Spatial variability in mechanized coffee harvesting at two travel speeds

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Abstract.

Within the scope of Precision Agriculture (PA), monitoring the spatial variability of mechanized operations is a strategy for improving operational efficiency in coffee plantations. The evaluation of mechanized harvesting should consider, in addition to the harvested volume, the proportion of coffee effectively detached in relation to fallen coffee (FC) and remaining coffee (RC), variables directly linked to operational efficiency. Harvesting was carried out at Mariano Farm, in Poços de Caldas, Minas Gerais, Brazil (21°41'54" S; 46°32'19" W), using the Catuaí IAC 62 cultivar and a TDI harvester, a conventional self-propelled 2010 model equipped with double vibrating rods, spring collectors, a 3000 L tank, and a maximum harvesting height of 3.9 m. The tested speeds were 854 m h^{-1} and 621 m h^{-1}, both with a shaking system vibration of 1200 rpm. Considering the spacing of 3.7 m between rows and 0.6 m between plants, the speed of 854 m h^{-1} provided an exposure time of 50.6 s plant^{-1}, while 621 m h^{-1} resulted in 69.6 s plant^{-1}. The experimental design was based on Statistical Process Control (SPC), with eight coffee rows, four designated for destructive sampling and four for harvester passage, alternated between each other. In each row, five sampling points were established at 15 m intervals, totaling 20 points per treatment and 40 points overall. The yields from the destructively sampled rows supported the calculation of the percentages of harvested coffee, FC, and RC. The mean percentages of harvested coffee were 78.77% for 854 m h^{-1} and 69.75% for 621 m h^{-1}, with an overall mean of 74.26%. The control chart analysis, processed in Minitab, showed that for RC at the speed of 854 m h^{-1}, the mean was 0.46 kg, with an Upper Control Limit (UCL) of 1.212 kg, Lower Control Limit (LCL) of 0 kg, variability (UCL − $\bar{x}$) of 0.752 kg, no points outside the limits, and a stable process. At 621 m h^{-1}, the mean was 0.508 kg, UCL of 1.813 kg, LCL of 0 kg, variability of 1.305 kg, no points outside the limits, and a stable process. For FC, at 854 m h^{-1}, the mean was 0.668 kg, UCL of 1.13 kg, LCL of 0.206 kg, variability of 0.462 kg, no points outside the limits, and a stable process. At 621 m h^{-1}, the mean was 1.296 kg, UCL of 3.023 kg, LCL of 0 kg, variability of 1.727 kg, no points outside the limits, and a stable process. Although both processes were statistically stable, reducing speed from 854 to 621 m h^{-1} increased the variability of FC (from 0.462 to 1.727 kg) and RC (from 0.752 to 1.305 kg), indicating greater mechanical aggressiveness under longer exposure time. In conclusion, increasing the exposure time from 50.6 s to 69.6 s did not reduce the average RC, but increased FC and widened the control limits, characterizing a less efficient operational condition.

Keywords.

harvesting, coffee, speed, exposure, losses, efficiency, variability.

1. Introduction

Brazil is the world's leading producer and exporter of coffee, which makes it strategic to adopt technologies that increase operational efficiency and reduce production costs. The mechanization of harvesting stands out as an alternative to sustain the competitiveness of the sector in the face of the scarcity and high cost of rural labor (Santinato *et al*., 2015).

The efficiency of mechanized harvesting depends on the ability of the harvester to promote the detachment of fruits efficiently. Thus, in addition to the volume harvested, it is essential to quantify the indices of fallen coffee (CC) and remaining coffee (CR), variables that express the quality of the operation and directly influence the profitability of the activity (Santinato *et al*., 2015). In the context of Precision Agriculture, Statistical Process Control (SPC) has been used to monitor the quality and stability of mechanized agricultural operations, allowing the identification of special causes of variation (Cassia *et al*., 2013).

In mechanized coffee harvesting, the time of exposure of the plants to the vibrating rods, resulting from the speed of displacement and the frequency of vibration of the harvester, directly influences the detachment of the fruits (Oliveira *et al*., 2007). Evaluating the fallen and remaining coffee under different exposure times subsidizes adjustments for greater efficiency and quality of the harvest.

2. Objective

To evaluate, by means of Statistical Process Control (SPC) tools, the influence of different times of exposure of coffee plants to the action of the vibrating rods of the harvester on the indices of fallen coffee (CC) and remaining coffee (CR), analyzing the stability and operational variability of mechanized harvesting.

3. Material and methods

The experiment was carried out at the Mariano Farm, in Poços de Caldas, MG (21°41'54" S; 46°32'19" W), in a crop of the cultivar Catuaí IAC 62, harvested with a conventional self-propelled harvester TDI (2010), with a double vibrating rod derriça system, spring collectors, a 3,000 L reservoir and a maximum harvest height of 3.9 m. 854 m h^{-1} and 621 m h^{-1}, maintaining the vibration frequency at 1,200 rpm. The exposure time(TE) was determined by Equation1, described by Silva and Francetto (2025):

$$TE = 60 \times EPL \times V_H / V_C \quad (1)$$

where TE is the exposure time (s $plant^{-1}$); EPL is the spacingbetween plants in the row (m); VH is the frequency of vibration of the rods (rpm); and VC is the speed of displacement of the harvester (m h^{-1}) (Silva; Francetto, 2025). Considering the spacingof 3.7 m between rows and 0.6 m between plants, exposure times of50.6 s $plant^{-1}$ (854 m h^{-1}) and 69.6 s $plant^{-1}$ (621 m h^{-1}) were obtained.

Eight rows of coffee were selected, four for mechanized harvesting and four for destructive sampling, interspersed, with five sampling points spaced at 15 m per row, totaling 20 observations per treatment and 40 in the experiment. The destructive sampling lines allowed to estimate the actual yield and calculate the percentages of harvested, fallen (CC) and remaining (CR) coffee. The data were analyzed by control charts for individual values (Minitab®), determining the process mean, the Upper and Lower Control Limits (LSC and LIC) and the control amplitude, and the stability was evaluated by the presence of points outside the limits and by patterns indicative of special causes of variation (Noronha *et al*., 2011).

4. Results and discussion

The averages of coffee harvested were 78.77% (854 m h^{-1}) and 69.75% (621 m h^{-1}), with an overall average day of 74.26%, indicating that the reductionin speed, and the consequent increase in exposure time, did not increase the efficiency of the harvest.

For the remaining coffee (CR), the average was 0.46 kg at the speed of 854 m h^{-1} (LSC of 1.212 kg; amplitude of 0.752 kg) and 0.508 kg at the speed of 621 m h^{-1} (LSC of 1.813 kg; amplitude of 1.305 kg), with no out-of-bounds points in both treatments, showing static stability of the process.

For fallen coffee (CC), the average was 0.668 kg at the speed of 854 m h^{-1} (amplitude of 0.462 kg) and 1.296 kg at the speed of 621 m h^{-1} (amplitude of 1.727 kg). Despite the static stability verified, a significant increase in soil losses was observed with the reduction of velocity.

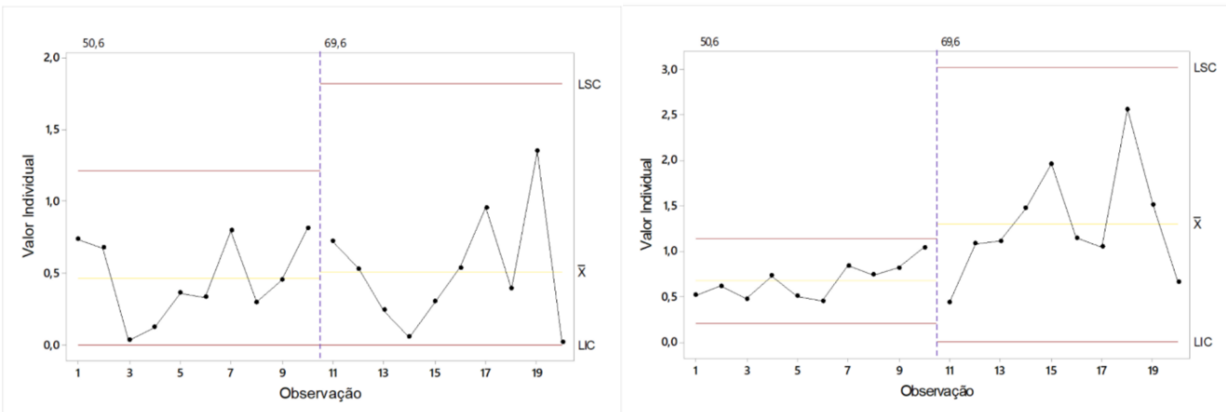

Fig 1. Control charts of remaining coffee and fallen coffee respectively.

5. Conclusion

In general, the increase in exposure time from 50.6 to 69.6 s $plant^{-1}$ did not significantly reduce the remaining coffee, but it did increase the coffee and process variability, indicating that the prolongation of the actionof the vibrating rodsintensifies the detachment of fruits, increasing, however, greater fall of fruits to the ground, reducing the operational efficiency of the harvest.

6. References

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