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Comparison between manual and semi-mechanical harvest of coffee fruit in mountainous areas

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In the coffee production, the most expensive operation is the harvest, mainly by lack the labor this time of year. In regions of large and flat areas, the use of mechanization allows a good reduction in the production cost. In mountainous areas the coffee harvest is performed manually. With the aim of reducing production costs, there has been a continuous increase in the use of machinery, especially at harvest. In mountainous regions the semi-mechanized harvest is already being used by aid of portable harvesters that harvest the coffee quickly and at low cost. Family agriculture dominates in Brazil and the use of portable harvesters in small farms can contribute to income increase. This study evaluated manual and semi-mechanical harvest of coffee fruit in a mountainous region of northwest Rio de Janeiro State. The experiment was conducted in June 2012 on arabica coffee crop, cv. Catucaí Vermelho 785/15, spaced 0.5 × 2.2 m, three years old, without irrigation, with a height and yield average of 1.75 m and 72 bags ha^{-1}, respectively. Results showed that the use of portable harvesters yielded up to ca. eight times more than manual harvest. This is probably due to the high productivity presented by this crop, fruit ripening uniformity and the small amount of green fruit. The semi-mechanized harvest showed a cost reduction of 27% when compared to manual, it also showed the highest efficiency, but had the highest leaf drop, more than 33%. Other studies should be performed to identify the level at which leaf drop is detrimental to coffee productivity, in this condition.

Key words: *Coffea arabica* L., performance, operational cost.

INTRODUCTION

In recent years, coffee production has exceeded 8 million tons of coffee, mainly from the countries of South America and Asia (ICO, 2014a). It is estimated that coffee production chain, from the export and processing to the final product for consumption, generates a global income of *ca.* US$ 173.4 billion (ICO, 2014b), constituting

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the social and economic base of many countries.

Among the management practices related to coffee production, the harvest is an operation that requires large costs in production, accounting, on average, 30% of the total cost and about 50% of the labor employed (Matiello et al., 2009). Regardless of the harvest system used, the detachment of fruits is the most complex operation, representing 75% of the time spent when using the manual system (Bártholo and Guimarães, 1997). Therefore, it becomes important to use practices which maximize harvest operation such as mechanized and semi-mechanized harvest.

The use of coffee mechanical harvest increases the operation efficiency, contributing to cost reduction (Cassia et al., 2013) and, furthermore, decreased harvest time reduces fruit exposure to the environment, which contributes to increased drink quality, if care is taken in the following steps (Silva et al., 2006). However, the slope of the coffee cultivated in coffee mountainous regions, that are present in many of the countries of South America, Asia and Africa, hinders mechanization.

Aiming to improve harvesting efficiency, small and medium producers have used a semi-mechanized system termed portable mechanical coffee harvesters, which have yields up to eight times higher than manual harvest (Silva et al., 1997), and also exhibits itself as a viable solution to the mountainous regions. Besides supplying the labor shortage, the adoption of this type of machine can improve workers' pay, since its use and maintenance requires higher technical qualification (Souza et al., 2006).

Portable mechanical coffee harvesters have been driven by pneumatic system, internal combustion or electric motor. The drive potencies of these systems are above 735 W for pneumatic systems and internal combustion motors and 500 W for electric motors (Barbosa et al., 2005).

The use cost of an agricultural machine is divided into fixed and variable costs. Fixed costs are those that do not vary with the use intensity of the machine, citing depreciation, interest on invested capital, taxes, cost associated with machine insurance and shelter, while the variable costs are influenced by intensity use of machine and involve costs associated with fuel and lubricants, repair and maintenance costs and the labor to operate the machine (Balastreire, 1987).

Despite presenting as a great option for small and medium producers and for mountainous areas, portable mechanical coffee harvesters need to be widely studied, because there are few studies related to the matter, such as those performed by Barbosa et al. (2005). Thus, it is possible to improve the information on how conditions related to the crop (spacing, height, yield, maturity, and other factors) may influence the efficiency and cost of semi-mechanized harvest. Thus, the objective of this study was to compare the manual and semi-mechanized harvest methods with emphasis on performance and operation cost.

MATERIALS AND METHODS

The experiment was conducted in June 2012, in a mountainous region in the northwest Rio de Janeiro state, Brazil, with an average annual temperature of 19°C, with winter minimum temperatures averaged at 14.2°C, and summer maximum temperatures averaged at 24.6°C. Two treatments (manual and semi-mechanized harvest) were applied on, three years old, Catucaí Vermelho 785/15 (*Coffea arabica* L.) cultivar plants, spaced 2.2 × 0.5 m, managed without irrigation, with a height and yield average of 1.75 m and 72 bags-60 kg ha^{-1}, respectively and 96.6% of ripe fruit.

Manual harvest was performed by four workers, which separated the fruits from dropped leaves after fruit detachment. In turn, the semi-mechanized harvest was performed by three workers, one operated the portable mechanical coffee harvester (M230 Shindaiwa 22.5 displacement model, 1.2 hp, 4.2 kg, – Figure 1), while the other two workers did the manual repass (manual removal of the fruits that don't detached by the action of portable machine). All contributed to the separation of leaves and fruits. In both methods, the coffee fruits were harvested on cloth. After harvest, the volume of harvested coffee (in liters) and weight of dropped leaves were measured, with the aid of a portable digital scale.

The statistical design used, was complete randomized blocks with two treatments (manual and semi-mechanized harvest) and six blocks (three morning and three in the afternoon), each plot containing 20 plants. The blocks were separated by four planting rows, and the first 20 plants each row were used as border. In each plot harvest time (HT), time of leaf separation (TS), volume of harvested coffee (HC), weight of dropped leaves (WFL), were measured.

From these data it was possible to calculate: the volume of coffee cherries harvested by worker (VH), the volume of harvested coffee cherries per worker per hour (HHV) and the amount of harvested coffee per worker per hour, considering the time of leaves separation (VHHn).

To determine the operational cost of portable mechanical coffee harvesters we used the following methodology: linear depreciation for a lifespan of 2,500 h, interest rate of 4% pa, cost associated with machine insurance and shelter of 2%, fuel and lubricating oil according to field measurements, repair and maintenance according to maintenance plan from the manufacturer's manual and worker's salary (for both manual and semi-mechanized methods) of US$ 17.93 (including social charges and value at the time of experiment).

The variables were subjected to analysis of variance and means were compared by Tukey test at 5% probability. All analyzes were performed using the statistical analysis program Genes (Cruz et al., 2013).

RESULTS AND DISCUSSION

There were significant differences between harvest methods for HT, VH, VHH, VHHn, WFL and cost of harvest variables. For TS and HC no significant differences were observed (Table 1). The manual harvest showed a higher HT than semi-mechanized (approximately 50%), indicating a potential for reducing the collection time in the semi-mechanized method

Figure 1. Portable mechanical coffee harvester used in the experiment.

Table 1. Summary of analysis of variance and variation coefficients (CV) for harvest time (HT); time to separate leaf (TS), volume of harvested coffee (HC), gross volume of harvested coffee per worker (VH), gross volume of harvested coffee per worker per hour (VHH), net volume of harvested coffee per worker per hour (VHHn), weight of fallen leaves (WFL) and operational cost.

SF	HT[1]	TS[1]	HC[1]	VH[1]	VHH[1]	VHHn[1]	WFL[2]	Cost[3]
Bl	2.93	0.93	28.75	3.68	511.62	205.80	414.92	32739.08
Trat	56.36**	0.33^{NS}	2.08^{NS}	133.80*	24301.80**	6474.20**	40194.19**	213600.87**
Res	1.33	4.67	160.48	14.65	235.45	92.48	553.19	9947.09
CV %	10.66	15.66	16.39	16.97	11.38	11.54	5.81	8.83
Average	10.83	6.17	77.25	22.54	134.78	83.34	404.46	1129.39

d.f. = degrees of freedom; *, **significant at 1 and 5% probability, respectively; [1] in minute; [2] in Kg; [3] In US$ ha^{-1}.

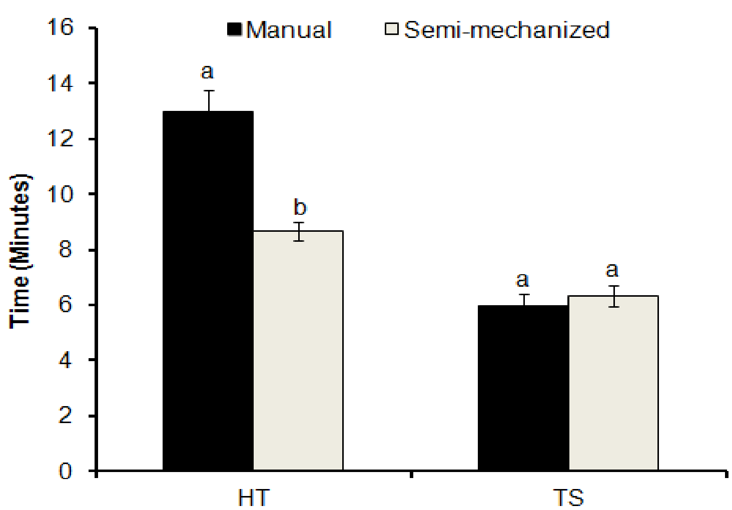

Figure 2. Harvest time (HT) and time to separate leaf (TSL) in manual and semi-mechanical harvest of coffee fruit. Means followed by the same letter do not differ by the Tukey test at 5% probability. Each value represents the mean ± S.E. (n=6).

(Figure 2). As both harvest methods showed the same TS, the HT was what significantly influenced the other variables.

The HT is highly influenced by crop conditions, especially productivity, plant height and green fruits percentage and also by machine setting conditions

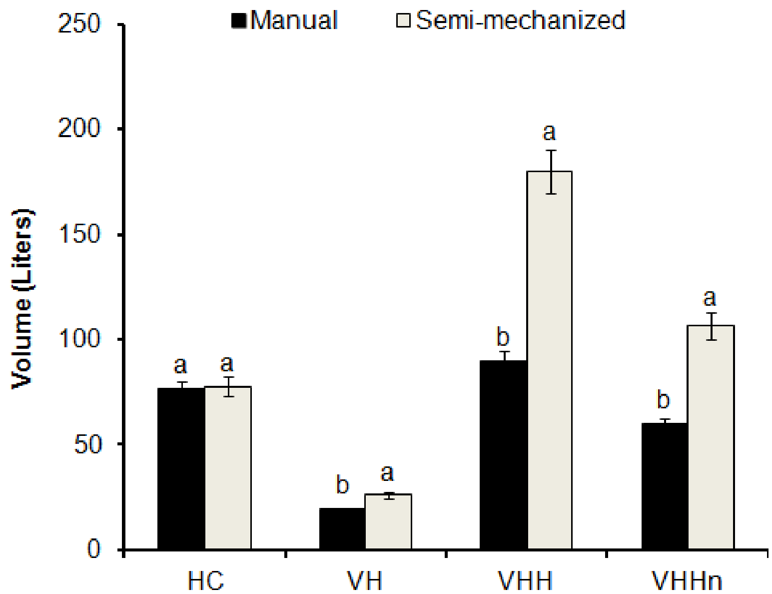

Figure 3. Harvested coffee volume (HC), gross volume of harvested coffee per worker (VH), gross volume of harvested coffee per worker per hour (VHH) and net volume of harvested coffee per worker per hour (VHHn) in manual and semi-mechanical harvest of coffee fruit. Means followed by the same letter do not differ by the Tukey test at 5% probability. Each value represents the mean ± S.E. (n=6).

(Barbosa et al., 2005; Souza et al., 2006). A large percentage of green fruits can reduce the volume of detached fruits, by machine, forcing the operator to spend more time in each plant, in order to detach the greatest possible amount of fruits, which ultimately contributes to reducing the harvest efficiency, through portable mechanical coffee harvester. In this work, the green fruit percentage of the plant was only 3.4%, indicating that the crop showed a good homogeneity of mature fruits, when it was decided to start the harvest, favoring the semi-mechanized harvest, this is also observed in mechanized harvest (Silva et al., 2006). Furthermore, reduction of HT increases the possibility of improving the coffee drink quality (Silva et al., 2006).

Although coffee quality analyzes were not made, there is the possibly that it would be the same between treatments, as observed by Carvalho Júnior et al. (2003) which did not find differences in the coffee quality in the various harvest methods, including what we carried out in this study, manual compared to semi-mechanized harvest with aid of portable mechanical coffee harvester.

Both harvest methods showed similar values of HC (Figure 3), indicating a good homogeneity of the crop and thus differences in other variables were closely related to harvest methods. Considering the number of workers involved in each method, the VH to semi-mechanized was approximately 35% higher than the manual method (Figure 2), indicating the highest yield for the first method. It is more evident when considering the VHH, wherein the semi-mechanized method was superior in more than 100% (Figure 3). However, when considering the VHHn, semi-mechanized was approximately 78% higher than manual method (Figure 3). Barbosa et al. (2005) evaluated different settings to the portable mechanical coffee harvester and they found highest yield from 100 until 150% for semi-mechanized compared to manual method for a crop with plants of 1.3 m height and 6.27% green fruit. These differences may be related to the plants conditions, work speed of workers, machine setting conditions and machine operator. According to Silva et al. (1997), the performance of portable mechanical coffee harvester can be up to eight times higher than manual method.

The use of machines for coffee harvest beans can cause damage to the plant, such as defoliation, branches (plagiotropic branches) and trunk apex breaking (orthotropic branch) (Aristizábal-Torres et al., 2003). In this work, the WFL to semi-mechanized was 33% higher than manual method (Figure 4).

According to Bártholo and Guimarães (1997), the defoliation caused in the coffee, by the use of machine in the mechanized harvest, which, in most cases, is superior to defoliation caused by manual harvest, can reduce the productivity of the next year, because the

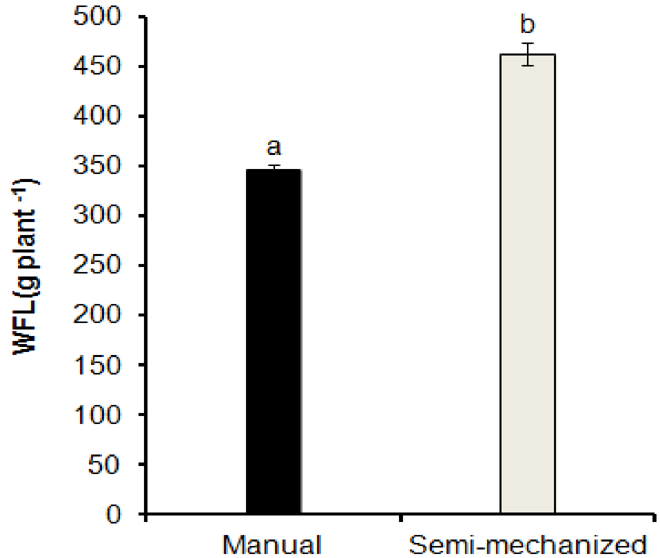

Figure 4. Weight of fallen leaves (WFL) in manual and semi-mechanical harvest of coffee fruit. Means followed by the same letter do not differ by the Tukey test at 5% probability. Each value represents the mean ± S.E. (n=6).

plant will use its reserves for vegetation restoration, which can result in stress and reduce its longevity. In turn, Cassia et al. (2013) describe that the damage caused to plants by mechanical harvest showed defoliation values within the acceptable.

The fruits are preferred drains to photoassimilates, during the reproductive period, with a high degree of dependence on plant nutritional status and functional relationship between leaf and fruit, due to the high demand for nutrients (Laviola et al., 2009; Partelli et al., 2014), so higher defoliation can influence the productivity of the next year. Silva et al. (2010) observed that manual harvest drops more leaves in sites of higher productivity, resulting in reduced productivity in coffee crop in subsequent years, because of the increased defoliation in plants with higher productivity and subsequent reduction in the use of photosynthetically active radiation.

However, defoliation needs to be studied and evaluated carefully because weather events will affect leaf recomposition of the coffee plant, such as water availability, temperature, plant nutritional status, pests and diseases, among others. Thus, it is possible that up to 30% defoliation does not significantly compromise the productivity of coffee plantations, especially in more densely populated crops, where the leaf/fruit ratio is usually higher.

When the plants have many green fruit, there is a tendency for the operator or to increase the machine vibration to also remove the greens and/or increase the harvest time in each plant, which may contribute to increasing defoliation. Oliveira et al. (2007) observed increased defoliation with the use of a mechanical harvester for harvest and repass, and noticed that the increased defoliation contributed to the reduction of the next crop productivity. However, the authors argue that increased defoliation may have been aggravated by the occurrence of rust (*Hemileia vastatrix*).

Thus, the use of semi-mechanized harvest with aid of portable mechanical coffee harvester requires knowledge and management suitable to increase harvest efficiency and reduce damage to plants and hence the next crop productivity. As noted by Oliveira et al. (2007), the control of rust is needed to reduce the defoliation levels. Furthermore, there are products available that can accelerate or retard the ethylene synthesis (Silva et al., 2006; Dias et al., 2014) and thus increase the ripe fruit percentage and consequently the efficiency of the semi-mechanized method. Yet, the specifications for the regulation of the portable mechanical coffee harvester are critical to compose whole system efficiency (Souza et al., 2006).

It is noteworthy that, currently, several types of pruning have been used in coffee crop, with the goal of plants adapting and renewing and in some cases concentrate production in a given year (as a system termed “safra zero”) due to shortages and cost of labor in coffee regions. Thus, the higher defoliation caused by semi-mechanized method is not a limiting factor if, after harvest, some type of pruning takes place, for example, the type termed "esqueletamento" (cutting of plagiotropic

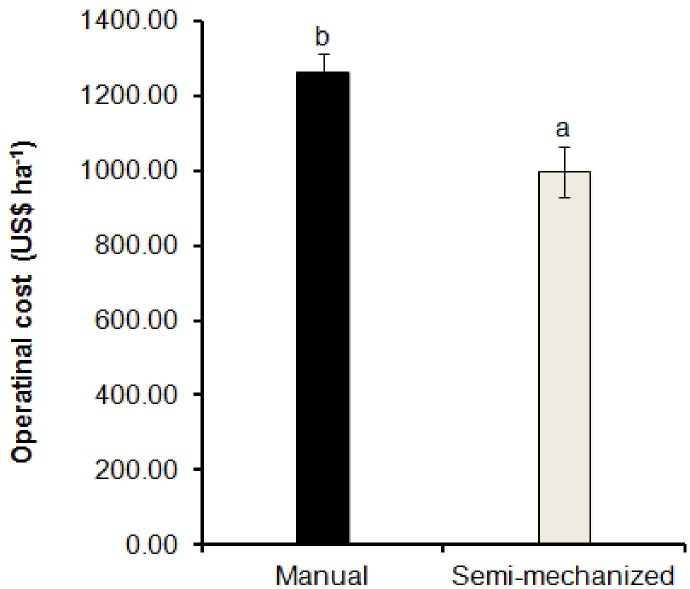

Figure 5. Operational cost in manual and semi-mechanical harvest of coffee fruit. Means followed by the same letter do not differ by the Tukey test at 5% probability. Each value represents the mean ± S.E. (n=6).

branches from 20 cm from the orthotropic branch).

In this study, the semi-mechanized showed higher defoliation, however, it showed similar value of TS to manual harvest method, but with a tendency to be higher in the first, if the sampling period is longer. However, even with higher TS, the repass seems to be the operation that contributed the most to reduce the net yield of the semi-mechanized harvest (Barbosa et al., 2005) and increased harvest cost. These factors can be mitigated by increased maturation uniformity of fruits and/or increased percentage of ripe fruit in the field.

Regarding the harvest operational cost, the semi-mechanized method showed a cost reduction of *ca.* 27% (Figure 5), close to the values obtained by Barbosa et al. (2005), which observed a reduction from 57 to 74% for a yield with plants of 1.3 m height, 6.27% green fruit, in the south Minas Gerais, Brazil. However, the authors observed large variation in the operation cost for various crops conditions and machine regulation, with a cost reduction for the semi-mechanized harvest of 28% on average.

Besides being useful for harvest, it is also worth mentioning the feasibility of the portable mechanical coffee harvester, it can be transformed or adapted to function as a weed control equipment or pruning machine, thinning the costs and expanding its use in crop management, reducing the problem of labor, which would help in reducing the overall cost of management of coffee plantations.

The data presented in this study reinforces the use of semi-mechanized harvest with the aid of portable mechanical coffee harvester as a viable solution to the mountainous regions, since they allow a quicker and cheaper harvest. Other studies should be conducted, in long term, in order to verify the effect of continuous use of portable mechanical coffee harvester, on the crop productivity and longevity, for systems that do not use systematic pruning.

Conclusion

The semi-mechanized harvest method with the aid of portable mechanical coffee harvester provided the highest yield at harvest and the lowest operating costs. The semi-mechanized harvest showed the highest defoliation.

Conflict of Interest

The author(s) have not declared any conflict interest.

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