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Full Length Research Paper

Operational performance of the mechanized picking of coffee in four soil slope

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Received 3 August, 2016; Accepted 11 October, 2016

The coffee mechanized picking is an essential operation in modern coffee crop, however, is still an activity with few studies that emphasize the factors that could interfere in its operational performance. Assuming that the slope of the land can be one of these factors, it aimed to evaluate operational performance of a mechanized set of coffee picking in different terrain slopes. The treatments consisted of coffee mechanized picking in four slope lanes (0.0 to 5.0%, 5.1 to 10.0%, 10.1 to 15.0 and 15.1% to 20.0%) distributed in experimental design in lanes with three replications. The evaluation of the operational performance was materialized by means of timing and movements' analysis, collecting up time in operation, unloading and maneuvering, as well as efficiencies analysis of picking and cleaning. The operation was performed in crop with 1.133 kg of coconut coffee ha⁻¹ to be picked. The slope of the land, from 15.1%, interferes in the performance of the harvester, significantly reducing the effective and operational field capacity. Slopes of up to 20% do not harm the cleaning efficiency; on the other hand, for picking efficiency, slopes higher than 15% significantly reduce the performance of the machines.

Key words: *Coffea arabica* L., land slope, mechanical harvesting, machine performance, harvesting loses.

INTRODUCTION

The Brazilian coffee production experienced in recent years, a change of scenery, in which occurred the increase of costs with input and labor, but without the corresponding increase in prices received by the production (Fernandes et al., 2012). Thus, the producers had to adapt, reducing the possible costs and increasing crop yields. The way was to invest in technologies that

increase yields and reduce the demand for labor, such as the substitution of manual harvesting by mechanized (Lanna and Reis, 2012).

Coffee mechanized harvesting is currently constituted of two stages; the first being represented by the coffee harvest in the plant, while in the second, there is the coffee picking lying on the ground, also called sweeping

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coffee (Tavares et al., 2015). Total replacement of manual harvesting by mechanized allows reducing the cost of harvesting up to 60% (Santinato et al., 2015a; Lanna and Reis, 2012; Silva et al., 2003).

While big part of the producing regions choose to mechanized harvesting, areas with sloping reliefs can reduce or even prevent the use of machinery (Fernandes et al., 2012). Höfig and Araujo-Junior (2015) classifies soil slope with potentiality for mechanization in the coffee culture in extremely apt (0 to 5%), very apt (5.1 to 10%), apt (10.1 to 15%) moderately apt (15.1 to 20%) and not recommended (> 20%). On the other hand Santinato et al. (2015b) reported that recent improvements in harvesters, as well as good planning of crops, have favored the harvest in areas with up to 30% of slope.

In the second step of mechanized harvesting, referring to the sweeping and picking, few studies are available in the literature. According to Tavares et al. (2015), there are many factors that affect the quality of these operations, such as differences in level and uneven ground, amount of impurities and quantity of coffee. On the other hand, there is no information if the slope interferes in the coffee mechanized picking operation efficiency.

In one of the few studies evaluating effects of slope in mechanized operations, Pereira et al. (2012) studying subsoiling found that to the measure in which the slope increases, the depth reached by the subsoiler decreases. On the other hand, Robert et al. (2013) found no significant losses in operating capacity of a forest harvester to the slope of 27%. Therefore it is liable to study each operation to verify their limitations about the slope of their workable areas.

In surveys conducted by Bernardes et al. (2012), in the state of Minas Gerais that represents 50% of national production, crops are found in almost all the slope tracks, however, there is a predominance of crops on slopes between 5 and 15%.

Assuming that the slope can affect the performance of coffee mechanized picking operation, the objective of this study was to evaluate, through the analysis of time and motion as well as the efficiency of picking and cleaning, the performance of the harvester in four slope lanes.

MATERIALS AND METHODS

The experiment was conducted in August 2015 in the agricultural area of the municipality of Presidente Olegário, Minas Gerais, near the geodetic coordinates latitude 18° 33 'South and longitude 46° 20' West, with an altitude of 1030 meters. The soil is classified as Dystrophic Oxisol by the EMBRAPA classification (2006), having sandy texture with 70% of sand. The weather is Aw according to the classification of Peel et al. (2007), with average rainfall of 1,400 mm annually.

The experimental area corresponds to 2.0 ha with lines of 235 m in length, of Catuaí Vermelho IAC 144 variety, cultivated in level in the spacing of 4.0 m between rows and 0.5 m between plants (5,000 plants ha⁻¹) at 32 months of age, drip irrigated.

The coffee picking was conducted using the mechanized

combination of a tractor 4 x 2 with a nominal power of 55.2 kW (75 hp) and a Master II coffee harvester, operating at 540 rpm in TDP rotation and theoretical speed of 1.0 km h⁻¹. It is emphasized that, because it is an area with slope bigger than 15%, the tractor had liquid and metal ballast, in addition to working with larger track gauge (1.23 m). In this sense, it the front axle was equipped with 240 kg of metallic ballast and 220 kg of liquid ballast and on the rear axle was used 200 kg of metal ballast and 350 kg of liquid ballast, providing greater stability and safety in the operation.

The treatments consisted of collecting mechanically the fallen coffee in four slopes lanes: 0.0 to 5.0%; 5.1 to 10.0%; 10.1 to 15.0% and 15.1 to 20.0%. This slope was evaluated by the average of 15 points for interrow, spaced 15 m apart, with the aid of a digital clinometer 1.4 Apk. Thus, the experimental design was in lanes with three replications (3 lines of coffee for each treatment).

Previous to picking efficiency analysis, it was performed the area characterization. It was determined the quantity of coffee present in each plot, raking up in an interrow area of 30 m², obtaining the existing coffee load of 1,133 kg ha⁻¹ (8.1 bags ha⁻¹).

During the operation, it was evaluated the timing and movements, measuring with aid of stopwatch and a field notebook, the time spent picking, making maneuvers and unloading, as shown in Table 1.

After data acquisition, the times obtained were extrapolated to the area of one hectare. Operational efficiency was calculated according to ASABE EP 496.3 rules (2011), while the time efficiency and the operational and effective field capacity were determined in accordance with Mialhe (1974).

The effective field capacity was adapted from Mialhe (1974) and calculated by means of Equation 1.

$$Efc = \frac{S \times R}{10} \quad (1)$$

Where:

Efc: effective field capacity (ha h⁻¹);

S: displacement speed (km h⁻¹);

R: interrow spacing of coffee (m);

10: adequation fator of the units.

Operational field capacity has already been adapted from Mialhe (1996) according to Equation 2. Is worth emphasizing that the harvester efficiency is the percentage of time where the same is operating effectively, discounting the maneuvers and the unloading compared to the total time (Equation 3).

$$Ofc = \frac{S \times R \times Ef}{10} \quad (2)$$

Where:

Ofc: operational field capacity (ha h⁻¹);

S: displacement speed (km h⁻¹);

R: interrow spacing of coffee (m);

Ef: efficiency of harvester;

10: adequation fator of the units.

$$Ef = \left\{ \frac{Tc}{Tc + Tm + Tu} \right\} \times 100 \quad (3)$$

Where:

Ef: efficiency of harvester (%);

Tc: Collecting time (s);

Tm: Maneuver time (s);

Tu: Unloading time (s).

Table 1. Division of activities in the coffee mechanized picking.

Activity	Description
Total time	Time in which the harvester starts working (picking) to end of the unload, including picking time, maneuvering and unloading.
Picking time	Time demanded for the coffee picking, comprising the time the harvester platform remains positioned on the ground picking the windrows.
Maneuvers time	Time spent to transport the harvester from one row to another, counted from the moment in which the harvester platform is lifted of the ground, in the interrow end, until the repositioning of the same on the ground at the beginning of another interrow.
Unload time	Time required to unload and return to the crop, being the time counted after the removal of the platform from the ground, including the displacement until the transport unit (bucket, trailer or truck), the unload and the return to the crop, when the harvester platform is positioned again on the ground.

For evaluation of cleaning efficiency, it was collected directly from the elevator that carries the collected material for the machine deposit, three sub samples of 1 L, per repetition, resulting in twelve samples per treatment. And then, mineral and vegetable impurities were separated manually from the coffee. The materials have their mass determined in accurate weight balance to 0.1 g, and the values were transformed into percentage in order to obtain the purity and impurity of each sample, being the purity percentage that represents the separation efficiency of harvester.

The picking efficiency was calculated by the loss levels in each sample point (coffee not picked by the machine) according to the equation 4. Again, three random points per interrow were collected, totaling twelve points per treatment. These losses were collected with the aid of a metal frame of 3.8 m² (3.8 m x 1.0 m) subdivided into three parts, two of 1.1 m² in the extremities and one of 1.6 m² in the center part, positioned perpendicularly between the lines after the picking operation. Initially the fruits found in the central region of the frame were collected, which represents the place of the harvester performance and consequently the picking losses.

$$PE = \frac{(CW - L)}{CW} \times 100 \quad (4)$$

Where:

PE: Picking efficiency (%);

CW: Total amount of coffee in windrows (kg m⁻²);

L: Loss or remaining coffee (kg m⁻²).

The results were submitted to analysis of variance by F test of Snedecor and, when appropriate, Tukey test, both at 5% probability.

RESULTS AND DISCUSSION

In Figure 1, time spent on unloading is observed, maneuvers and in operation to perform the picking at one hectare. Given that the unloading time is influenced by the distance between the area and the place of unloading (trailer), it was used in this study the unloading average into the total area evaluated, obtaining the average time of sixteen minute unloading per hectare to the working conditions. On the other hand, the times of maneuvers and operation were affected by the slope. For the

maneuver times, it was noted that in areas from 10.1 to 15.0% and 15.1 to 20.0% of slope there was an increase in time spent on maneuvers in the order of 37 and 106%, respectively, in relation to the picking realized in area with lower slope (0.0 to 5.0%). The same occurred to the time spent on picking operations, in which to operate in the area from 15.1 to 20.0% of slope had an increase of 1 h 29 min ha⁻¹ (111%) on the time spent when compared to the same route in local lower slope (0 to 5%). This occurred by the fact that, in larger slopes; there are points of greater inclination that require the operator to change gears all the time to reduce speed and the risk of the harvester to fall over.

Similar results were found by Leite et al. (2014) in forestry mechanical harvesting, in which by working in areas of 17% of slope there an increase of 11% of the time is spent to perform the same amount of service to the area with 7% of slope, increasing the cost of harvesting. Höfig and Araujo-Junior (2014) emphasize the importance of considering the slope in the planning of the coffee mechanization, treating each slope level suitability in a unique way.

Efficiency of harvester was not affected by the slopes (Figure 2a) showing values between 82.9 and 83.6%. This fact is explained by the operation and maneuver times be harmed in a proportional way with increasing of the slope (Figure 2b). As also observed by Pereira et al. (2012), in which the slope increased the total time of subsoiling operation in pasture area. On the other hand, Robert et al. (2013) found no differences by studying the performance of a forest harvester working on high slopes, a fact that occurred due to the presence of continuous tracks.

In general, in places with greater irregularity, the picking operation has harmed their income significantly and may incur errors in the previous planning of time spent for this operation. This time interferes in the operational and effective field capacity (Figure 3) which decreases in a similar manner as long as it increases the slope of the terrain. The reason to present similar

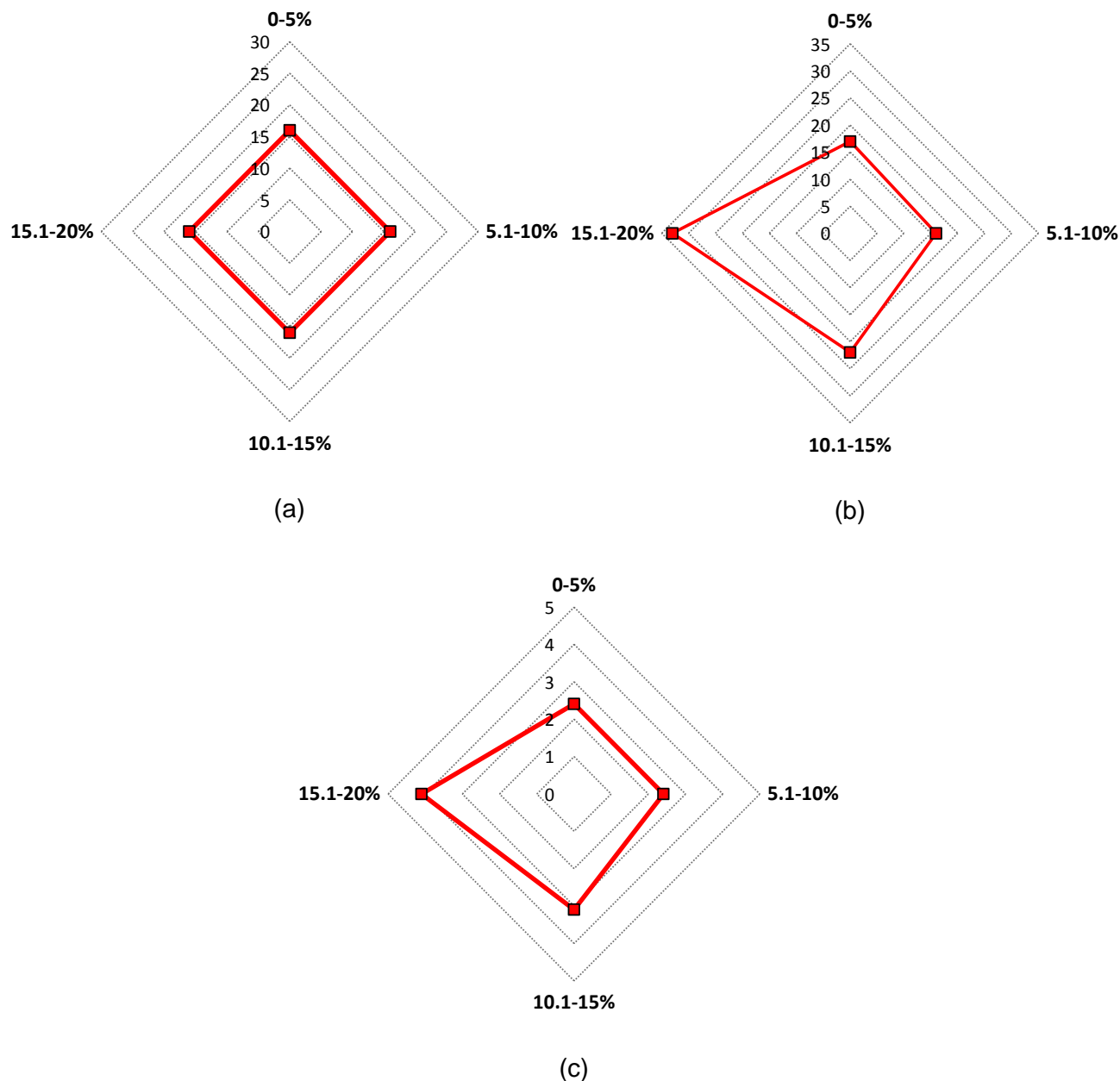


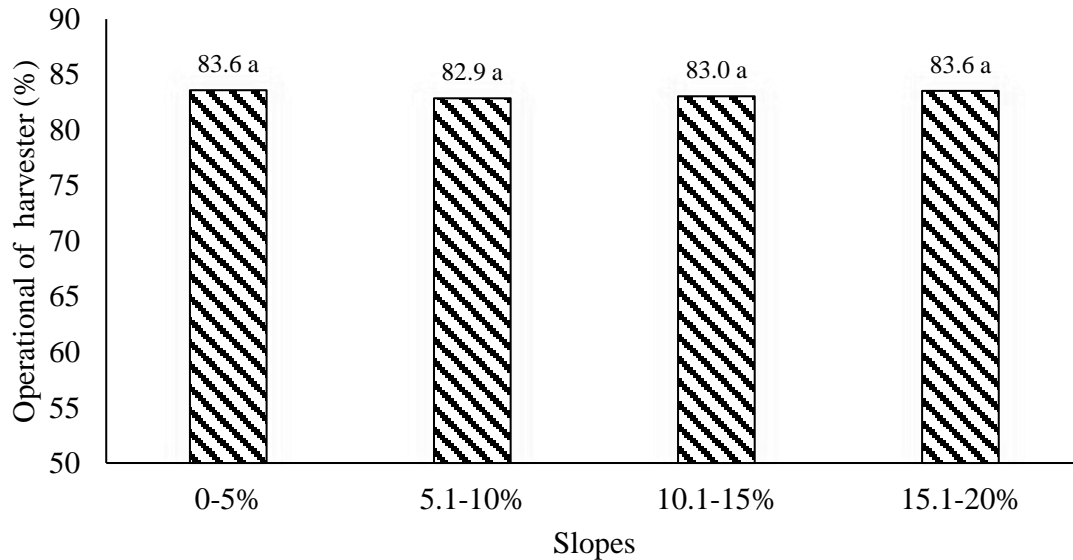
Figure 1. Estimated times for unloading (a), maneuvers (b), and time in operation (c) in min ha⁻¹. Means followed by the same letters do not differ by Tukey test at 5% probability.

behavior is only due to the fact that there was no difference in efficiency of harvester (Figure 2a) for the studied slopes. Therefore, in this case, the operational field capacity is equivalent to approximately 83.55% of the effective field capacity.

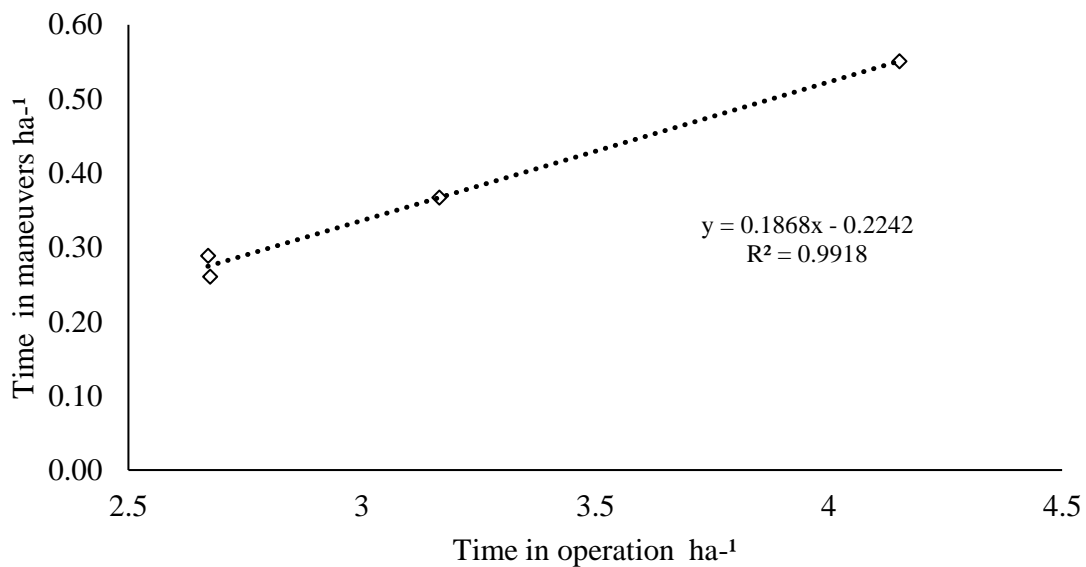
Also in Figure 3, it was observed that for standard working speed used on the farm, it would be possible to perform the picking of 0.31 ha in a one hour period (without stopping) in areas from 0.0 to 10.0% of declivity, however, for areas with 10.1 to 15.0% and 15.1 to 20.0% of slope had reduced by 13 and 42%, respectively, the

operational field capacity. This fact should be considered in the harvest planning, and can be adjusted the number of tractor-harvester sets to perform the picking in the required period.

Molin et al. (2006) reported that information on the performance and working capacity of agricultural machines are of great importance in the management of agricultural mechanized systems, helping in decision making. Thus, it is necessary to adjust the number of mechanized sets to the crop situation and the time to perform the service. Corroborating with this, Leite et al.



(a)



(b)

Figure 2. Efficiency of harvester (a) and correlation between time in operation and time in maneuvers (b) in function of the slope, equivalent to 1 h^{-1} .

(2014) report that for the eucalyptus mechanical harvesting there is a demand service 11% higher in declivous locations when compared to flat areas.

Besides the operational characteristics, we should also analyze the quality of the operation itself. In this way, we used two variables: picking efficiency and cleaning. The results obtained are shown in Figure 4, by which it is noted that the picking efficiency is significantly influenced

by the slopes, which is not observed in the cleaning efficiency.

The harvester picked on average 70.1% of the ground coffee, then the remaining coffee was not picked for two reasons: first because the area is of the first crop, with certain irregularity of the ground surface. Usually this irregularity was adjusted over the years as a result of other tracts such as weed control with macerator (brush);

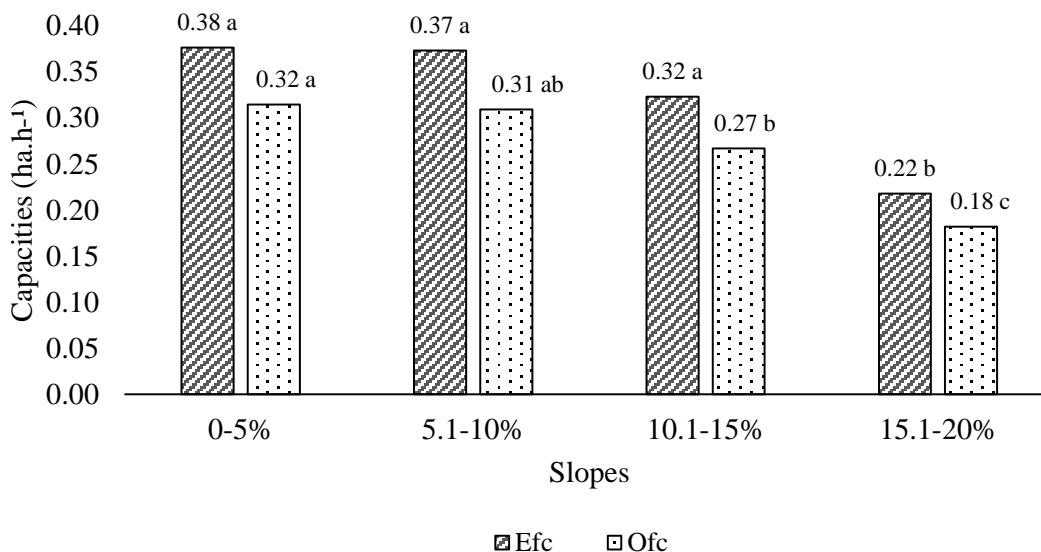


Figure 3. Effective field capacity (Efc) and operational field capacity (Ofc) in function of the slope, in hectares h⁻¹.

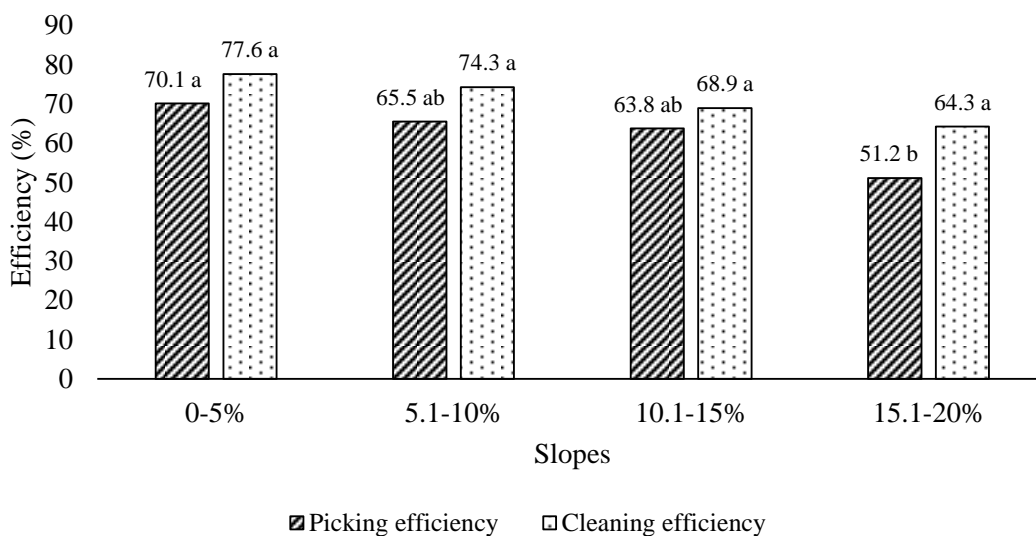


Figure 4. Picking and cleaning efficiency of the harvester due to the slope of the terrain.

the second reason is related to the type of soil that had a high percentage of sand, favoring the moment of squaring, the burying of the fruit, preventing them to be captured by the harvester platform.

Tavares et al. (2015) explain that the harvesters have great sensitivity to the shape and composition of the windrows, as well as the surface soil disuniformity, being necessary to perform previous operations to facilitate the process of picking and cleaning the sweeping coffee. Santinato et al. (2015) points out that the mechanization of harvesting activities have an important role to reduce

costs as well as increases the operational capacity, being of great importance for sustainability of the activity.

The cleaning efficiency had average between 77.6 and 64.3%, lower values than those found by Tavares et al. (2015) conducted in adult crops with soft relief (3% of slope), in which they obtained average of 85% of cleaning efficiency. It was also noted that the slope did not affect significantly on the harvester cleaning process. In principle this can be explained by the existence of partitions in the cleaning sieves which prevent the material to concentrate only on one side of the harvester

when it is inclined. In this way, the material is distributed during the cleaning process, assists in the separation capability and in the elimination of impurities. In case of does not exist these partitions, the material would concentrated only on one side and would not occur the separation of the coffee impurities, that could increase them in the picked coffee and raise the losses levels.

Conclusions

- 1) The coffee mechanized picking may be made with the same performance in slopes of 0 to 15%.
- 2) From 15.1% of slope there is a reduction of 42% of operational and effective field capacities when compared to plain areas.
- 3) In areas with slopes up to 15.1% the demand for mechanized sets increases by 72% should be considered in the dimensioning of the fleet.
- 4) The cleaning efficiency is not affected by slopes of 20%, on the other hand, the picking efficiency; from 15.1% of slope was significantly hampered, picking only 51.2% of the coffee contained in the area.

Conflict of Interests

The authors have not declared any conflict of interests.

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