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Quality of mechanized coffee harvesting in circular planting system

Qualidade da colheita mecanizada de café em sistema de plantio circular

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ABSTRACT

Mechanized coffee harvesting is one of the main technological advances that benefit producers, but problems with planning for planting and crop development and faults in harvester adjustment can reduce the efficiency of the operation, making it more stressful for the crop than manual harvesting. Thus the present study was carried out in the municipality of Patos de Minas, MG, Brazil with the objective of assessing the damage in the vegetable part and the quality of the mechanized harvesting of coffee cropped in a circular planting system under a center pivot, with two rod vibration frequencies and statistical control of the process. It was observed that the negative biennially on the crop reduced the initial coffee load eliminating the effects of the insolation conditions. The harvest quality indices were distributed asymmetrically and the samples varied greatly and only the stripping efficiency was influenced by the axles assessed and were shown to be stable by the statistical control. The damage to the plants by the harvester presented desirable values and did not vary in function of the factors analyzed, but was considered under statistical control.

Key words: ***Coffea arabica*** *L., harvesting loses, statistical control process.*

RESUMO

A colheita mecanizada de café se destaca como um dos principais avanços tecnológicos em benefício dos produtores, porém, problemas com planejamento no plantio e desenvolvimento da cultura, bem como falhas na regulagem da colhedora, podem acarretar em redução na eficiência da operação, tornando-a mais estressante para a cultura que a colheita manual. Diante disso, o presente trabalho foi realizado no município de Patos de Minas, MG, com o objetivo de avaliar os danos na parte vegetativa e a qualidade da colheita mecanizada do café cultivado em plantio circular sob pivô central, com duas frequências de vibração das hastes, sob o controle estatístico do processo. Observou-se que a bienalidade negativa sobre a cultura reduziram a carga inicial de café, eliminando o efeito das condições de insolação. Os índices de qualidade da colheita apresentaram distribuição assimétrica, com grande variabilidade nas amostras, sendo apenas a eficiência de derriça influenciada pelos eixos avaliados, e se mostrando estável pelo controle estatístico. Os danos causados às plantas pela colheita apresentaram valores desejáveis, não variando em função dos fatores analisados, mas sendo considerado sob controle estatístico.

Palavras-chave: ***Coffea arabica*** *L., perdas na colheita, controle estatístico de processo.*

INTRODUCTION

Considered the largest coffee exporter and producer, the coffee harvest in Brazil is still a bottleneck to exploitation of the crop, representing 30% of the production cost and 50% of the labor force used in the productive process (MATIELLO et al., 2009). The advances in technological development in favor of the coffee producers include the coffee harvester to cut production costs using mechanization (SILVA et al., 2001).

With the increase in the technological levels used in coffee cropping, LIMA et al. (2008) estimated that most of the production in one of the main Minas

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Gerais producing regions, the Cerrado, Northern and High Paranaíba came from irrigated areas and it is possible that half is under a center pivot, and the circular planting system predominates, guaranteeing localized irrigation on the coffee plant. However, producers adopting circular planting in low latitude and high temperature regions are concerned with solar radiation that according to MATIELLO et al. (2005) can cause scorched leaves, dry stems, yield loss and unequal ripening.

The correct form of orientation for planting the coffee tree rows should be studied for the best distribution of intercepted radiation on the two sides of the cropping row (BICALHO et al., 2009). LIMA et al. (2008) quoted a study carried out in the Minas Gerais triangle where the greatest productivity was obtained in the rows planted in the Northwest-Southeast and North-South directions. MATIELLO et al. (2005) reported data by SANTINATO et al. (2003) of the mean yield of two harvests for the recommended planting (East-West) and for the Southeast- Northwest planting.

Regarding damage, the action of the shaking rods of the harvester on the coffee tree, similarly to manual stripping, is a relatively stressful operation for the plant. Results by SILVA et al. (2006) and OLIVEIRA et al. (2007a) agree that when dealing with greater efficiency in mechanized harvesting, it causes significantly less damage than manual stripping, but, stripping quality is lost with the harvester and new passes are required over the same plant and damage to the plants increases.

But SILVA et al. (2001) worked with an automated Jacto harvester model K3 and reported 85 to 97% harvest efficiency, with moving speeds ranging from 500 to 1500m h^{-1}, collecting up to 200 sacks per hour. They further observed that, on average, 89% and 86.2% of the coffee stripped by the mechanical harvester was collected, that is, 13.8% of the production remained in the field, 11% because it was not stripped and the rest because it fell on the ground.

In coffee cropping, as in other crops, it is very important the agricultural operations be perfect as a mean to improving the harvest process. Researchers such as SILVA et al. (2000), SILVA et al. (2003), BARBOSA et al. (2005), SILVA et al. (2006) and OLIVEIRA et al. (2007 a, b, c) have studied the operational performance in different harvest systems, locations and field conditions endeavoring to reduce coffee production cost with reduced harvest time and number and harvest efficiency. However, studies are not easily found using statistical control tools in the mechanized harvesting process bearing in mind the need to widen the knowledge base to improve the coffee harvest. TOLEDO et al. (2008) reported that statistical control of the process improves the quality of the process because it reduces variability, but there is no variability-free process so the solution is the search for stability.

Thus, starting from the hypothesis that the variation in the crop development conditions in relation to the planting alignment and alteration in the rod vibration frequency alter the quality of the harvesting operation, the objective of the present study was to assess the mechanized harvesting of coffee cropped in a circular planting system under a center pivot, with two rod vibration frequencies, under exploratory data analysis of the data (descriptive statistics) and the statistical control of the process (SCP) with the use of control charts.

MATERIAL AND METHODS

The study was carried out on the Fazenda São João Grande, located in the municipality of Patos de Minas, MG, 18º33' South and 46º20' West, in the Cerrado region, 1100m average altitude, Cwa climate according to the Köeppen classification. The assessments were made during the harvest in the 2009/2010 growing season in Pivot 5, glebes 1 and 2 in a circular planting system assessed in December 2004, for localized irrigation only on the canopy of the plants by the center pivot, using the Catucai Vermelho cultivar, with 4.0m between row spacing and 0.5m between plant spacing, corresponding to 5000 plants ha^{-1} population density.

The coffee was harvested by the KTR model Jacto harvester manufactured in 2003 with 4000 work hours that operated over the plant rows, powered by a coffee tractor. The harvester has vibratory rods that act around each plant, picking the berries that are collected by a set of retractable blades closing the space under the coffee tree skirt. The harvester is pulled., and operates attached to a MF 265 model 47.8kW (65cv) coffee tractor with a 0.48m s^{-1} (1.74km h^{-1}) average speed during the study, always in the same direction as the plant rows.

The harvest was an average fruit ripeness percentage at the green (14%), cherry (21%) and coco (65%) stages with a mean hanging load obtained by sampling 2.65L $plant^{-1}$, both obtained from the mean of all the sample points. Average operation speeds were maintained in the harvest and the rod vibration frequency was varied from 750rpm (12.49Hz) to 950rpm (15.83Hz), in function of the vibration used by the plantation management at the time of harvest (F1), and the second (F2) chosen from research results obtained by OLIVEIRA et al. (2007c).

Four plant alignment axles were adopted within the tested area to identify the influence of sun exposure on the uniform berry ripening and consequently on the harvest operation quality called Axle I to Axle IV and the position were varied by 45°. Axle 2 was considered by BICALHO et al. (2009) to be the best planting condition because it was the alignment where the sun passed most of the day on the plant canopies, preventing sunray incidence on only one side of the plant. Thus Axle IV was considered the worst planting condition because in one part of the day the sun shone on only one side of the plant, while during the rest of the day it shone on the opposite side, and Axles I and III were considered as intermediate situations.

The experimental design consisted of a combination of two factors, the vibration frequencies (F) used in alternate rows and exposure axles within the center pivot (A) with five replications totaling 40 sample cells. Each one consisted of five plants assessed, with indicative markings and geo-referenced by a Garmin brand GPS model GPSII (with absolute positional accuracy of less than 15m (95%)), and the coordinates were recorded on the UTM Cartesian plan system.

First the coffee load was estimated per plant by hand stripping three plants beside each sample cell, being careful to keep the alignment of the axles assessed. Each cell production was weighed individually and the volume was assessed in a graded recipient to determine the mean yield per plant (L $plant^{-1}$), and then compound samples were separated in the green, cherry and coco conditions. The water content was determined in each sample by the standard chamber method at 105°C for 24 hours. The masses of all the samples estimated in each variable analyzed were corrected for standard 12% water content, and then the values corresponded to the masses of beneficiated coffee (dry) (PINTO et al., 2006).

In each sample cell the harvester operated on stripping cloths covering the ground under the area of five plants of the plant spacing to determine the loss from coffee fallen on the ground after the harvester passed. The berries fallen on the cloth in this area were collected, weighed and the mean losses per plant were calculated. The masses of the leaves and twigs pulled off and found on the cloth were also collected to calculate the damage to the plants from the action of the harvester vibratory rods.

To determine the coffee remaining on the plant after the harvester had passed, the same five plants were stripped manually and after stripping the berries were also collected and weighed separately. The volume of harvested coffee was calculated from the difference between the load in each cell and the sum of the volume of coffee for the manual stripping and the volume fell on the cloth. Harvest quality coefficients and stripping efficiency were determined, obtained by the ratio between the initial coffee load on the plants and the load remaining after the harvester had passed; the collection efficiency by the ratio of the volume of stripped coffee with the volume truly harvested and the harvest efficiency and the total quantity of stripped coffee (sum of the harvested coffee by the harvester and the volume of coffee fallen on the cloth) was compared with the initial load.

Exploratory analysis (descriptive statistics) was used to verify the normality of the data and outlier occurrence or the need to transform for their normalization. Later the analysis of variance of the data and the Tukey test were obtained by the Minitab® 15 computer program after finding the basic premises for statistical analysis. The same program was used to assess the quality of the harvest operation, following the methodology described by TOLEDO et al. (2008) that assessed the statistical quality control using control charts, selected for the quality indicators with a graph for the individual observation and another for the variation in the process, obtained from the amplitude calculated between two successive observations. When an observation surpasses the upper limits (UCL) and lower control (LCL) limits, calculated based on the standard deviation for the process, it is highlighted on the control chart and the process is considered out of control, because it is under the action of special causes of variation.

RESULTS AND DISCUSSION

The estimated values of the descriptive statistical parameters: central tendency (average mean, median and range) and dispersion (standard deviation and coefficient of variation) is showed in table 1. The descriptive statistics were the initial coffee load on the plant, percentage of harvested coffee, stripping and collection efficiencies, and for the leaf loss caused to the plant. For the production values, the average and mid values were close and although the standard deviation and the coefficient of variation (CV) values were very high, with the kurtosis index (Ck) distant from zero indicating high variability among the points evaluated, the values presented normal distribution by the Anderson-Darling test. The positive skewness coefficient (Cs) indicated that the data distribution curve was longer to the right side and the data were concentrated more to the left side compared to the normal distribution curve.

For the indicators assessed of the mechanized harvesting process, the harvested coffee volume and stripping and gathering efficiency showed asymmetrical data distribution by the Anderson-Darling test requiring transformation of the data for their

Table 1 - Descriptive statistics for coffee per plant, stripping and collection efficiency, harvested coffee and leaf loss per plant.

Variable	Coffee load (L plant^{-1})	Stripping efficiency	Collection efficiency (%)	Harvested coffee	Leaf loss (g plant^{-1})
Mean	2.65	63.3	53.9	43.8	187.4
Median	2.70	78.1	71.8	57.0	180.8
Range	7.75	98.9	94.4	91.3	197.4
St Dev	1.56	29.9	36.3	32.9	48.0
CV(%)	59.00	47.31	67.44	75.23	25.62
Cs(%)	0.86	-0.85	-0.57	-0.23	0.88
Ck(%)	2.04	-0.53	-1.41	-1.58	0.62
AD	N	A	A	A	N

CV: coefficient of variation, Cs: skewness coefficient, Ck: kurtosis coefficient;
AD: Anderson-Darling normality test (N: normal distribution; A: asymmetrical distribution)

normalization. The data presented distant average means and median values, and the standard deviation and the coefficient of variation were very high in all these variables that also indicated high variability of the data collected, a common fact in assessments of mechanized operations (TOLEDO et al., 2008). Only for the leaf loss variable, although its coefficient of variation was still high according to classification by PIMENTEL-GOMES & GARCIA (2002), the asymmetry and kurtosis indexes indicated normal distribution of the data, that was confirmed by the Anderson-Darling test.

The analysis of variance with the means test for the variables under study, and there was no significant influence of the treatments on most of the variables analyzed (Table 2). The means observed for the coffee load per plant characterized the crop as being in a negative biannuality year, that is, in a harvest area with low production, with great variability among the points sampled, that raised the coefficient of variation values.

Even with low production, the yields varied among the axles assessed, that was not confirmed statistically also due to the great variability in the data. BICALHO et al. (2009) also assessed the effects of different planting directions on yield in Patrocinio, MG, a region close to where the present study was carried out and obtained greater yields for the Topazio cultivar for the conditions of axles III and IV in low yield years, a fact that did not continue in the high yield years, when the planting direction did not affect the yields.

There was significant influence on the harvest quality indicators from the alignment axles in the stripping efficiency of the harvester. Stripping on axle II was greater than that on axle IV that represented the best and worst planting conditions, respectively. It is pointed out that the other means among the axles assessed performed uniformly among the indicators that influenced the harvest quality, especially the ripeness uniformity of the crop, similar to data reported by BICALHO et al. (2009). The irregularity and the low load volumes observed in the crop affected the distribution of the values obtained and eliminated the effect of variation in the rod vibration, that presented a direct relation with the same variables analyzed by OLIVEIRA et al. (2007c) who worked with the same vibration frequencies also in a KTR harvester but in a positive biannual year (high yield growing season).

Regarding to the plant damage by the harvester, the leaf loss values remained at low levels for all the factors analyzed. SILVA et al. (2003) and OLIVEIRA et al. (2007b) also worked with a KTR model harvester in the municipality of Boa Esperança, Minas Gerais and reported that Novo Mundo cultivar coffee trees presented average damage around 810g plant^{-1}. OLIVEIRA et al. (2007b) also in Boa Esperança studied the influence of the rod vibration variation and moving speed in the coffee bean stripping process of the KTR harvester, setting the moving speed and varying the rod vibration at one pass and two passes and observed that for the first harvester pass the increase in damage was directly linked to the increase in rod vibration presenting values close to 700g plant^{-1} for 765rpm (15Hz) vibration, values much greater than those detected in the present study, because the authors used a slower moving speed (0.45m s^{-1}) leaving the rods in contact with the plants for a longer period.

In the control charts for the indicators of volume harvested coffee, stripping and harvesting efficiencies, met out of control in all observations during the study period (Figure 1). All the harvest quality indices assessed showed that the mechanized coffee harvest process was under control, because there was no occurrence of points outside the limits (UCL and LCL) in the cards obtained. As in the descriptive statistical

Table 2 - Analysis of variance and means test for coffee per plant, stripping and collection efficiency, harvested coffee and leaf loss per plant.

Variable	Coffee load (L plant-1)	Stripping efficiency	Collection efficiency	Harvested coffee	Leaf loss (g plant-1)
		---------------(%)---------------			
---Vibration frequencies (F)---					
750 rpm	2.84	62.2	57.6	44.8	174.7
900 rpm	2.45	64.5	50.1	42.5	200.0
---Axle (A)---					
I	2.76	69.8 ab	61.7	49.6	187.7
II	3.25	79.3 a	70.3	58.9	173.8
III	2.14	58.0 ab	48.7	36.6	185.1
IV	2.44	46.3 b	34.7	29.7	202.9
---F test (P<0,05)---					
F	0.451^{ns}	0.773^{ns}	0.397^{ns}	0.623^{ns}	0.115^{ns}
A	0.483^{ns}	0.045^{*}	0.097^{ns}	0.112^{ns}	0.631^{ns}
F x A	0.977^{ns}	0.480^{ns}	0.340^{ns}	0.227^{ns}	0.869^{ns}
CV(%)	59.00	32.07	51.80	54.97	25.62

In each column, for each factor, means followed by the same letters do not differ by the Tukey test at 5% probability. ^{ns} No significant; * Significant at 5% probability by the F test.

analyses (Table 1), great temporal variability was also observed in the samples, but due to the crop conditions, the harvest process was maintained within acceptable standards, attributing reliability to the process.

In the control charts for the damage in the harvest (Figure 2), it was also observed that the process remained under statistical control, maintaining the damage means at 187.4g, desirable values for the

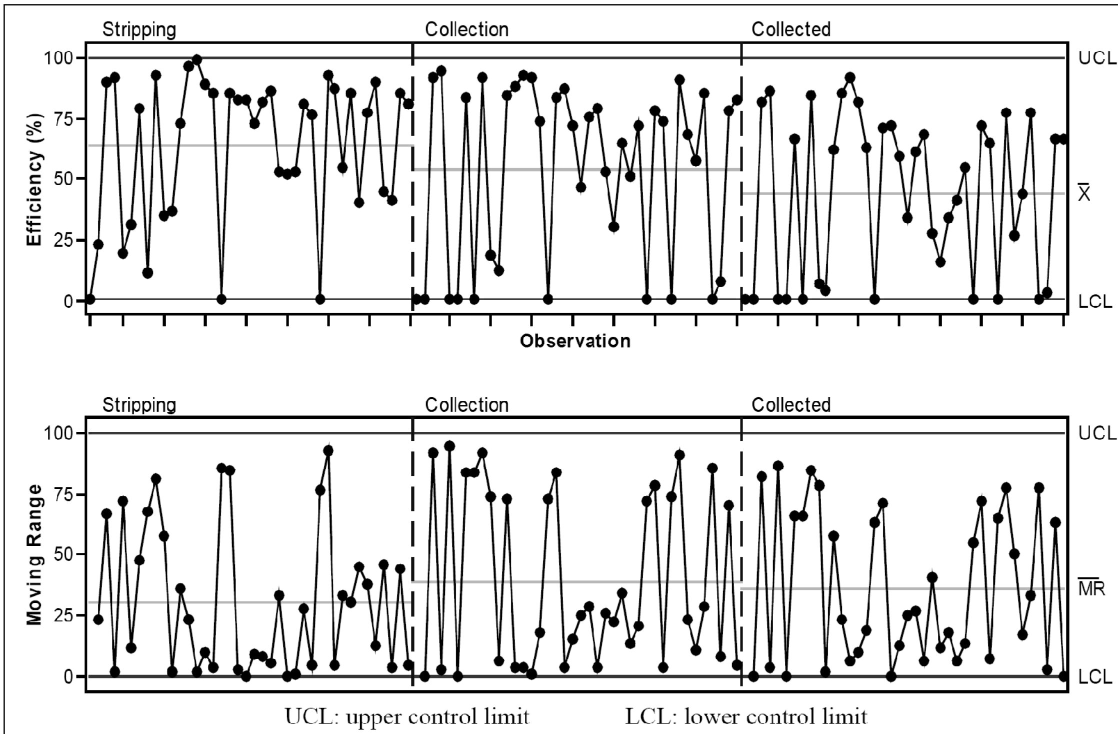

Figure 1 - Control chart for stripping efficiency (%), collection efficiency (%) and harvested coffee (%).

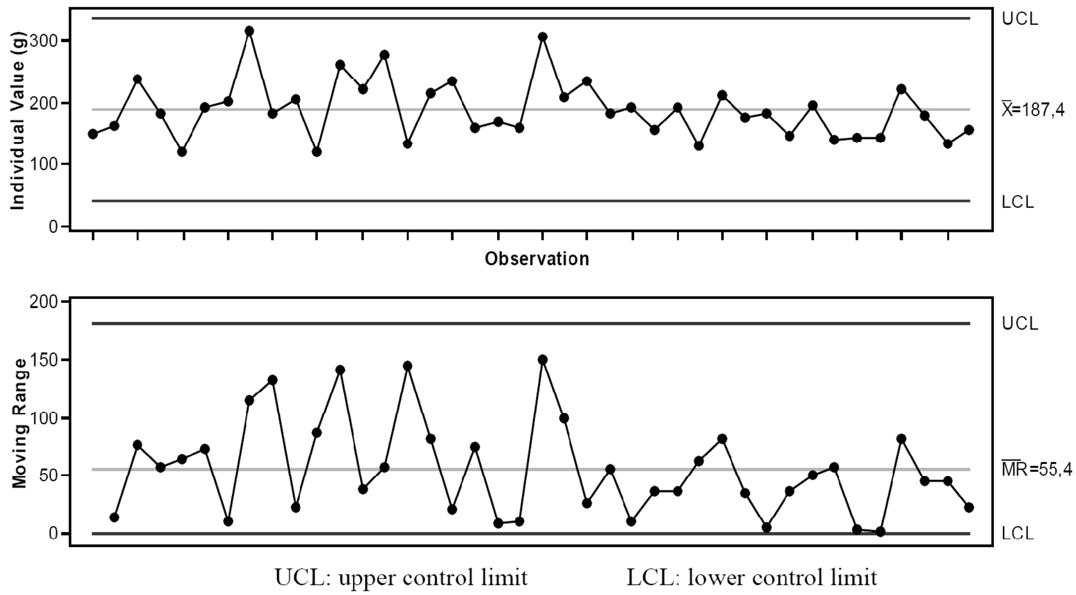

Figure 2 - Control chart for leaf loss per plant (g).

mechanized harvesting process compared with research results obtained under the same conditions (OLIVEIRA et al., 2007a). Because it was shown to be under statistical control, greater reliability was attributed to the mechanized coffee harvesting process, showing there was a standard maintained during the development of the operation subject only to the effect of common causes, that influenced the process in a controlled manner, without loss of confidence in the process as a whole (MILAN & FERNANDES, 2002).

CONCLUSION

The harvest quality indices presented asymmetric distribution, with great variability in the samples, but they were shown to be stable by the statistical control, and only the stripping efficiency was influenced by the axles of solar exposure of the coffee plants within the center pivot.

The damage caused to the plants by harvesting presented desirable values, and did not vary in function of the factors analyzed, but was considered to be under statistical control.

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