence during this operation. According to TOLEDO et al. (2008), proper planning and management of mechanized systems contribute to the rationalization and reduction of costs and improvement of the final product. The mechanized harvesting of soybeans fits this context, since it is the last operation performed in the field, being directly related to the profitability of the producer. Despite the existence of mechanisms for monitoring crop losses, it is still essential to use sampling to verify the efficiency of the harvesting operation in order to minimize losses.

Crop losses occur due to factors inherent in both culture and combine (CARVALHO FILHO et al., 2005; MAGALHÃES et al., 2009). Among the factors related to the combine, we can mention: cutting height, reel speed, the threshing cylinder rotation, gap between concave and cylinder and inappropriate moving speed. Regarding factors inherent in culture, we can mention: dehiscence of pods, inadequate seeding, weed occurrence, poor crop development (FERREIRA et al., 2007) and water content of the grains (BAUER et al., 2007).

For TOLEDO et al. (2008) losses from the action of the mechanical harvesting of soybeans can be classified as losses due to deficiency of cutting height, remaining lodged to stalk (LSL), when the beans inside the frame were in parts of the plant which contained pods; losses caused by the threshing system (TSL) for grains inside pods disposed on the soil; losses by the separation system (SSL), determined by the mass of free grains found in the soil within the frame, and total grain loss (TGL), calculated by the arithmetic sum of the previous losses. There are several methodologies for determining losses, which differ from each other by the speed and accuracy during sampling. By quantifying losses in the mechanized harvesting of soybeans, CUNHA & ZANDBERGEN (2007) compared EMBRAPA's volumetric cup methodology, which associates the volume with the number of lost grains, and the weighing methodology, which consists of the collection and subsequent determination of mass in scales, noting that in some cases there were differences between the methods.

CÂMARA et al. (2007) found the existence of high variation coefficients, and consequently, high variability in studies on losses in the mechanized harvesting of soybeans quantified using frames of 2 m². As a result, the authors evaluated two frame sizes, two combine moving speeds and two gaps between the cylinder and the concave, observing interference of these factors on the values of losses as well as on the coefficients of variation for the evaluated frames, with better results observed when using a frame of 3 m².

The high variability found in evaluations of losses is a factor that deserves further investigation, since the variability affects the quality of the harvesting operation. The statistical process control (SPC) has been used in agriculture, seeking, by reducing the variability, the reduction of costs and improvement of the final product (SILVA et al., 2008; CHIODEROLI et al., 2012; CASSIA et al., 2013; SILVA et al., 2013). The SPC is a tool with great potential for studies related to the improvement of agricultural operations, and considered effective in characterizing the variability and quality review of operations (SUGUISAWA et al., 2007; TOLEDO et al., 2008).

Assuming that the size of the sample area affects the reliability and variability between samples to quantify losses, this study aimed to analyze the variability and feasibility of using different sizes of sample areas (1, 2 and 3m²) in quantifying losses in the mechanical harvesting of soybeans from the perspective of statistical control process.

MATERIALS AND METHODS

The crop was harvested in the area of Fazenda Santa Margarida, located in area the city of Guatapar, SP, near the geodetic coordinates: latitude 21°17' S and longitude 48°11' W, with an average altitude of 680 m Cwa climate (subtropical), according to the Koppen classification. The culture harvested was Coodetec 206, with row spacing of 0.45 m, using an MF 5650 combine from

Massey Ferguson, year 2004, with the engine capacity of 129 kW (175 hp), working at an average speed of 4.8 km h⁻¹. The combine had a tangential flow track system, platform of 5.0 m width and 5000 L of grain tank capacity.

The work was carried out in a field with gently undulated terrain, evaluating an area of 1.8 ha, where 30 points were demarcated, spaced 30 m apart, resulting in regular sampling grid (Figure 1). The sampling points were geo-referenced with the help of a GPS device from Garmin, with accuracy from 1 to 10m.

In order to determine the water content in the grains, samples of 100 g were collected at each point of the grid, which were then placed in a portable meter, model Multigrain, with accuracy of 0.1 %. Samples were taken directly at the grain entrance in the grain tank, from signals from beacons positioned on the grid points.

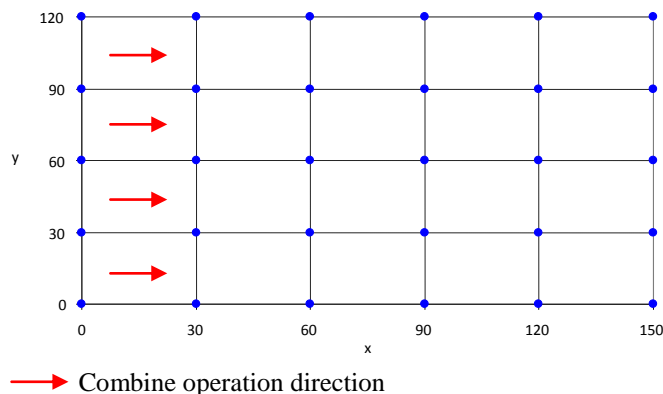


FIGURE 1. Sketch of the harvested area with sampling points.

The evaluation of the straw distribution by the combine was performed based on the adaptation of the method of LAFLEN (1981), using the frame used to quantify losses, of length equal to the width of the cutting platform of the combine (5 m), on which 24 points were marked, equally spaced. This frame has been extended on the ground after the passage of the combine, each node being considered as a point for determination of straw on the ground. Subsequently we determined the percentage of coverage for each sampling period.

Sampling was performed to determine the losses in each grid point, using a rectangular frame divided into three different areas (Figure 2), with 1 m² (frame A), 2 m² (frames A+B1+B2) and 3 m² (frames A+B1+B2+C1+C2). After collection, the grains were separated and had their weight measured and calculated as kg ha⁻¹.

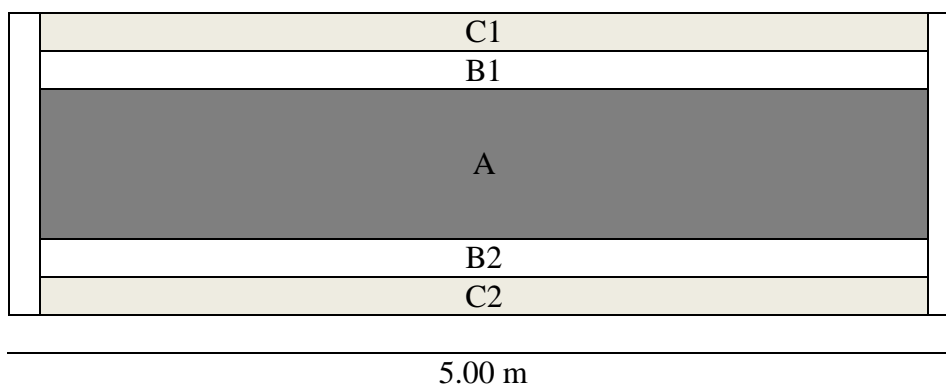


FIGURE 2. Scheme of the sampling area for the 1, 2 and 3 m² frames.

Losses due to deficiency in cutting height (LSL); losses in the combine (TCL), corresponding to the losses caused by the threshing systems (TSL), separation system (SSL); and total losses (TGL) were evaluated, as defined by TOLEDO et al. (2008).

The results were analyzed using descriptive statistical analysis (PIMENTEL-GOMES & GARCIA, 2002), performed using Minitab[®] software. To allow visualization of the general behavior of the data, measures of central tendency (arithmetic mean and median), of dispersion (maximum and minimum values, standard deviation and coefficient of variation) and the coefficients of skewness and kurtosis were calculated, in addition to the Anderson-Darling test, to verify the normality of the data. Measures of central tendency were used for allowing the indication of a value that tends to typify a set of data, while the parameters of dispersion allow us to indicate whether the values are relatively close to or apart from each other. Upon the occurrence of non-normality of the results, their transformation was carried out ($\sqrt{x}/100$), and subsequently they were subjected to analysis of variance by the F test. In order to compare the means, the Tukey test at 5% probability was used.

The grains water content, straw distribution and crop losses were evaluated from the perspective of statistical process control (SPC), using control charts by average, also with the aid of Minitab[®] software. The control charts show as central line the overall average and the average amplitude, respectively, and upper and lower control limits, defined as UCL and LCL, calculated based on the standard deviation of the variables (for UCL, mean plus three times the deviation standard, and, for LCL, mean minus three times the average deviation, when greater than zero). The charts were subdivided into five stages, according to the location they were at in the field and in the light of the terrain analyzed (contour lines).

RESULTS AND DISCUSSION

For the water content of the grains (Table 1), the average obtained (13.5%) is within the optimal harvest conditions recommended by literature (MARCONDES et al., 2010). BAUER et al. (2007) assert that the smaller the water content of the grains (to 11.4%), the lower the losses in mechanical harvesting of soybeans. It was also noted that, according to the criteria presented by PIMENTEL-GOMES & GARCIA (2002), this variable showed low values for the coefficient of variation and the standard deviation, indicating that in the sampled points the values observed were close to the average, with little variability, which is desirable in order to harvest with lower losses and mechanical damage.

Unlike the water content of the grains, productivity showed high values for standard deviation and coefficient of variation. However, both the grains water content and productivity had close values between the mean and median, and skewness and kurtosis coefficients near zero, parameters that indicate the normality of the data, and this is proven by the probability test of Anderson-Darling. The average productivity obtained was of 3232 kg ha⁻¹, above the average productivity value estimated for the state of Sao Paulo in the 2011/2012 harvest, which was of 2800 kg ha⁻¹ (CONAB, 2012).

For the distribution of the straw by the combine it is observed that the mean was 82.64%, a result which lies close to the values found by TOLEDO et al. (2008) in soybean harvest. The percentage losses were high, with means of 3.6, 3.7 and 3.8% (116.8, 119.1 and 121.7 kg ha⁻¹) for frames of 1, 2 and 3 m², respectively. According to MESQUITA et al. (2001) the allowable mechanized soybean harvest losses should be of 60 kg ha⁻¹, which would total 1.8% of the productivity of this experiment.

The straw distribution showed a variation coefficient of 13.38%, ranked by PIMENTEL-GOMES & GARCIA (2002) as average (10-20%) and mean close to the median. However, the amplitude value was high and the coefficients of skewness and kurtosis were far from zero, which

indicates a lack of normalcy of the data, which was confirmed by the Anderson-Darling test. The high value of the amplitude indicates the great variability of the straw distribution, with the occurrence of points with full coverage and others with little coverage. This type of distribution is not desirable, for the combines should be able to evenly distribute the straw on the soil on a track equivalent to the width of the cut belt.

TABLE 1. Descriptive statistics for the variables water content of the grains, straw distribution, productivity, combine losses (TCL), cutting losses (LSL) and the total losses (TGL) for the 1, 2 and 3 m² frames.

Variable	Parameters								
	Average	Median	σ	Amplitude	CV (%)	Cs	Ck	AD	
Water content (%)	13.5	13.4	1.07	5.4	7.95	0.27	0.96	N	
Straw distrib. (%)	82.64	83.33	11.06	54.17	13.38	-1.35	3.12	A	
Productiv. (kg ha ⁻¹)	3232	3287	1063	3588	32.90	-0.01	-1.18	N	
TCL (%)	1 m ²	2.78	1.15	3.75	12.49	134.71	1.92	2.45	A
	2 m ²	3.15	1.29	4.38	14.81	138.93	2.00	2.91	A
	3 m ²	3.21	1.35	4.36	14.88	135.99	2.01	2.89	A
LSL (%)	1 m ²	0.83	0.0	2.09	9.54	251.98	3.31	11.37	A
	2 m ²	0.53	0.0	1.25	5.28	235.91	3.01	8.86	A
	3 m ²	0.56	0.0	1.43	6.25	256.80	3.24	10.39	A
TGL (%)	1 m ²	3.61	1.20	5.17	21.34	143.04	2.13	4.29	A
	2 m ²	3.68	1.36	5.18	19.98	140.50	2.01	3.34	A
	3 m ²	3.77	1.42	5.25	21.12	139.46	2.14	4.13	A

σ : standard deviation; CV: coefficient of variation; Ck: coefficient of kurtosis; Cs: coefficient of skewness; AD: Anderson-Darling test; *A: asymmetrical distribution; N: normal distribution.

Cutting losses, combine losses and total losses presented asymmetric distribution of data for the three frames, which can be explained by the fact that they have high values for the standard deviation and very high coefficients of variation (PIMENTEL-GOMES & GARCIA, 2002), besides having mean values far from the median, high amplitude and kurtosis coefficients and asymmetry distant from zero. However, in the quantification of total losses there was low variation among frames, results which disagree with CÂMARA et al. (2007), which obtained a high variation (62%) of losses for the 3 m² frame in relation to the 2 m² one.

Regarding the coefficients of variation (Figure 3), for all kinds of losses evaluated, virtually no difference was observed between the types of frame, namely, the increase in area of the frame was not sufficient to reduce the values of the coefficients of variation obtained.

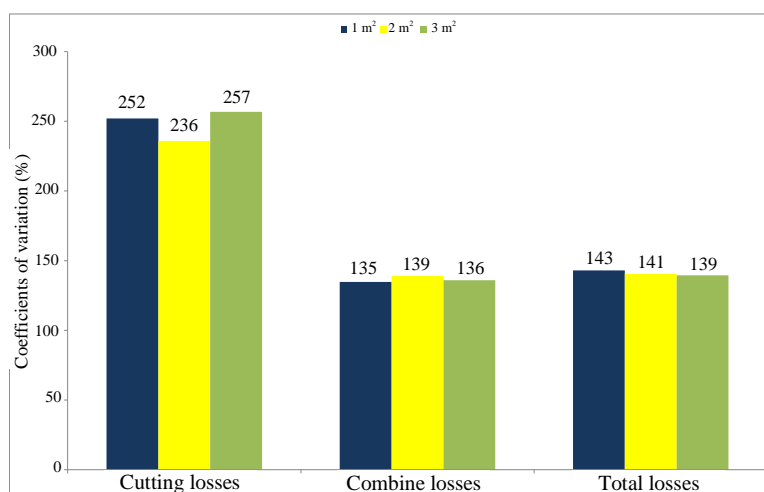


FIGURE 3. Coefficients of variation for cutting losses, combine losses and total losses for frames of 1, 2 and 3 m².

Analyzing the values shown in Table 3, it is observed that there was no difference between the frames for the variables in the combine, cutting and total losses, indicating that both the average values and the statistical parameters related to variability showed similar behavior, regardless of the frame size used. For better understanding of the variability, the statistical process control was applied (Figures 4, 5, 6 and 7).

TABLE 3. Test results for the average combine (PM), cutting (PC) and total losses (%) for frames of 1, 2 and 3 m².

Frame	TCL ¹	LSL	TGL
1 m ²	(2.78) 0.0140 a	(0.83) 0.0044 a	(3.61) 0.0156 a
2 m ²	(3.15) 0.0148 a	(0.53) 0.0038 a	(3.68) 0.0158 a
3 m ²	(3.21) 0.0151 a	(0.56) 0.0037 a	(3.77) 0.0162 a
F Test	0.096 ^{ns}	0.241 ^{ns}	0.015 ^{ns}

*Averages followed by the same letter in the columns do not differ by Tukey test at 5 % probability. ¹ The averages of the original values are in brackets, whereas the averages followed by letters represent the values after transformation ($\sqrt{x}/100$).

Control charts for the variables water content of the grains, straw distribution and productivity (Figure 4) are under the process statistical control, i.e., within the upper and lower control limits, indicating the absence of special causes during the operation of mechanized soybean harvest. For the straw distribution the variability of individual and process values were similar to those found by TOLEDO et al. (2008), despite the low distribution found in section 25. The productivity charts, however, despite being under control, show high variability between points, showing a significant difference in productivity for the different contour lines assessed, bringing some instability to the process, but not enough to make it out of control. Still, the first curve shows average productivity values lower than the others, which may be explained by the fact that the points on this curve are located near the terrace channel, where there was water accumulation.

The values obtained for total losses (Figure 5) showed unstable behavior considered out of control for all frames, for point 25 is above the upper control limit. These results agree with those observed by TOLEDO et al. (2008), who highlighted that the presence of causes not related to the process provided high variation between the values of losses, making the process out of control. Also according to these authors, these causes may be associated to the topography of the area, experience of the driver, operation time, among other aspects. In the present work the observance of process instability in the indicator "total losses" may be associated with the culture behavior, since the control of other factors was adequate during the experiment.

In control charts for cutting losses (Figure 6) the values obtained were null in curves 2 and 3 and close to zero in curve 4, indicating the efficiency of the cutting system during the mechanical harvesting of soybeans. However, in curves 1 and 5 losses were higher, and so again point 25 showed values of losses above the upper control limit, thus characterizing the process as being unstable. CHIODEROLI et al. (2012), when evaluating the mechanical harvesting of soy, found no losses due to deficiency in cutting height, justifying that this happens due to the insertion of the first pod being close to the ideal, thereby reducing losses from unharvested pods.

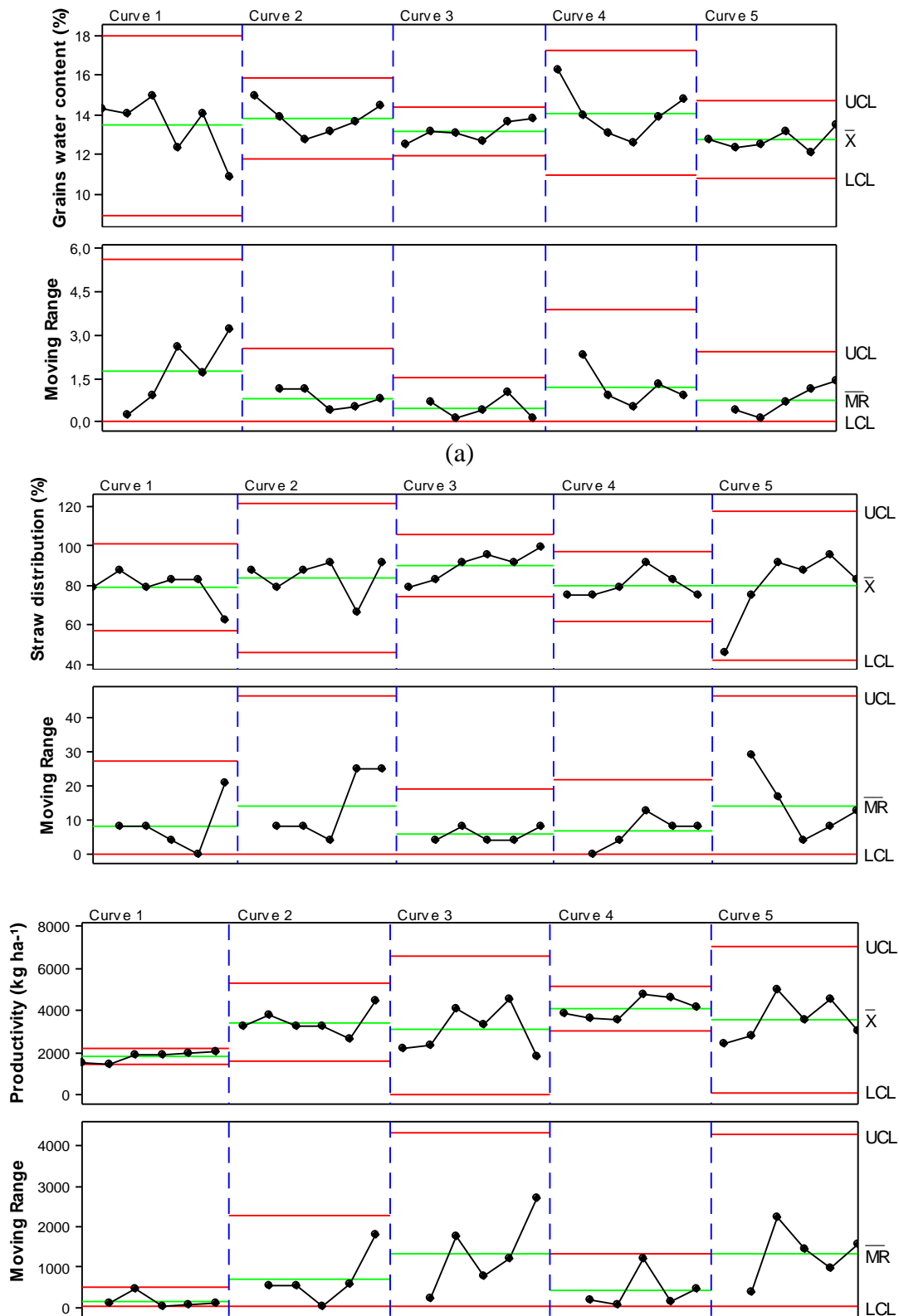


FIGURE 4. Control charts for: a) grains water content (%); b) straw distribution (%); and c) productivity kg ha⁻¹.

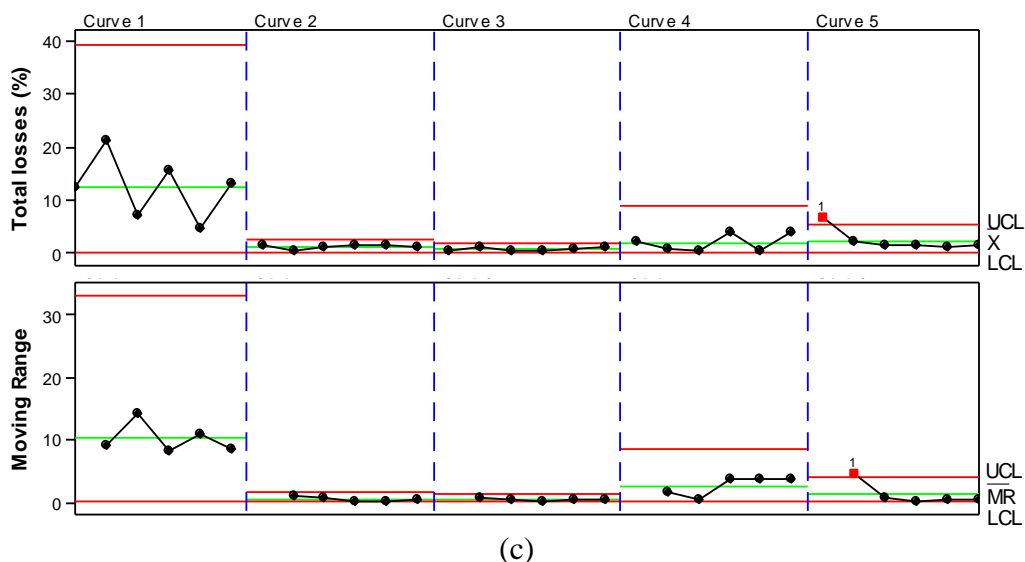
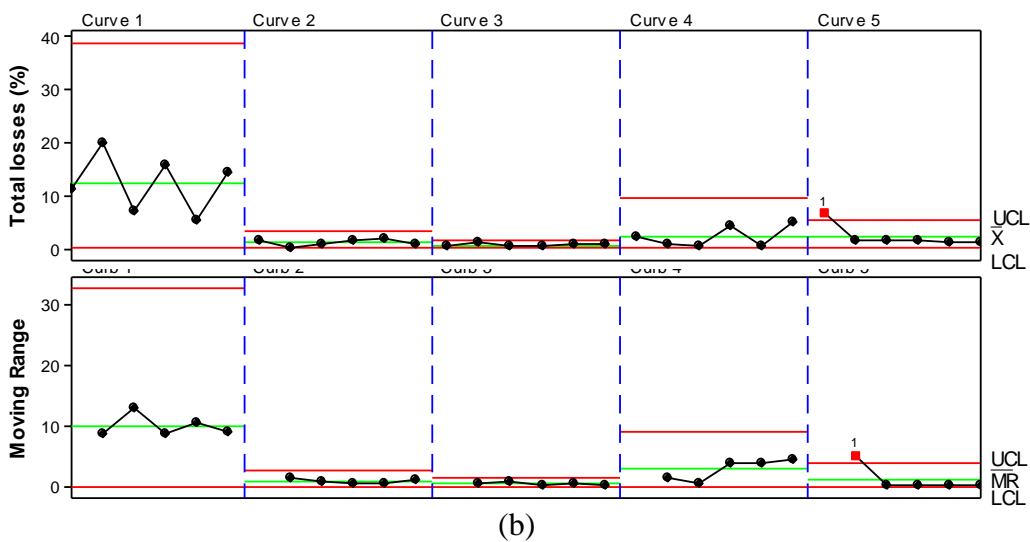
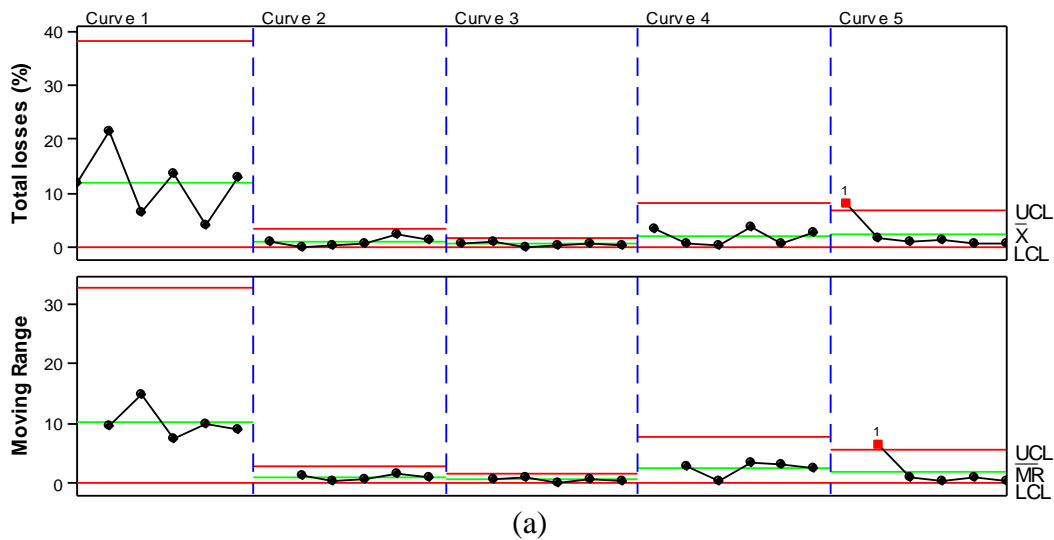
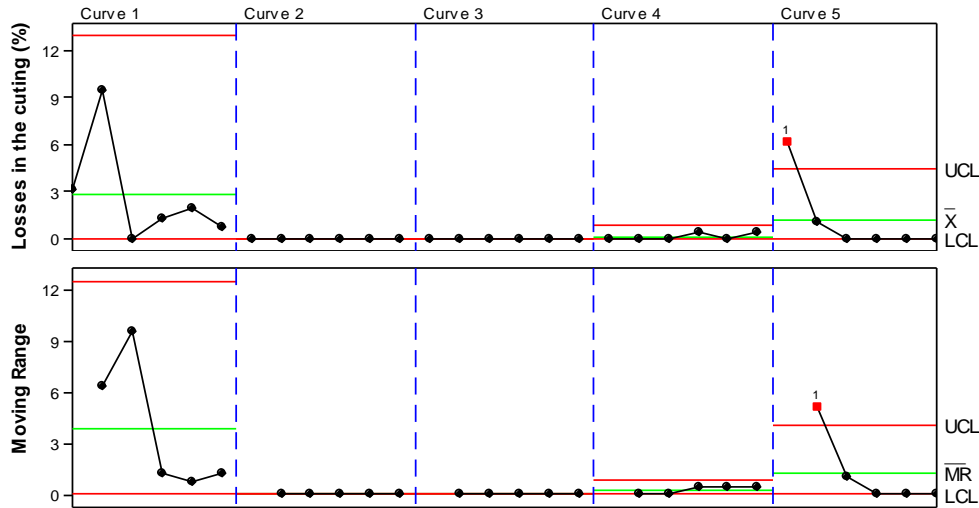


FIGURA 5. Control charts for total losses (%) for the frames: a) 1 m²; b) 2 m²; and c) 3 m².

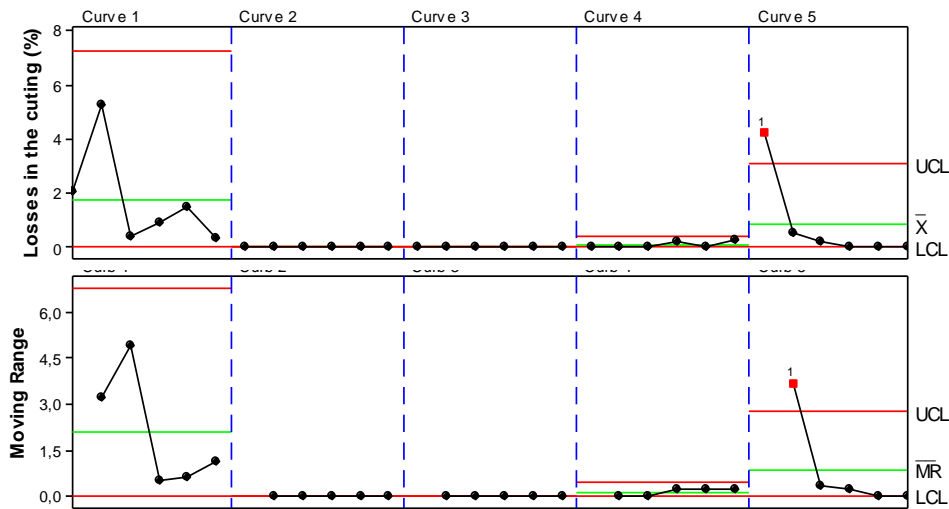
It is observed that regardless of the frame area, losses in cutting, combine and total losses (%) were higher for the points located on curve 1 (Figure 5, 6 and 7). This can be explained by the fact that the same curve shows reduced productivity, as the losses in question are percentages. This curve showed greater variability in the values, since limits are further away from the mean, indicating that the standard deviations were higher.

When comparing control charts for total losses with the other kinds of losses, we note that cutting losses are the main responsible for characterizing it as unstable, because of the marked value of losses found in point 25 due to flaws in the cutting system.

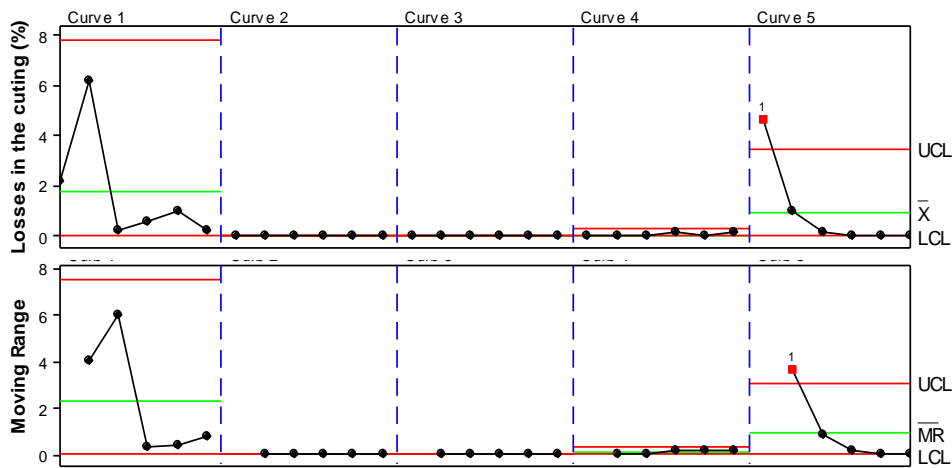
The fact that point 25 has also shown low straw distribution (Figure 4b) may indicate a power deficiency of the combine at this point, which may also have contributed to the higher losses observed there.



(a)



(b)



(c)

FIGURA 6. Control charts for cutting losses (%) for frames of: a) 1 m²; b) 2 m²; and c) 3 m².

Control charts for combine losses (Figure 7) are under statistical process control, in spite of the variation found between the curves, with values close to zero in curves 2, 3 and 5, and higher values in curves 1 and 4.

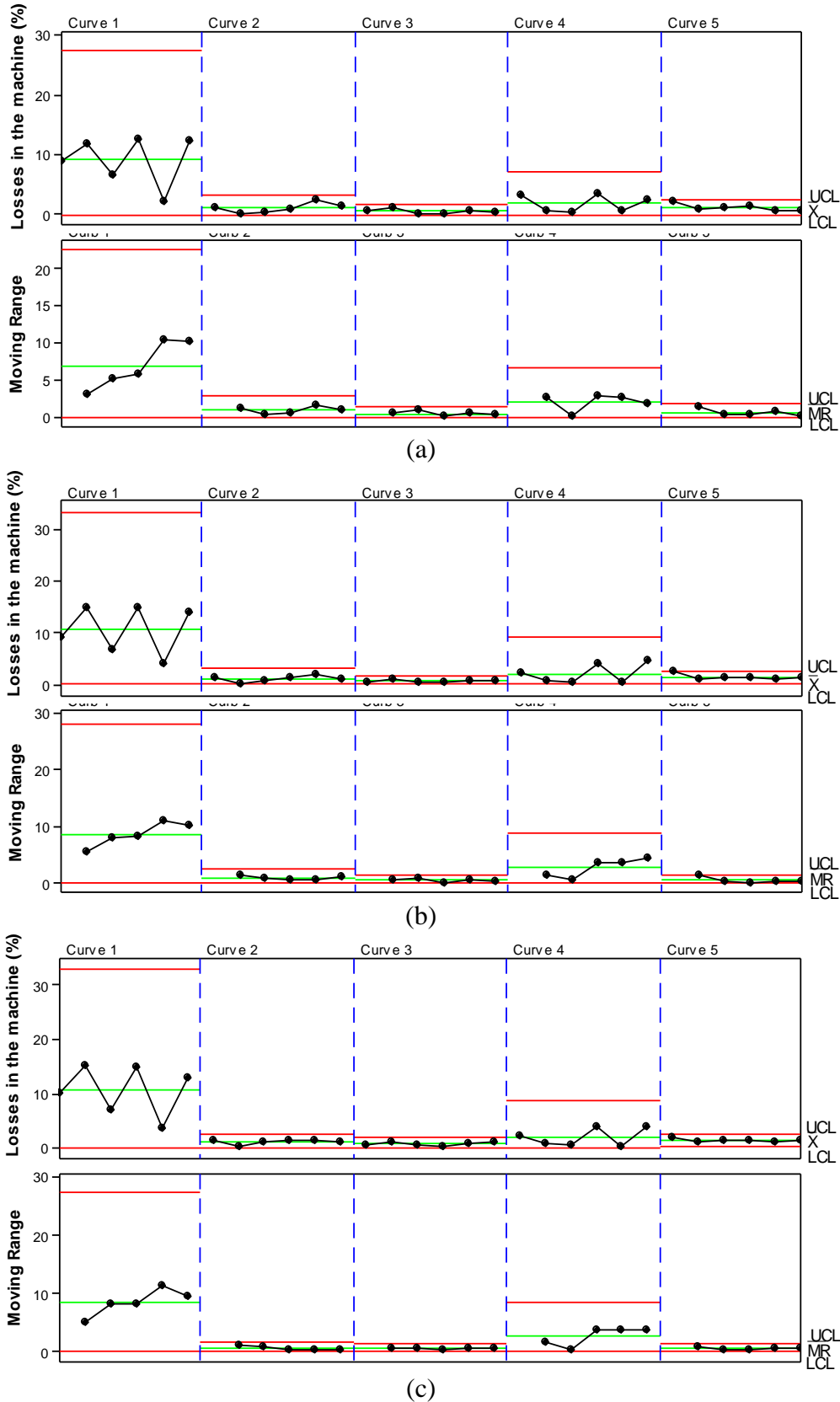


FIGURA 7. Control charts for combine losses (%) for frames: a) 1 m²; b) 2 m²; e c) 3 m².

Based on this information, it can be stated based on descriptive analysis of variance and statistical process control that the frame size does not interfere with quantification and variability of

losses in the mechanized harvest of soybeans. Therefore, the use of the 1 m² frame is fully justified, since it offers greater ease and speed in the sampling process in the field, thereby simplifying the monitoring of the quality of the harvesting operation when compared with the other frames analyzed (2 and 3 m²).

CONCLUSIONS

There was no difference in the quantification of losses with frames of 1, 2 and 3 m², recommending the use of the 1 m² frame due to greater convenience in sampling.

From the perspective of statistical process control, combine losses showed stable behavior in relation to the process assessment, while total losses and cutting losses showed unstable behavior.

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