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Morphological and productive influence of harvest on coffee plants

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Abstract

The harvest of coffee, manual or mechanical, causes damage to the plants in several ways. Such damage manifests negatively in the following harvest, increasing the bienniality of coffee. Therefore, the aim of this work was to evaluate the morphological and productive influence of the use of repeated operations of the harvester and manual harvesting in promoting coffee growth. The biennial production cycle, one of factors that most influence the coffee productivity, is an innate characteristic of the coffee, which refers the annual alternation of high and low fruiting. According to this, the objetive of the study was comparing mechanized crop harvesting with one to six operations of the harvester using a KTR harvester with manual harvesting in initially high-load crops and initially intermediate-load crops. An experimental design of randomized blocks with four replications was utilized. The damage to plants, variation in productivity between the second and the first harvest, leafiness for 270 days and the morphological composition of the branches of the plants were assessed. You can replace manual harvesting with mechanical harvesting using up to two operations of the harvester, regardless of the coffee load, with no increase in the amount of damage caused to plants or reduced productivity in the following harvest. Crops with high initial charge naturally defoliate more than crops with intermediate initial charge. Coffee has a high capacity for defoliation from one season to another irrespective of the defoliation intensity to which it is submitted.

Keywords: Biennial production; mechanical harvest; damages on coffee.
Abbreviations: CII_intermediate initial charge; CIA_high initial charge; Enf_leafiness; NF_number of leaves in each branch; Nn_Number of nodes.

Introduction

The harvest of coffee, manual or mechanical, causes damage to the plants in several ways. The removal of fruits promotes defoliation and directly damages flower buds in addition to causing the breakage and removal of plagiotropic branches. Thus, the plant can produce less in the following harvest because its reserves are used to recompose their vegetative parts at the expense of the production of new fruits (Bartholo and Guimarães, 1997). In addition, defoliation also causes a reduction in photosynthetically active radiation intercepted by the canopy of plants and physiological changes in their metabolism (da Silva et al., 2010), which also reduces productivity.
Fructification in coffee plants occurs approximately 80 to 100 days after flowering (Camarco and Camargo, 2001). If there is no energy reserves are available, the plants eventually abort part of their reproduction. This fact highlights the importance of maintaining the leaf area in the post-harvest period. Cannell (1976) states that 20 cm^2 of leaf area is required to produce one coffee fruit.

The damage caused to plants due to manual harvesting is approximately 0.753 kg $plant^{-1}$ (Silva et al., 2010), and the damage to due mechanical harvesting is variable depending on the number of operations of the harvester, the vibration of the sticks (Santinato et al., 2014) and the operating speed (Oliveira et al., 2007a). Generally, a mechanical harvest involving a single pass of the harvester causes less damage than the manual harvest (da Silva et al., 2000).
In addition to measuring the damage to plants, the productivity gap between one crop and another should be quantified to examine the influence on the production of the next harvest and correlate the values. The two-year cycle is explained by the simultaneous occurrence in the same branch plant vegetative and reproductive functions. As the coffee plant can not produce reserves sufficient to fruiting and growth at the same time in a year bookings are used for fruit, which enhances productivity. But this year, there is no food sufficient for the growth of the branches, making the fruit is low in production following year Therefore,

interchangeably, the coffee grows in a year and it bears fruit in the other (BACHA, 1998).

In addition to this, verification of the leafiness rate becomes necessary because coffee can present rapid plant recovery, minimizing the negative effects of the damage. These analyses must be conducted in fields that exhibit biennial years of negative and positive production due to differing productivities (Pereira et al., 2011; Valadares et al., 2013).

Therefore, the aim of this work was to evaluate the morphological and productive influence that the use of repeated operations of the harvester and manual harvesting promotes in two crops of coffee in positive and negative biennial years in the Cerrado Mineiro region.

Results

Damage on plants of coffee

The crops studied showed similar patterns in damage caused to plants for both crops, which was not differentiated by the F test (P ≤0.05). This shows that, independent of the plant load, for mechanized harvesting (one to six operations) or manual operations, the damage to the plants will be on the same ratio (Table 1).

The analysis of variance showed a significant difference (P ≤ 0.05) between treatments in both crops studied for damage to plants. In crops with high initial load, mechanized harvesting with one operation provided less plant damage (given the amount of lost plant material including leaves, branches and flowers) compared with the other treatments, 41.9% lower than the manual harvest. Mechanized harvesting with two operations caused damage to plants similar to manual harvesting. Mechanized harvesting with three operations damaged plants 31.1 to 49.4% more than the manual harvest, manifesting in a higher amount of lost plant material. The harvests with five and six operations caused the same amount of damage to plants . Similarly, for crops with intermediate initial charge, the harvest with one operation was the least harmful to the vegetal structures of the plants, with 30.96% less damage to plants than manual harvesting. Harvesting with two operations resulted in the same amount of damage to plants compared with manual harvesting. With three operations, there was a 28.36% increase in damage to plants compared to manual harvesting. Harvests with five and six operations resulted in similar values, approximately 50% higher than the manual harvest .

Biennial effect

According to the F test, significant differences (P ≤ 0.05) were found among the treatments studied on the two crops and also in each treatment on the productivity of the second harvest. In initial high-load crops (121,54 bags of coffee ha^{-1} in the 2013 harvest), the 2014 harvest produced approximately 44.14 bags of coffee ha^{-1}, representing a 63.68% reduction (Table 2). In crops with intermediate initial loads (50,78 bags of coffee ha^{-1} in 2013 harvest), the 2014 harvest produced 95,62 bags of coffee ha^{-1}, representing an increase of 46.82%. This shows the strong biennial effect of coffee. This happens because of the competition for metabolites used for plant growth and fruit production. Intermediate initial load crops, the highest yield in the 2014 harvest was obtained from the treatments with one and two operations of the harvester and the manual harvest. Such yields were approximately 64% lower than the first crop yield

We noted tha harvesting with three operations of the harvester promoted a 21.74% reduction in yield compared with manual collection, which corresponds to 9.42 bags of coffee ha^{-1}. The harvests using four to six operations resulted in lower yields 66.72 to 86.68 bags of coffee ha^{-1} than the manual harvest, corresponding to a reduction in productivity of 115.76 bags of coffee ha^{-1} in relation to the previous year's harvest (121.54 bags of coffee ha^{-1}) .

Due to the positive biennial years, in 2014, for the intermediate initial crops, there was an increase in yield over the previous harvest in all treatments, except for the harvest with five operations of the harvester, which yielded values similar to the harvest with six operations.The harvest with five and six operations decreased the productivity slightly.We realize that the highest yields were obtained from the harvests with one and two operations of the harvester and manual harvest, with an average increase of 83.84% over the previous harvest . Harvests with three or four operations entailed yield losses of 16.74 and 22.65%, respectively, in relation to the manual harvest.

Leafiness of the coffee plant

The F test showed differences (P ≤ 0.05) between treatments for leafiness on both studied crops. We noticed that in the fields of high initial load, the leafiness was lower soon after harvest when repeated operations of the harvester were used, yielding values from 21.79 to 46.6% for six and three operations of the harvester, respectively. This was due to higher leafiness provided by the repetition of operations that increases the contact time of the harvester rods with the vegetation of the plant. The harvest with one operation provided a leafiness value similar to that with manual harvesting (Fig 1).

After 90 and 180 days, the difference in leafiness between treatments decreased significantly, and the values were similar. According to the regression equations, the values tended to stabilize over the subsequent days (Table 3) . Analyzing the slope of the line, it appears that the leafiness rate was higher in treatments with the lowest initial values of leafiness, especially when six operations of the harvester were used.

During the last evaluation (270 days after harvest), we noted that the leafiness was similar for all treatments . This fact demonstrates the high ability of coffee to rebuild its branches and leaf area. The new nodes will have bud that will differentiate into sheets and also into fruits that belong to the following two-cycle harvest, as the subsequent crop is usually already defined by the growth in the previous year at harvest. This suggests that during the next harvest (2015), the productive capacity of plants may be similar between treatments regardless of the mechanism of harvest.

In the crops with intermediate initial load, the plants were leafier than the crops with high initial charge, with values above 55%, even when we used six operations of the harvester (Fig 2). This difference is related to the charge of the high initial charge crops before being harvested (121.54

Table 1. Damage caused to plants resulting from mechanized harvest with one to six operations of the harvester and manual harvest in two crops of coffee, Patos de Minas, MG.

Number of harvester operations	Crops with high initial charge	Crops with intermediate initial charge
	Damage caused to the plants (kg plant^{-1})	
1	0.57 Aa	0.68 Aa
2	1.15 Ab	1.02 Ab
3	1.43 Ac	1.37 Ac
4	1.65 Ad	1.67 Ad
5	1.82 Ade	1.94 Ae
6	1.94 Ae	2.16 Ae
Manual harvest	0.98 Ab	0.98 Ab
CV (%)	7.37	6.42

*Averages followed by the same lowercase letters, compared in columns, do not differ by Tukey test at 5% probability. Averages followed by the same capital letters, compared on the lines, do not differ by t-test at 5% probability.

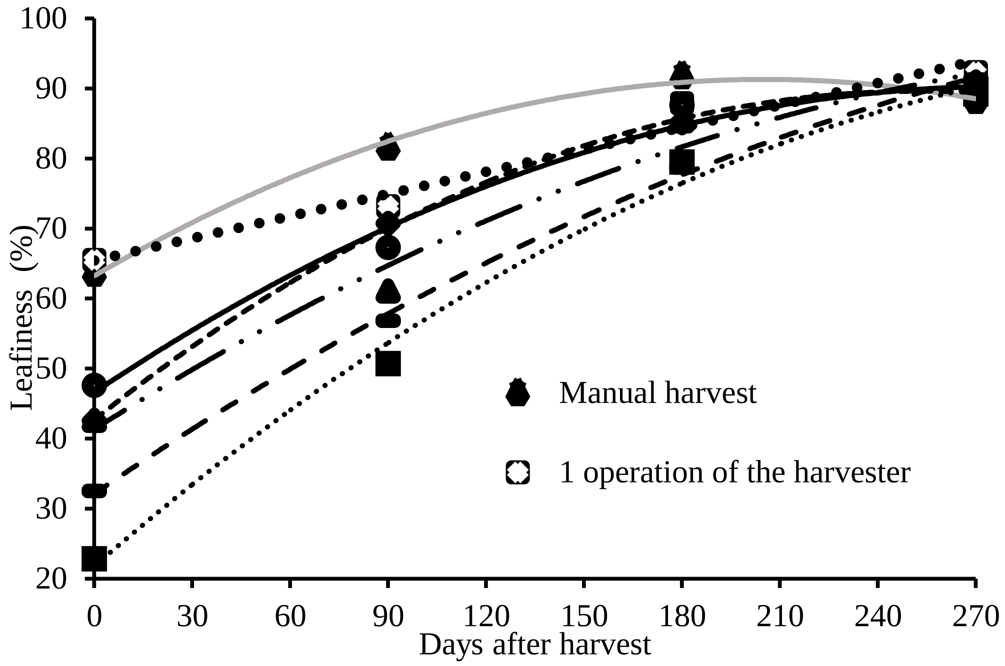

Fig 1. Leafiness related to the types of harvest over 270 days for the high initial charge tillage crop 2013/14, Patos de Minas, Brazil.

Table 2. Productivity of second harvest and variation of productivity in relation to the first harvest resulting from mechanized harvest with six operations of the harvester and manual harvesting carried out in the first harvest in two coffee plantations, Patos de Minas, MG.

Number of harvester operations	Crops with high initial charge		Crops with intermediate initial charge	
	Productivity of 2nd harvest in coffee **bags ha^{-1}	Productivity variation %	Productivity of 2nd harvest in coffee bags ha^{-1}	Productivity variation %
1	44.14 Aa	- 63.68	95.62 Ba	+ 88.3
2	43.27 Aa	- 64.39	93.21 Ba	+ 83.56
3	33.91 Ab	- 74.91	75.95 Bb	+ 49.58
4	14.42 Ac	- 88.13	70.56 Bb	+ 38.96
5	9.78 Ac	- 91.95	45.83 Bc	- 9.75
6	5.77 Ac	- 95.24	51.44 Bc	+ 1.31
Manual harvest	43.33 Aa	- 64.35	91.23 Ba	+ 79.67
CV (%)	25.89	-	20.69	-

The variation of productivy is negative because the second harvest was smaller than the first harvest
*Averages followed by the same lowercase letters, compared in columns, do not differ by Tukey's test at 5% probability. Averages followed by the same capital letters, compared on the lines, do not differ by t-test at 5% probability.**one bag of coffe = 60kg

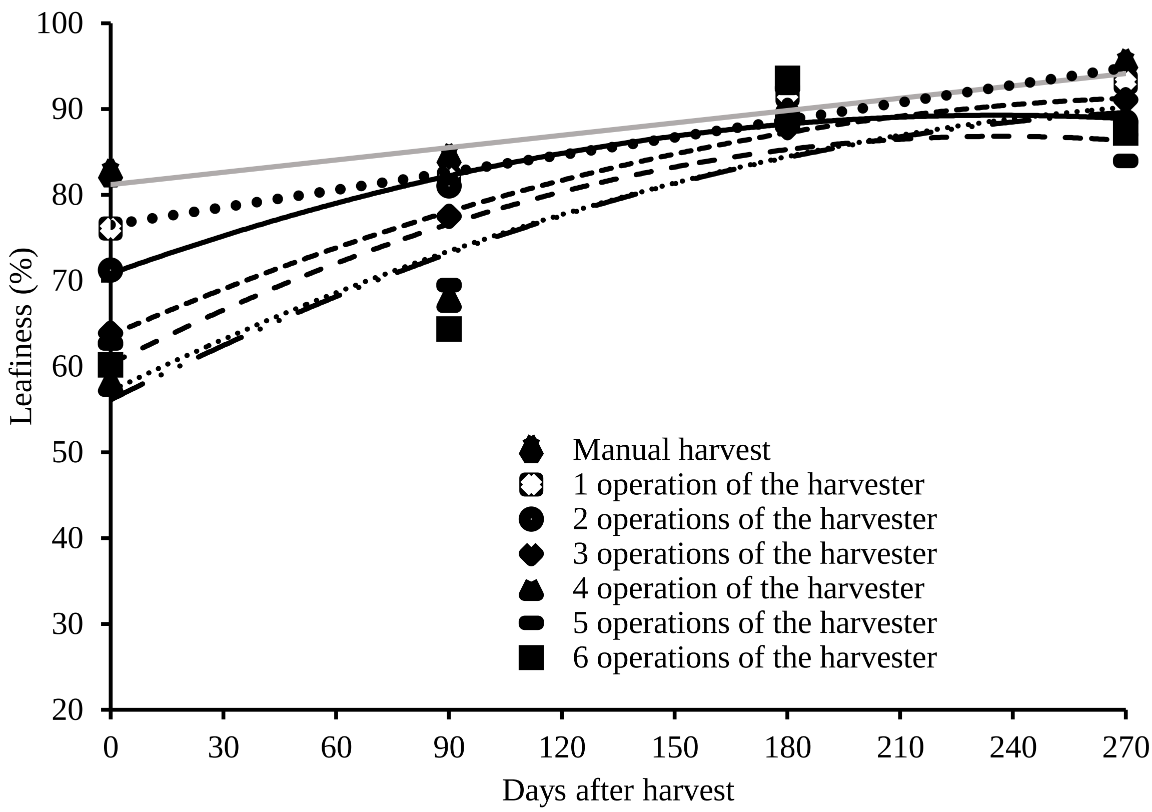

Fig 2. Leafiness related to the types of harvest over 270 days in the fields of the middle initial charge 2013/14 crop, Patos de Minas, Brazil.

Table 3. Coffee leafiness in crops with high initial charge and intermediate initial charge in relation to the number of the harvester operations and manual harvest, Patos de Minas, MG.

Number of harvester operations	Equation	F	R^2
	Crops with high initial charge (positive bienniality)		
1	$65.4362 + 0.1057x$	64.642**	0.96
2	$46.6046 + 0.3118x – 0.00055x^2$	9.23**	0.98
3	$42.6825 + 0.3706x – 0.00073x^2$	19.469**	0.99
4	$41.3304 + 0.2961x – 0.0004x^2$	6.741*	0.98
5	$32.1324 + 0.3183x – 0.00036x^2$	4.689*	0.99
6	$21.789 + 0.4046x – 0.00056x^2$	11.195**	0.99
Manual harvest	$63.2532 + 0.2731x – 0.00066x^2$	14.326**	0.99
	Crops with intermediate initial charge (negative bienniality)		
1	$76.5232 + 0.0678x$	37.728**	0.93
2	$70.8243 + 0.1566x – 0.00033x^2$	4.356*	0.98
3	$63.6633 + 0.1886x – 0.00032x^2$	4.694*	9.99
4	$56.0971 + 0.2227x – 0.00036x^2$	5.159*	0.91
5	$60.2938 + 0.2238x – 0.00047x^2$	9.207**	0.79
6	$57.1581 + 0.2103x – 0.00032x^2$	2.873**	0.78
Manual harvest	$81.1909 + 0.0479x$	14.139**	0.94

* = Significance at 5% probability; ** = Significance at 1% probability.

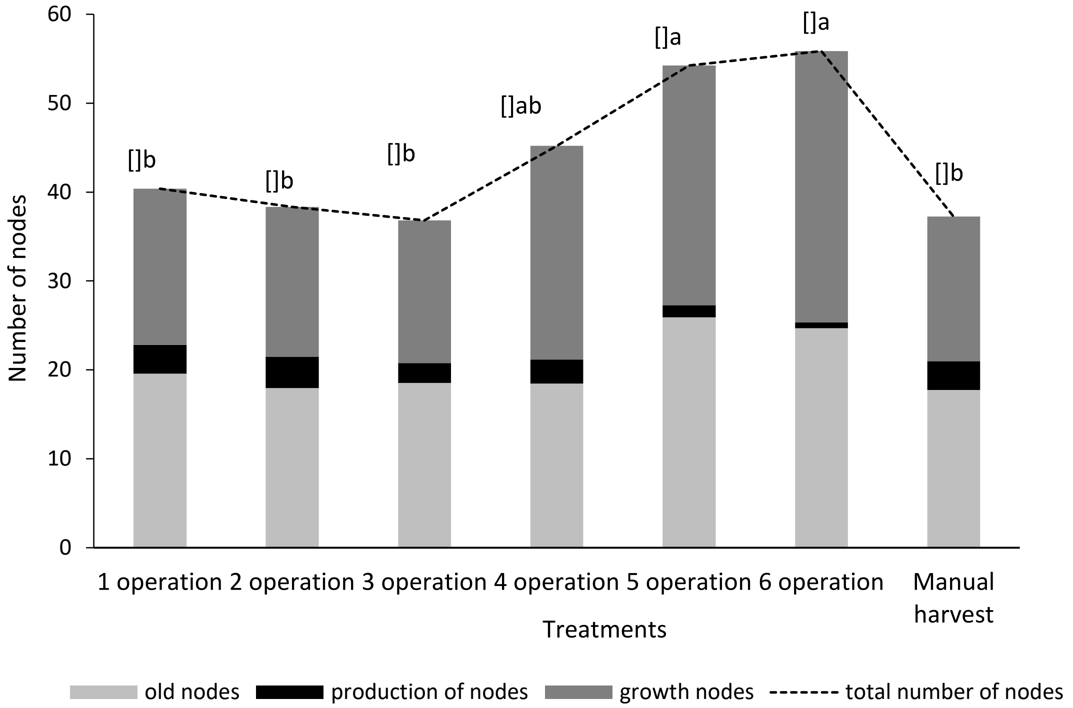

Fig 3. Total number of old nodes, production of nodes and growth nodes in coffee plants, 270 days after different types of harvest. Patos de Minas, MG.

bags of coffee ha^{-1}), which was greater than twice that of crops with intermediate initial charge.

Number of nodes

An analysis of variance showed differences (P ≤ 0.05) in the studied treatments in the number of total nodes, growth nodes and nodes of production only in crops with high initial charge, with no difference in the crops with intermediate initial charge. Additionally, there was no difference as found by the F test (P ≤ 0.05) on the crops with high initial charge for the variable old nodes. At 270 days after harvesting, the largest number of nodes in crops was obtained with five and six operations (Fig 3). This fact is due to the higher "palmeamento" of the branches and verified by the leafiness rate. There was no difference in this assessment on the crops with intermedial initial charge, probably due to the lower "palmeamento" due to the higher leafiness soon after harvest.

Crops with five and six operations of the harvester obtained the lowest number of production nodes with less presence of fruits on the branches . The results of this evaluation were confirmed by the lower yields obtained in 2014. The opposite is checked using the average of three harvests against the number of growth nodes, which may result in higher yields in the 2015 harvest, minimizing the negative biennial effect. There was no difference between treatments in the number of old nodes.

Averages followed by the same capital letters comparing the upper and lower columns of gray coloration and the middle columns of black color and the dotted line did not differ according to Tukey's test using a 5% probability for significance.

Discussion

Damage on plants of coffee

Oliveira et al. (2007b) obtained that mechanized harvesting with two operations resulted in an 11.8% higher loss of plant material than with the manual harvester and in more harm to the coffee plant. Our results also contradict those obtained by da Silva et al. (2003), where harvesting with two operations causes 26% more damage to the plants. This indicates that the improvements undertaken in the harvesters and the qualifications of operators over the years may have contributed to the reduction in damage caused to plants because the cited works are older.

Biennial effect

The bienniality pronounces more negative effects on the subsequent crop from a crop of high productivity because the coffee does not regulate the load that it will produce (Rena and Maestri, 1986). Increased production requires that the plant drain its nutrients in a very intensive form; therefore, the plant develops low growth and new branches and nodes. As a consequence, it presents low productivity during the following harvest (DaMatta, 2004).

For the biennial average, 82.84 and 73.2 sacks of coffee ha^{-1} for the high initial load crops and intermediate initial load crops were obtained, respectively. Both productivities are considered high yields for the coffee tree *Coffea arábica* L. (Fernandes et al., 2012; CONAB, 2014).One reduction in productivity is attributed to the biennial effect, also observed by Pereira et al. (2011) and Valadares et al. (2013), demonstrating the negative effects arising from the types of crop production.

Leafiness of the coffee plant

Analyzing the slope of the line, it appears that the leafiness rate was higher in treatments with the lowest initial values of leafiness, especially when six operations of the harvester were used. This was due to the "palmeamento effect" (growth of secondary and tertiary branches), which is given by the constant emission of secondary plagiotropic branches and thus a higher number of nodes and leaves (Matiello et al., 2010).

Naturally bigger leaf senescence occurs in crops with high initial charge due to the depletion of the reserves that were drained for fruit (Matiello et al., 2010). However, the final values of foliage between the two crops were similar, approximately 90%. According to DaMatta et al. (2007), for the period mentioned, the month of April is when there is the maximum gain of leaf area in each coffee cycle, which tends to stabilize and then decrease after harvest.

Number of nodes

According Martiello et al, (2010), the leafiness decreases the penetration of sunlight inside the plant canopy that sets the gems in secondary plagiotropic branches (Matiello et al., 2010).

Materials and methods

Experimental conditions

The study was conducted in the São João Grande and Dona Neném farms in the municipality of Patos de Minas, MG, located in the geodetic coordinates 18º33'18" south and 46º20'01" west in the Cerrado Mineiro region with an average elevation of 1100 m and a climate of Cwa according to the Köeppen classification (Köeppen, 1948).

The São João Grande farm commercially plants coffee plants under a center pivot with 250 m-long lines. The area cultivated is approximately 54.0 ha with an average slope of 3.8%. A transplantation was performed in 2003 with a spacing of 4.0 m between rows and 0.5 m between plants with a population density of 5,000 plants ha^{-1}. In the Dona Neném farm, the coffee crop was transplanted in 2007 in a mechanized hedgerow with a spacing of 4.0 m between rows and 0.5 m between plants (5,000 plants ha^{-1}). The planting rows are 200 m long and drip irrigated. The farm is approximately 30.0 ha in area, and the field has a 2% slope on average. In both farms, the cultivar used was Catuai Vermelho IAC 144.

Experimental design and plant materials

The harvests were made between 12/6/2013 and 12/8/2013. Two situations were compared: crops with an intermediate initial charge in 2013 (CII) in the year of negative bienniality (farm São João Grande) and crops with a high initial charge in 2013 (CIA), a year of positive bienniality (farm Dona Neném), when there were 50.78 and 121.54 bags of coffee beans ha^{-1}, respectively. Due to the biennial effect of coffee, in the following season (2014), the crops showed opposite productive behavior; thus, the São João Grande farm had a high load, and the Dona Neném farm had an intermediate load.

Mechanized harvesting in two farms was performed using a Jet harvester, KTR model, manufactured in 2003, and with approximately 5.800 hours of use. For all operations, a rod vibration rate of 850 rpm and operating speed of 1.05 km h^{-1} were used. These regulations were adopted as instructed (Oliveira et al., 2007a; Santinato et al., 2014). The harvester was pulled by a New Holland tractor, model TT 3880F, 4 x 2 TDA, with a nominal power of 47.8 kW to 36.6 Hz connected through the TDP to 9 Hz; this was always operated in the same direction of displacement as the planting lines.

Treatments

The work consisted of seven treatments, each corresponding to the number of passes of the harvester; thus, T1 = one operation, T2 = two operations, T3 = three operation, T4 = four operations, T5 = five operations, and T6 = six operations. The manual harvest treatment was labeled as T7. The treatments were designed in randomized blocks and executed at twelve-day intervals. There were four replications, totaling 28 experimental units, in each of the farms.

For each treatment, ten plants were evaluated for each experimental unit of coffee in two lines, one beside the other. In one of the lines, the manual harvest was performed to evaluate the production of five plants in 2013. In another line, the harvester was shifted according to the treatment for other evaluations in five plants.

Variables measured

The determination of crop productivity, also called the initial load, was estimated by manual detachment of five plants in each of the four replicates of each treatment prior to passage of the harvester. For this, cloths of approximately 3.0 m x 2.0 m were placed under the canopy of five plants for "seed dropping" on both sides of the line so that the coffee beans overlapped each other. Afterwards, the fruits were taken from the coffee trees. The harvested volume was quantified individually by a volumetric flask to calculate the average yield (L $plant^{-1}$); then, the volume was converted to coffee ha^{-1}, as described by Reis et al. (2008). The productivity in 2013 and 2014 was determined.

The morphological influence was measured by damage to plants caused by harvest, leafiness over time (leafiness rate) and the coffee composition of branches, the latter two being calculated from biometric reviews. To determine the damage to plants (number of lost plant material, including leaves, branches and flower buds), "seed dropping" cloths were placed under the canopy of plants. Then, the harvester was operated. After its passage, all plant material, except the fruits that had fallen off the plants into the "seed dropping" cloths, were collected, and their weight (kg $plant^{-1}$) was determined.

After the 2013 harvest, biometric evaluations were repeated four times in periods of three months (0, 90, 180 and 270 days after harvest). These evaluations aimed to quantify the leafiness and leafiness rate (given by leafiness regression equation by function to time). Therefore, eight branches were marked up in each plot, four on each side of the coffee line, and the number of nodes and sheets were measured. With these data, the leafiness was calculated (Equation 01). The number of nodes was multiplied by two to give the maximum number of sheets that each branch may contain because only two leaves originate from each node:

$$Enf = \left[\frac{NF}{(Nnx2)} \right] x100 \qquad 1$$

where
Enf = leafiness (%);
NF = number of leaves in each branch; and
Nn = number of nodes.

At the last evaluation in May 2014 (270 days after harvest), we divided the branches evaluated into old nodes (lignified branches), production nodes (nodes matching the growth of the previous year, which may or may not have fruit in the 2014 harvest) and growth nodes (which may have buds that differentiate into leaves or the production yield of the 2015 harvest).

Statsitical analysis

In each of the farms, an analysis of variance ($P \leq 0.05$) was performed on the damage caused to plants, productivity of the second harvest, leafiness and total number of nodes, old nodes, nodes production and growth nodes. When appropriate, we used the Tukey test at 5% probability, except for leafiness. Using an F test ($P \leq 0.05$), we also compared the damage in each treatment of the two crops caused to plants and the productivity of the second harvest. When appropriate, we used the t-test at 5% probability.
For leafiness data, we used a regression analysis. The coefficients of each model component were tested, and significant models with a higher coefficient of determination were chosen.

Conclusion

You can replace manual harvesting with mechanical harvesting using up to two operations of the harvester, regardless of the coffee load, with no increase in the amount of damage caused to plants or reduced productivity in the following harvest. Crops with high initial charge naturally defoliate more than crops with intermediate initial charge.
Coffee has a high capacity for defoliation from one season to another irrespective of the defoliation intensity to which it is submitted.

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