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Effect of planting axles, sunlight faces and rod vibration frequencies in the mechanized coffee harvesting

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Several studies have investigated the harvest systems, locations and conditions of the coffee crop, but there are no studies about the rod frequency vibration, particularly with regard to the effects of the position of the coffee with respect to exposure of sunlight regarding production, fruit maturation, and harvest levels. Thus, this study, conducted in two crops in Patos de Minas, Minas Gerais state, Brazil, evaluated the productivity, fruit maturation, and operation of mechanical harvesting of a coffee crop planted in four rows, with two faces of solar exposure and at two frequencies of rod vibration. Because of the regional conditions and culture, the planting alignments altered the levels of low-production harvests and the maturation of the fruit produced in high-production harvests, but no differences were observed between the faces of the plants. The increased frequency of the rod vibration varied according to the planting alignments in the low-production harvest, and increased harvesting capacity and the amount of picked mature fruits, reducing the losses of the remaining coffee of the high-production harvest.

Key words: *Coffea arabica* L., ripeness stage, sunlight, agricultural mechanization, coffee production, harvesting loses.

INTRODUCTION

In the coffee production system (*Coffea arabica* L.), the harvest and postharvest stages have several factors to be analyzed, because coffee is one of the few agricultural products that is priced based on qualitative criteria and whose value increases significantly with improved quality (Oliveira et al., 2007a). According to Pimenta and Vilela (2003), harvesting Brazilian Arabica coffee at different stages of maturation can affect the qualitative properties of this crop in the international market.

With the expansion of coffee growing in the Cerrado regions, the mechanization of agricultural operations is a key factor for Brazil to continue leading the world in

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coffee production (Oliveira et al., 2007c). Studies have shown that mechanized coffee harvesting represents 30% of the cost of production and 40% of the manpower employed, and increasing harvesting efficiency directly relates to cost reductions, without impairments and loss of the production system or damages to the crop (Santos et al., 2010).

The mechanical harvesting process of coffee is characterized by removal of the fruits from the plant by a procedure called strip-picking, which is highly complex and occurs through the use of vibration of rods (Aristizábal et al., 2003a). According to Barbosa et al. (2005), the vibration of the rods on the plants is an efficient method for harvesting coffee; however, the defoliation caused by this method forces the coffee tree to use reserves to restore vegetation, resulting in a lower subsequent production.

The level of solar radiation is an environmental variation that physiologically affects coffee plants and causes the plants to create adaptation mechanisms that can consequently interfere with fruit yield and maturation. Studies reported by Pinto et al. (2006) found a deleterious effect of light exposure to the afternoon sun with reduced growth and incidence of pests and diseases in a region with a high average temperature.

Researchers such as Pimenta and Vilela (2003), Silva et al. (2006), Oliveira et al. (2007a, b, c), Queiroz et al. (2007a, b) and Santos et al. (2010) have been studying the operational performance of cropping systems, and the locations and conditions of farming to reduce the cost of coffee production by reducing the time and number of harvests. However, there are few studies about the vibration frequency of the rods under conditions of sun exposure regarding the production and maturation of the fruits or about the rates of crop losses and the damages caused to the plants.

Thus, assuming that the sun exposure of the plants alters the maturation of the culture and that the frequency of the rod vibration could optimize indexes and reduce crop losses, this study evaluated the productivity, fruit maturation and operation of mechanical harvesting of the coffee crop in four planting rows, with two faces exposed to the sun and two rod vibration frequencies.

MATERIALS AND METHODS

This experiment was conducted at São João Grande Farm, located in Patos de Minas city, in the Savana's region of the Minas Gerais state, Brazil, during the harvest seasons of 2009/2010 and 2010/2011, in a circular planting area under a central pivot. This study used cultivar Catucaí Vermelho 785-15, which was six years old at the first evaluation, with a spacing of 4.00 m between rows and 0.50 m between plants, totaling 5,000 plants ha^{-1}. The geographic coordinates are approximately 18°33'18" south latitude and 46°20'01" west longitude, 6% slope, at an average elevation of 1,100 m, and the climate is rated as Cwa, according to the Köeppen method.

The tests were carried out with a mechanized harvesting of two crops. The 2009/2010 crop was named "low production" (negative biannuality) and 2010/2011 crop was named "high production" (positive biannuality). The harvest dates were defined based on the rate of green fruits in the plant. The first harvest was made on 06.04.2010, with an average of 14% green, 21% cherry and 65% coco grains in the plant; and the second was made on 05.21.2011, with an average of 10% green, 65% cherry and 25% coco. These plants were considered appropriate for harvesting, because the percentage of green fruits should be below 20% (Pimenta and Vilela, 2003).

Machinery

For the mechanized coffee harvest, a Jacto harvester, model KTR, was used. This harvester was made in 2003 and had approximately 4,000 h of functioning. This harvester operated displaced and attached to the hydraulic system of a three-point Massey Ferguson tractor, model 265 4x2TDA, with 47.8 kW (65 hp) of power in the motor to 36.6 Hz (2,200 rpm), and start-up is achieved through TDP at 9 Hz (540 rpm).

The harvester has a frame gantry and runs mounted ("over the row") over the plants among the coffee rows, with two picking cylinders equipped with vibrating rods that involve the coffee plant laterally, strip-picking the fruits through the effect of the vibration of the rods. The fruits fall into the collection system and are simultaneously discharged into a transfer set after cooling. During the harvesting operation, all the rods of the two cylinders of the harvester were used with the average speed fixed at 0.48 m s^{-1} (1.74 km h^{-1}), and the harvest was always performed in the same direction.

Statistical analysis

The experimental design was similar to a randomized block design. For crop productivity, four alignments (axes) of planting (A) were adopted, and the internal and external faces of the plants were separated from the center pivot (F). A factorial scheme of 4 × 2 with ten repetitions was analyzed, totaling 80 sample cells containing three plants in a row.

Since in earlier experiments no significant differences were detected regarding the production between the internal and external facing plants, the variables related to this mechanical harvesting factor were disregarded. Two frequencies of rod vibration (F) in alternating rows of harvest were tested, and four planting axes (A) in a 2 × 4 factorial arrangement with five replications were compared, which totaled 40 sample cells containing five plants in a row (Figure 1).

Four rows of planting (axes) inside the assessed area (A) were marked to identify the influence of sun exposure on the uniformity of fruit maturation and, consequently, the harvesting operation. Alignments were denominated as axes I to IV, with the positions varying by 45 degrees. The I axis is considered by Pinto et al. (2006) as the most favorable cultivation condition of the region, because the rays of the sun are over the tops of the plants for most of the day. In Axis III, the sun shines on only one side of the plant for part of the day and then shines on the opposite side for the rest of the day. Axes II and IV are considered intermediates to the aforementioned situations.

During mechanized harvesting, the vibration frequencies were 12.5 and 15.8 Hz (750 and 950 cycles/min). These frequencies were selected based on the vibration used at the moment of harvesting in the studied area (F1) and the results obtained by Oliveira et al. (2007b) (F2).

The crop productivity was initially determined by manual strip-picking of three plants in each cell sample, and the amount of coffee produced on each side of the plants was measured (L $plant^{-1}$). To determine the losses in the harvesting operation, the soil

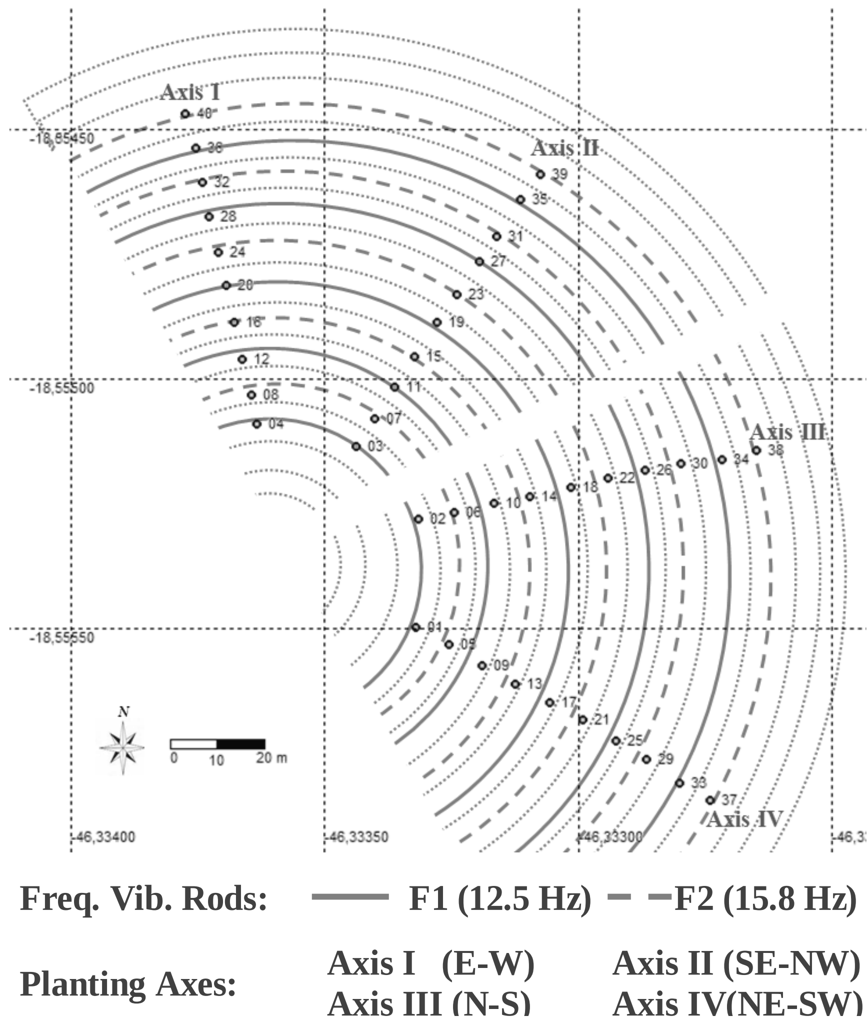


Figure 1. Georeferenced sampling grid, indicating the planting alignments and frequencies of the rod vibration.

beneath the top of five trees was lined with cloths of manual picking for each cell, and after the passage of the harvester, the volume of fallen fruit was measured (L $plant^{-1}$). Based on the productivity of the cell sample, the percentage of coffee dropped was determined.

The remaining volume of coffee was manually picked from the same five plants and was added to the volume of fallen fruit to determine the percentage of remaining coffee. The percentage of coffee harvested by the operation was determined by the difference between the yield and the loss rates obtained in each cell sample. Samples were taken from 1 L of coffee of all variables for the classification of fruit maturation stages (green, cherry and coco); the mature fruits, the portion of fruit at cherry and coco stages (Ch + Co), are of greater interest (Silva et al., 2006).

Defoliation caused by mechanical operation was quantified by the mass of leaves and fallen branches (g $plant^{-1}$) on picking cloths after the passage of the harvester and was determined when quantifying the loss of coffee.

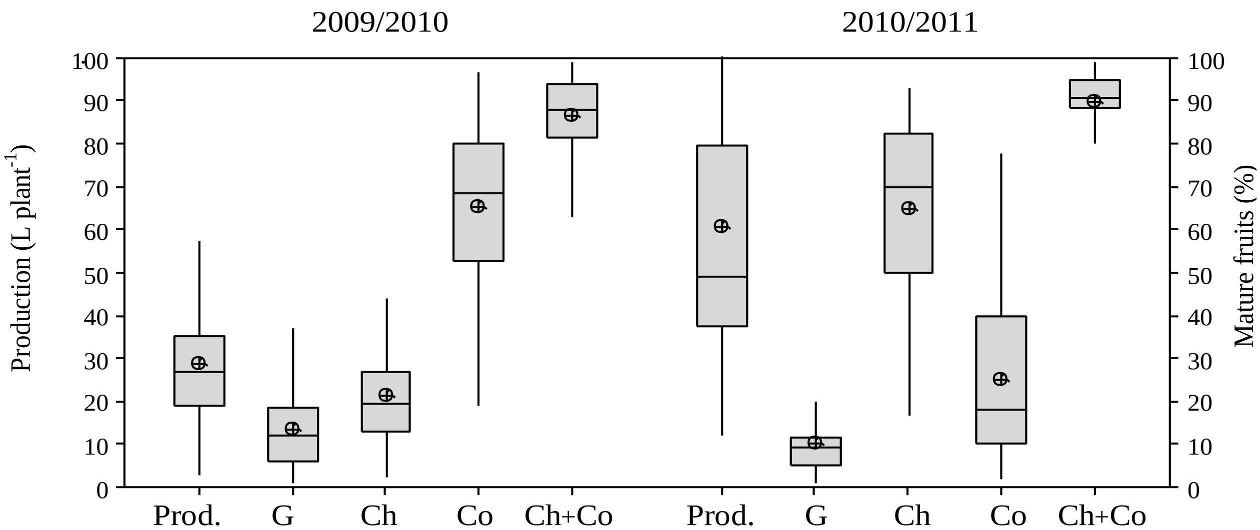
The results were statistically analyzed with the program Minitab® 16, which was passed through an exploratory analysis (descriptive statistics) to ensure normality of data, or the need for transformation to normalization. The variability behavior and the occurrence of disparate data are illustrated by boxplots.

The boxplots represent the distribution of a set of data based on the median (Q2), the lowest quartile (Q1), the higher quartile (Q3), interquartile range (IQR = Q3 - Q1) and minimum and maximum values of a parameter. This analysis illustrates the symmetry and the dispersion of the data, and it shows the presence or absence of disparate data. Boxplots are especially suitable for comparing two or more data sets corresponding to the categories of a variable.

A single factor analysis of variance (ANOVA) was conducted by applying the F test with a significance level of 5% to verify any significant differences between the averages of the variables. When appropriate, Tukey's test was applied at 5% probability to compare the means.

RESULTS AND DISCUSSION

The descriptive analysis (Figure 2) of the crop, showed an increase in the average of crop from 2009/2010 to 2010/2011. According to Oliveira et al. (2007a), this increase is due to culture biannuality, which demonstrates the stress caused by the production of a crop in the subsequent season. This phenomenon



	Prod.	G	Ch	Co	Ch+Co	Prod.	G	Ch	Co	Ch+Co
χ	2.89	13.4	21.3	65.3	86.6	6.05	10.0	65.0	24.9	90.0
σ	1.61	9.2	11.5	18.7	9.2	3.38	7.2	19.9	19.2	7.2
CV	55.9	68.7	53.7	28.7	10.7	55.9	71.9	30.5	77.1	8.0
AD	1.55^{A}	1.11^{N}	1.16^{A}	0.69^{N}	1.11^{N}	2.95^{A}	4.85^{A}	1.48^{A}	2.81^{A}	4.85^{A}

Figure 2. Descriptive statistics of the parameters related to coffee productivity and distribution of the maturation of fruits, in 2009/10 and 2010/11 crops. ¹ Variables: Prod.: Production (L plant^{-1}); G: Green fruits (%); Ch: Cherry fruits (%); Co: Coco fruits (%); (C+P): Mature coffee, cherry fruits + coco fruits (%).²Parameters: χ: Arithmetic mean; δ: Standard deviation; CV: Coefficient of variation (%); AD: Anderson-Darling normality test. (N: normal distribution; A: asymmetrical distribution).

explained the repetition of the work in two seasons, and the high-production harvest obtained more than twice the average crop of low production harvest (2009/2010). Regarding the variability between samples, similar behaviors were observed between the two crops, with high coefficients of variation (Pimentel-Gomes and Garcia, 2002) and asymmetric distributions of the data by the Anderson-Darling test.

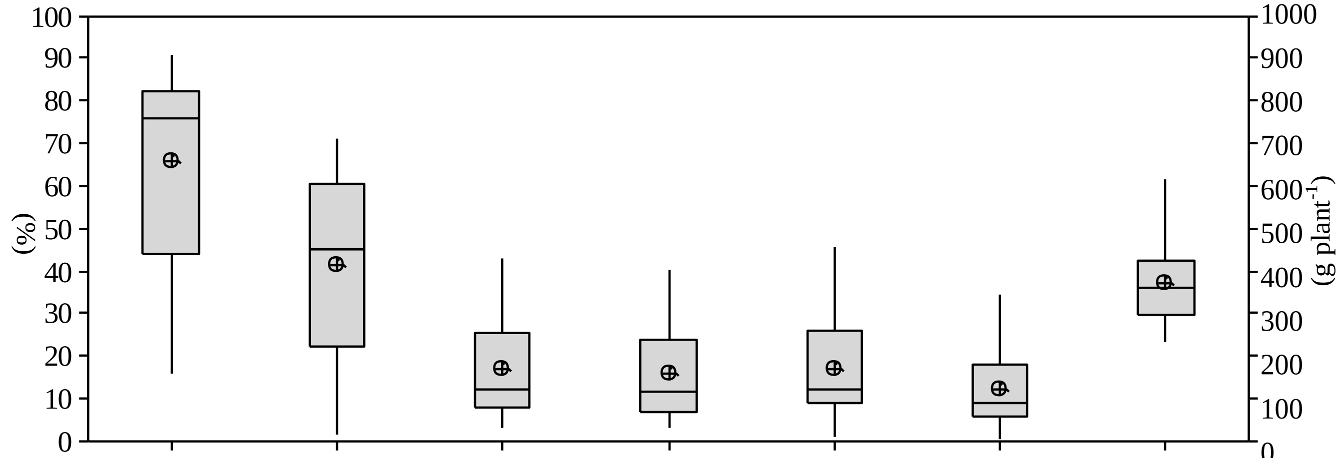
Regarding the distribution of fruit maturation, the 2009/2010 crop had a higher occurrence of coco fruits while the 2010/2011 crop had a higher occurrence of cherry fruits, which can give better qualitative properties (Queiroz et al., 2007a). Both harvests had a similar proportion of green fruits, which consequently resulted in the same proportion of harvested mature fruits (Ch + Co). Concerning the variability of the results, all stages of fruit maturation displayed differences between the averages and the median, with high values of standard deviation and coefficients of variation for both crop seasons. Only the results of green coffee and raisins in 2009/2010 had a normal distribution by the Anderson-Darling test. Only the sum of the mature fruits (Ch + Co) presented less variability, with low coefficients of variation and asymmetric distributions in the 2010/2011 crop.

The descriptive statistics for the variables related to the mechanized harvesting of coffee in two crop seasons (Figure 3) indicate similar behavior for the two crops, with high amplitude data, high values of standard deviation and high coefficients of variation. The harvesting capacity of the operation might be considered insufficient (Oliveira et al., 2007b) for both seasons, because the averages were below 70%, which resulted in a loss of approximately 30%. These losses were distributed between coffee and plant remnants lying on the ground after a machine pass in the row.

Furthermore, the operation did not undertake a selective harvest, according to Silva et al. (2006). The production was, on average, 85% of mature coffee, while the coffee collection index was 60%, resulting in high rates of green fruits, which may influence the quality of the produced beverage (Queiroz et al., 2007a). Concerning the variability of the samples and the coffee collected, maturation also had high coefficients of variation, but still had normal distributions.

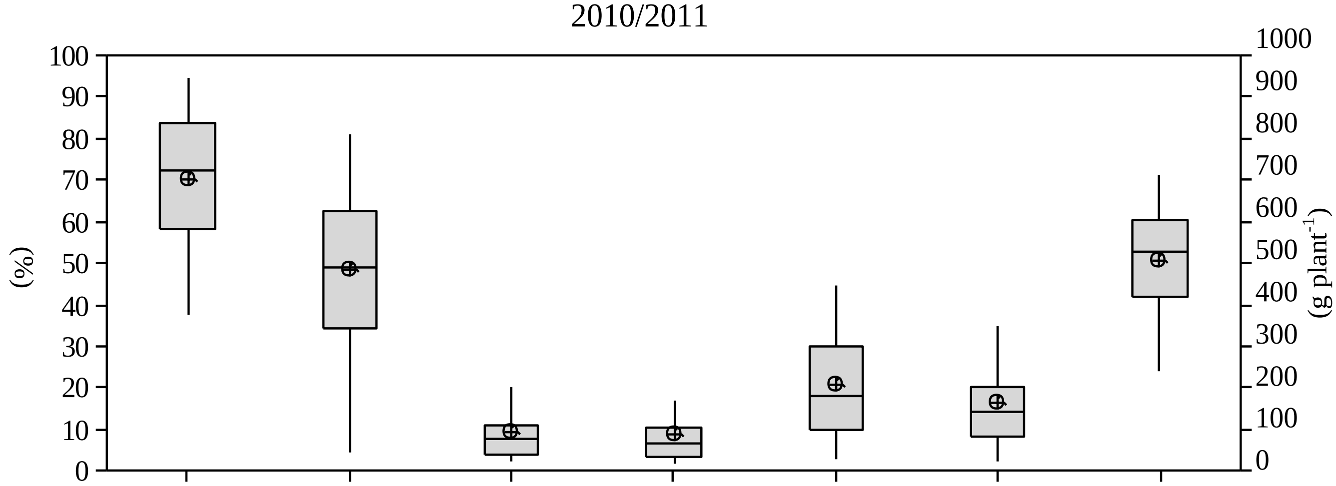
The losses of the fallen coffee and the remaining coffee were similar in the 2009/2010 crop, but the losses in the 2010/2011 crop were predominantly the remaining coffee in the plant. This result can be related to increased crop productivity and the greater availability of the fruits to be harvested (Silva et al., 2006). The coffee on the ground contained a higher concentration of mature fruit, and the fruit that remained on the tree contained a higher

2009/2010



	Coffee harvested (%) Sum	Coffee harvested (%) (Ch+Co)	Coffee dropped (%) Sum	Coffee dropped (%) (Ch+Co)	Coffee remaining (%) Sum	Coffee remaining (%) (Ch+Co)	Defol. (g plant^{-1})
χ	65.96	41.53	17.28	16.10	16.76	11.99	374.7
σ	20.75	10.60	12.61	1.08	11.29	1.52	96.0
CV	31.45	27.45	72.93	6.78	67.38	12.67	25.62
AD	1.52^{A}	0.39^{N}	1.93^{A}	2.93^{A}	1.40^{A}	0.56^{N}	0.58^{N}

2010/2011



	Coffee harvested (%) Sum	Coffee harvested (%) (Ch+Co)	Coffee dropped (%) Sum	Coffee dropped (%) (Ch+Co)	Coffee remaining (%) Sum	Coffee remaining (%) (Ch+Co)	Defol. (g plant^{-1})
χ	69.98	48.25	9.49	8.56	20.54	16.25	505.4
σ	17.47	11.44	9.40	0.41	14.19	2.85	114.9
CV	24.97	25.03	99.11	4.77	69.08	17.60	22.73
AD	0.47^{N}	0.99^{N}	3.58^{A}	1.02^{N}	1.12^{N}	1.49^{A}	0.59^{N}

Figure 3. Descriptive statistics of parameters related to coffee mechanized harvesting, fruit maturation and plant defoliation in 2009/2010 and 2010/2011 crops. [1]Parameters:χ: Arithmetic mean; δ: Standard deviation; CV: Coefficient of variation (%); AD: Anderson-Darling normality test. (N: normal distribution; A: asymmetrical distribution).

Table 1. Analysis of variance and average test for productivity and distribution of the coffee fruit maturation for 2009/2010 and 2010/2011 crops.

Factor	2009/2010					2010/2011				
	Prod.	G	Ch	Co	Ch+Co	Prod.	G	Ch	Co	Ch+Co
Faces (F)										
Internal	2.66	14.6	22.6	62.8	85.4	6.80	9.98	64.1	25.9	90.0
External	3.12	12.3	20.0	67.7	87.7	5.29	10.1	65.9	24.0	89.9
Axle (A)										
I	3.19	13.0	22.8	64.2	86.9	4.71	12.8[a]	65.7	21.5	87.2[b]
II	2.24	10.9	19.3	69.9	89.1	5.90	10.5[ab]	66.8	22.7	89.5[ab]
III	3.25	15.9	24.1	59.9	84.1	6.36	6.7b	64.7	28.6	93.3[a]
IV	2.88	13.9	19.1	67.0	86.1	7.21	10.0[ab]	62.9	27.0	90.0[ab]
F test (P<0.05)										
F	1.67[ns]	1.35[ns]	1.08[ns]	1.06[ns]	1.11[ns]	3.58[ns]	0.09[ns]	0.09[ns]	0.37[ns]	0.01[ns]
A	1.68[ns]	1.11[ns]	1.04[ns]	1.45[ns]	1.35[ns]	1.85[ns]	3.38*	0.14[ns]	0.60[ns]	2.40*
F × A	0.77[ns]	2.59[ns]	1.30[ns]	2.13[ns]	2.59[ns]	0.13[ns]	0.89[ns]	0.08[ns]	0.51[ns]	0.63[ns]

¹Variables: Prod.: Production (L plantc^{-1}); G: Green fruits (%); Ch: Cherry fruits (%); Co: Coco fruits (%); (Ch+Co): Mature coffee, cherry fruits + coco fruits (%).²In each column, for each factor, means followed by the same letters do not differ by the Tukey test at 5% probability. [ns]No significance; *Significant at 5% probability by the F test.

concentration of green fruit, because mature fruits are more easily detached from the plants than the green fruits (Ciro, 2001).

The variability of the loss results showed similar behavior in the two crops, with high standard deviations and coefficients of variation and an asymmetric Anderson-Darling distribution. The distribution of maturation of loss rates showed a variability ranging from low to medium and a normal distribution only for the coffee losses during the 2009/2010 and 2010/2011 crop, respectively.

Defoliation caused by the plant operation was higher in the high production harvest, which is a phenomenon of biannuality culture (Oliveira et al, 2007a). However, the mean values were inferior to the results obtained by Silva et al. (2006) and Oliveira et al. (2007b), which showed defoliation of approximately 800 g plant^{-1} in a similar model. Regarding the variability of the samples, although the values of standard deviation and coefficient of variation were high, the results showed normal distributions.

The analysis of variance and the average test for variables related to crop productivity and distribution of fruit maturation (Table 1) showed no difference between the planting alignments and the faces of the plants for the variables evaluated in the 2009/2010 crop. These results suggest that, despite the low productivity, there was uniformity in the volume of coffee produced and fruit maturation across all insulation conditions.

Similar behavior was observed in the 2010/2011 crop, even with a higher production volume (high-production year). This variable remained stable between the different planting alignments and for different faces. There was no difference between the evaluated axes for the ratio of green and mature coffee (Ch+Co) produced. The highest concentration of mature coffee was on Axis III in relation to the Axis I, which may be related to increased sunlight on the side of the plant during the day (Pinto et al., 2006). The analysis of variance and the means test for the variables in relation to the mechanized coffee harvesting, fruit maturation and defoliation (Table 2) showed that, for the 2009/2010 crop, the rod vibration frequency showed interaction evaluated with the axes, and then the splitting was carried out (Table 3). The evaluated axes differed in the maturation of the harvested coffee, resulting in lower maturation for Axis I. The fallen coffee losses were greater for axes I than for axes II and III, although there was no difference between the axes to mature in this crop.

None of these factors significantly influenced the defoliation of the plants. The defoliation rates were low, even with the increased vibration frequency, which is directly related to the damage caused the harvester (Aristizábal et al., 2003b). This behavior can be explained by the reduced productivity of the crop, which according to Santos et al. (2010) stimulates the stems less.

The interaction deployment for the harvested coffee and the remaining coffee in the plant (Table 3) showed that the increase in the rod vibration frequency provided a smaller amount of coffee harvested in Axis IV, which according to Barbosa et al. (2005), may be related to crop losses. Between the rows of planting, a smaller amount was harvested from Axis I than axes II and III at the higher frequency, which is linked to the loss results of

Table 2. Analysis of variance and the average test for the parameters of the mechanized harvesting of coffee, fruit maturation and defoliation of plants, in 2009/2010 crop.

Factor	Coffee harvested		Coffee dropped		Coffee remaining		Defoliation ($g\ plant^{-1}$)
	Sum	(Ch+Co)	Sum	(Ch+Co)	Sum	(Ch+Co)	
Rod vibration frequency (F)							
12.5 Hz	68.0	42.4	13.8	12.5	18.2	13.3	349.4
15.8 Hz	63.9	35.1	20.8	19.4	15.3	10.7	400.0
Axle (A)							
I	52.6	24.4^{b}	27.6^{b}	25.8	19.8	14.0	405.7
II	67.2	41.5^{a}	14.2^{a}	12.9	18.6	13.8	370.1
III	74.6	47.4^{a}	12.3^{a}	11.2	13.1	9.3	347.6
IV	69.4	43.4^{a}	15.1^{ab}	14.0	15.5	10.9	375.4
F test (P<0.05)							
F	0.69^{ns}	2.86^{ns}	4.14^{ns}	1.73^{ns}	0.94^{ns}	1.29^{ns}	2.64^{ns}
A	3.16*	3.21*	3.04*	0.32^{ns}	0.67^{ns}	0.45^{ns}	0.59^{ns}
F × A	3.21*	1.43^{ns}	1.58^{ns}	1.18^{ns}	5.27*	2.23^{ns}	0.24^{ns}

¹In each column, for each factor, means followed by the same letters do not differ by the Tukey test at 5% probability. ^{ns}No significance; *Significant at 5% probability by the F test.

Table 3. Deployment of the interaction between the factors for the harvested and remaining coffee in the plant, in the 2009/2010 crop.

Coffee harvested (%)	Vibration frequencies (F)	
Axle (A)	**12.5 Hz**	**15.8 Hz**
I	61.4^{Aa}	43.8^{Ab}
II	59.3^{Aa}	75.1^{Aa}
III	68.7^{Aa}	80.5^{Aa}
IV	82.6^{Aa}	56.3^{Bab}
Coffee remaining (%)	**Vibration frequencies (F)**	
Axle (A)	**12.5 Hz**	**15.8 Hz**
I	$17.3A^{ab}$	22.4^{Aa}
II	29.0^{Aa}	8.1^{Ba}
III	17.0^{Aab}	9.3^{Aa}
IV	9.5^{Ab}	21.5^{Aa}

¹For each variable, the means are followed by the same capital letters with row, and lowercase letters in the column show a non-significant result by Tukey's test at a 5% probability.

the fallen coffee described in Table 2.

On Axis II, the higher rod vibration frequency increased the picking ability of the harvester. The amount of coffee remaining on Axis IV was lower than that on Axis II for the lowest vibration frequency.

Analysis of variance in the 2010/2011 crop (Table 4) showed that in years of high crop production, although there were differences in fruit maturation in productivity (Table 1), the planting alignments did not influence the variables in relation to the crop, the distribution of mature plants or the defoliation of the plants. These results suggest a uniformity in the operation, regardless of the insulation conditions of the culture.

The increase in the rod vibration frequency raised the rates and maturity of the harvested coffee, thereby reducing the losses by the remaining coffee on the plants after the passage of the mechanized harvester. This result demonstrates the increased capacity of picking of the harvester by increasing the vibration frequency without increasing damage to the crop, which has been

Table 4. Analysis of variance and the average test for the parameters of the mechanized harvesting of coffee, fruit maturation and defoliation of plants, in 2010/2011 crop.

Factor	Coffee harvested		Coffee dropped		Coffee remaining		Defoliation
	Sum	(Ch+Co)	Sum	(Ch+Co)	Sum	(Ch+Co)	Sum
Rod vibration frequency (F)							
12.5 Hz	64.3[b]	37.6[b]	10.9	9.9	24.7[a]	19.8	483.7
15.8 Hz	75.6[a]	54.6[a]	8.0	7.1	16.3[b]	12.6	527.1
Axle (A)							
I	70.6	45.5	8.9	7.8	20.5	15.9	564.5
II	75.5	53.2	7.7	6.9	16.8	12.7	508.1
III	63.3	38.8	9.8	9.1	26.9	21.8	503.3
IV	70.5	45.8	11.5	10.4	17.9	14.5	445.7
F test (P<0.05)							
F	4.38*	7.97*	0.68[ns]	1.55[ns]	4.32*	0.35[ns]	1.43[ns]
E	0.87[ns]	0.63[ns]	0.17[ns]	2.19[ns]	1.27[ns]	0.31[ns]	1.78[ns]
F × E	0.64[ns]	0.64[ns]	0.75[ns]	0.95[ns]	2.62[ns]	0.15[ns]	0.05[ns]

[1]In each column, for each factor, the means are followed by the same letters were not significantly different according to Tukey's test at a 5% probability; [ns]No significance; *Significant at 5% probability by the F test.

directly linked to the action of vibration of the rods (Oliveira et al., 2007a), and this observation agrees with the results of previous research (Ciro, 2001; Aristizábal et al., 2003a; Barbosa et al., 2005; Silva et al., 2006; Oliveira et al., 2007b; Santos et al., 2010).

Conclusion

The harvesting operation proved inadequate for the two crops analyzed, with a low rate of harvested mature fruit. Planting alignments altered the rates of the harvest in the crop of low production and maturation of fruits produced in high-production harvest, with no differences between the rows facing different directions.

The effects of the increased rod vibration frequency varied according to the planting alignments in the low-production harvest and increased the harvesting capacity by increasing the amount of picked mature fruit and by reducing the losses of the remaining coffee in the high-production harvest.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Aristizábal TID, Oliveiros TCE, Alvarez MF (2003a). Physical and mechanical properties of the coffee tree related to harvest mechanization. Trans. ASABE 46(2):197-204.

Aristizábal TID, Oliveiros TCE, Alvarez MF (2003b). Mechanical harvest of coffee applying circular and multidirectional vibrations. Trans. ASABE 46(2):205-209.

Barbosa JA, Salvador N, Silva FM (2005). Operational performance of portable mechanical coffee harvesters in different conditions of coffee planting. Rev. Bras. Engenharia Agrícola Ambiental 9(1):129-132.

Ciro HJV (2001). Coffee harvesting I: Determination of the natural frequencies of the fruit stem system in coffee trees. Appl. Eng. Agric. 17(4):475-479.

Oliveira E, Silva FM, Salvador N, Figueiredo CAP (2007b). The influence of the sticks vibration and the speed in the displacement of the harvester machine on mechanized coffee harvest process. Engenharia Agrícola 27(3):714-721.

Oliveira E, Silva FM, Zigomar MS (2007a). Influence of the mechanized harvest in the coffee production. Ciênc. Rural 37(5):1466-1470.

Oliveira, E, Silva FM, Salvador N, Souza Z.M, Chalfoun SM, Figueiredo CAP (2007c). Operational costs of mechanized harvest of coffee. Pesqui. Agropec. Bras. 42(6):827-831.

Pimenta CJ, Vilela ER (2003). Effect of type and harvest period on coffee quality (*Coffea arabica* L.). Acta Sci. Agron. 25(1):131-136.

Pimentel-Gomes F, Garcia CH (2002). Applied statistics the agronomic and forestry experiments: Exhibition with examples and guidelines for application use. Piracicaba: FEALQ 309 pp.

Pinto FAC, Alves EA, Queiroz DM, Santos NT, Abrahão SA (2006). Exposure face orientation to the sun produced coffee plots and mountain region and its effect on the quality of drinking. Rev. Bras. Armazenamento 9:32-39.

Queiroz DM, Alves EA, Pinto FAC (2007a). Spatial and temporal variability of coffee quality. ASAE Annu. Meet. 07:11-15.

Queiroz DM, Santos FL, Pinto FAC (2007b). Analysis oh coffee harvesting process by vibration. ASAE Annu. Meet. 07:41-46.

Santos FL, Queiroz DM, Pinto FAC, Santos NT (2010). Analysis of the coffee harvesting process using an electromagnetic shaker. Acta Sci. Agron. 32(3):373-378.

Silva FM, Souza ZM, Arré TJ, Juan RS, Oliveira E (2006). Evaluation of mechanized coffee (*Coffea arabica* L.) harvest with ethephon use. Coffee Sci. 1(1):1-6.