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QUALITY EVALUATION OF *Coffea canephora* 'Apoatã' SEEDS FOR ROOTSTOCK PRODUCTION

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ABSTRACT: *Coffea canephora* 'Apoatã' seeds are used for the formation of rootstocks for grafting of *C. arabica* seedlings. The quality of seeds and the individualization of used genotypes are prevalent factors for the formation of vigorous rootstocks that will enhance the formation of quality seedlings. The aim of the present study was to characterize and evaluate the seed quality of *C. canephora* 'Apoatã' genotypes for potential use of rootstocks for *C. arabica* species. Were used seeds of 30 *C. canephora* 'Apoatã' genotypes, obtained from the experimental field of Embrapa Rondônia in Ouro Preto do Oeste, RO, Brazil. The seeds were processed and subjected to germination, first germination count and tetrazolium tests. Moisture, 100-seed mass and chemical composition analyses of seeds were also determined. The mass, physiological quality and chemical composition of *C. canephora* 'Apoatã' seeds vary according to the genotype. The variation of the physiological quality of *C. canephora* 'Apoatã' seeds is not related individually to caffeine, total sugars, ash, ether extract, crude fiber protein and chlorogenic acid. Seed batches of *C. canephora* 'Apoatã' from different genotypes contain seeds of different sizes, being indicated the classification before the processing stage in order to prevent mechanical damages.

Index terms: Physiological quality, physical quality, germination, rootstock.

AVALIAÇÃO DA QUALIDADE DAS SEMENTES DE *Coffea canephora* 'Apoatã' PARA A PRODUÇÃO DE PORTA-ENXERTOS

RESUMO: Sementes de *Coffea canephora* 'Apoatã' são utilizadas para formação de mudas de porta enxertos, para enxertia com mudas de *C. arabica*. A qualidade das sementes e a individualização dos genótipos utilizados é fator preponderante para a formação de porta enxertos vigorosos que potencializará a formação de mudas de qualidade. O objetivo neste trabalho foi caracterizar e avaliar a qualidade de sementes de genótipos de *C. canephora* 'Apoatã' para potencial utilização de porta-enxertos para a espécie *C. arabica*. Foram utilizadas sementes de 30 genótipos de cafeeiros 'Apoatã' oriundos do Campo Experimental da Embrapa Rondônia em Ouro Preto do Oeste-RO. As sementes foram beneficiadas e submetidas aos testes de germinação, primeira contagem da germinação e tetrazólio. Também foram determinadas a umidade, a massa de 100 sementes e as análises da composição química das sementes. A massa, a qualidade fisiológica e a composição química de sementes de *Coffea canephora* 'Apoatã' variam em função do genótipo. A variação da qualidade fisiológica de sementes de *Coffea canephora* 'Apoatã' não está relacionada isoladamente aos teores de cafeína, açucares totais, cinza, estrato etéreo, proteína fibra bruta e ácido clorogênico. Lotes de sementes de *C. canephora* 'Apoatã' de diferentes genótipos contém sementes com diferentes tamanhos, sendo indicada a classificação antes da etapa de beneficiamento para evitar danos mecânicos.

Termos para indexação: Qualidade fisiológica, qualidade física, germinação, porta enxerto.

1 INTRODUCTION

Coffea arabica L. species shows more than 90% of self-fertilization and is considered as autogamous, thus being very uniform, reason why its cultivars are propagated by seeds. However, the grafting technique has been used primarily to confer nematode tolerance on cultivars susceptible to these diseases (DIAS et al., 2009, 2013).

Besides the possibility of nematode attack control, the use of rootstocks can also improve plant vigor, increase fruit yield, nutrient use efficiency, adaptation to soil conditions and areas with limited rainfall, since some rootstocks have a more developed root system (TOMAZ et al., 2005). However, despite the mentioned benefits, the rootstock can also negatively influence the development of plants (PAIVA et al., 2012; TOMAZ et al., 2005) due to the incompatibility that can occur among some used genotypes.

The 'Apoatã' is the most commonly *C. canephora* cultivar used as rootstock for *C. arabica* cultivars (PAIVA et al., 2012) due to reports of resistance to nematodes from this cultivar (FERREIRA et al., 2011; SANTOS et al., 2017). However, the *C. canephora* species is

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allogamous, which entails great variability among the plants (MONTAGNON; CUBRY; LEROY, 2012; MOTTA et al., 2014; SOUZA et al., 2013). Thus, seeds from the 'Apoatã' cultivar are in practice crossbreeds of genotypes derived from a plant population. Moreover, once the cultivar has been propagated by seed over the years, the populations distributed in Brazil are distinct, being possibly in different generations (AGUIAR et al., 2005).

Based on this genetic variability, it is believed that the different responses found in the literature (DIAS et al., 2008, 2009; TOMAZ et al., 2005) are due to the interactions between the grafted cultivars and the 'Apoatã' populations, since the studies do not report the individualization of the used 'Apoatã' genotypes.

The genotype individualization may imply in the grafting process since seed obtaining and germination, considering that, similarly as *C. arabica*, the genetic variability can lead to different seed sizes (GIOMO; NAKAGAWA; GALLO, 2008), integument resistance (MEIRELES et al., 2007; RUBIM et al., 2010), and concentration of inhibitory substances (ROSA et al., 2007). For instance, some authors suggest that the caffeine present in the endosperm may affect the seed germination (MEIRELES et al., 2007; ROSA et al., 2006), although the influence process is not totally known.

The aim of the present study was to characterize and evaluate the quality of *C. canephora* 'Apoatã' seeds for production of rootstocks for *C. arabica* species.

2 MATERIAL AND METHODS

The research was performed at the Seed Laboratory of the Brazilian agricultural research company (Embrapa), in Porto Velho, RO, Brazil, and at the Laboratory of the Seed Sector of the Federal University of Lavras, in Lavras, MG, Brazil. Seeds of *C. canephora* 'Apoatã' derived from crops with 15 years of age were used, located in the experimental field of Embrapa, in the municipality of Ouro Preto do Oeste, RO, Brazil. The crop was formed based on seeds obtained from the Federal University of Viçosa in the 1990s. A total of 30 genotypes of late maturation cycle were selected, from which fruits were harvested manually in the "cherry" stage. The fruits were pulped in horizontal pulpers model DPMM-02 (Pinhalense®) and the seeds were dried under shade until reaching 13% moisture. After drying, the seeds were packed in paper bags and kept in air conditioned rooms at 25±2 °C.

The seeds were processed (elimination of the endocarp) and divided into two batches, being one of 500 g and another of 100 g. The first batch was sent to the Seed Laboratory of the Embrapa Rondônia where the tests were performed in order to evaluate the physiological and physical quality. The second batch was sent to the Laboratory of the Seed Sector of the Federal University of Lavras where the chemical components of seeds were determined.

The characteristics evaluated were: *water content*, which was performed before the germination and vigor tests by the oven-drying method at 105 °C (±3 °C) for 24 h with results expressed as percentage (wet basis); *100-seed mass*, performed with eight replicates of 100 seeds and with results expressed in grams; *germination*, performed with four replicates of 50 seeds per batch, in germinator at 30 °C and results expressed as percentage of normal seedlings; *first germination count*, determined together with the germination test, consisted of the normal seedling counting in the 15th day after the test installation (BRASIL, 2009), with the results expressed as percentage; and *tetrazolium test*, performed according to the methodology of Clemente, Carvalho and Guimarães (2012).

In order to perform the chemical analyses, the green coffee beans were ground for about 1 min in a Tecnal model TE 631/2 mill, adding liquid nitrogen to facilitate milling and prevent oxidation in the samples. After grinding, the samples were conditioned in plastic bottles with a screw cap and stored in a freezer at -18 ºC until the analyses were performed.

For the determination of moisture, crude protein, total lipids, crude fiber and ash (fixed minerals) in ground coffee seeds, the methods described by the Association of Official Analytical Chemists (AOAC, 1997) were used. Total sugars were determined by the method of Somogyi & Nelson (NELSON, 1944). Total chlorogenic acids were evaluated according to the methodology proposed by Clifford and Wight (1976), and the caffeine content was determined by spectrophotometry according to methodology proposed by Li, Berguer and Hartland (1990).

Tests were performed using completely randomized design with four replicates. Data were subjected to analysis of variance ($p \leq 0.05$) and the averages were grouped by Scott-Knott test ($p \leq 0.05$) through the SISVAR software (FERREIRA, 2008). The association among the evaluated characteristics was measured by Pearson correlation coefficient and its significance was verified by Student's t test ($p \leq 0.05$).

3 RESULTS AND DISCUSSION

The *C. canephora* genotypes presented different seed mass, being grouped into 13 size classes ranging from 10.34 g to 22.85 g (Table 1). Differences among genotypes have also been reported for 89 genotypes from the Embrapa Rondônia active germplasm bank (ROCHA et al., 2013). These results reflect the genetic variability among genotypes, since they constitute a population of individuals derived from allogamy.

Seed size variability was also found in 39 progenies, F4 generation, derived from the *C. arabica* hybridization, whose evaluation allowed differentiating four grains size groups (PEDRO et al., 2011). These results reinforce that segregating genotypes from the genus *Coffea* spp. may show high phenotypic variability. These authors also suggest that seed sizes have simple genetic control, but are usually associated with other characteristics, varying according to the age, position in the plant, year, yield and general growth conditions at the time of endosperm and seed development.

Regarding the physiological quality of seeds, the germination test showed different levels of quality, although most of the genotypes showed germination above 70% (Table 1). Based on the results, it was possible to differentiate six genotype groups with similar germination.

Still based on the first germination count test, variations from 22 to 90% were observed, which allowed forming four distinct groups, with 27 out of 30 genotypes presenting vigor equal to or above 60% and thus framing into groups A and B (Table 1).

In the present study, there was no significant differences among the evaluated genotypes for water and ash (fixed mineral), presenting an average content of 12.48% and 4.07%, respectively. The other variables caffeine, total sugars, ether extract, crude protein, crude fiber and chlorogenic acids were significant (Table 2).

Regarding the results of the chlorogenic acid contents, significant differences were observed among the genotypes (Table 2), being that the genotype 30 showed the lowest percentage (7.03%) and the genotype 22 the highest on (9.58%) and the found average content was 8.31%. The results are lower than observed by Aguiar et al. (2005), which found a content of 5.99% in their studies related to the chemical diversity of *C. canephora* species from the same cultivar under study. Chlorogenic acid (5-CQA) is one of the major soluble phenolic compounds that accumulated in green coffee beans and exert a protective, antioxidant action of aldehydes, which is an important factor in the maintenance of seed quality during storage (ABRAHÃO et al., 2009; MAHESH et al., 2007). However, despite the differences, no correlation was observed between chlorogenic acid contents and physiological quality of the seed.

Germination was negatively correlated with seed size (-0.64), with caffeine content (-0.33), total protein content (-0.34) and ash (-0.40), but correlated positively with the tetrazolium test (0.41) (Table 3).

The first count, as well as the germination, was also negatively correlated with the 100-seed mass (-0.65), caffeine content (-0.42), total protein content (-0.37) and ash (-0.48), but positively correlated with the tetrazolium test (0.39) (Table 3). The 100-seed mass was negatively correlated with the viability of seeds by the tetrazolium test (-0.39) (Table 3).

The negative correlation between physiological quality and seed size differs from those reported for *C. arabica*, whose seeds of smaller size showed lower physiological quality than the larger one (GIOMO; NAKAGAWA; GALLO, 2008). However, it is believed that, for the results found in the present study, the lower germination of higher mass seeds is associated to damages during pulping, since the equipment regulation was not altered for the different fruit sizes, which is confirmed by the negative correlation between the 100-seed mass and vigor by the tetrazolium test.

With the relationship of the mechanical damages to the low physiological quality of seeds, it can be suggested that the seed classification by size before the processing is an alternative to the use of 'Apoatã' seeds, without distinction of genotypes. However, the separation of seeds by size is a necessary but not sufficient condition for adequate selection in order to estimate their physiological potential and to form quality seedlings. This is because, despite the presented correlation, some genotypes, such as genotypes 14 and 24, showed low indices of 100-seed mass as well as low values of germination and vigor. These results suggest that the physiological quality of the studied seeds is related not only to size but also to other characteristics inherent to the genotype.

The ash content correlated negatively with germination and the first germination count, i.e., the higher the ash content, the lower the germination and vigor of the seed (Table 2).

TABLE 1 - Physiological quality (WC: Water content; HSW: 100-seed mass; G: Germination; FGC: First germination count; TZ: Tetrazolium) of seeds from 30 *C. canephora* 'Apoatã' genotypes.

Genotype (Clone)	WC	HSW	G	FGC	TZ
1	11.20	16.11f	65d	65b	17e
2	11.21	14.70h	77c	76a	65b
3	10.82	22.13b	57e	41c	55b
4	10.98	11.78k	77c	67b	68b
5	10.74	12.62j	82c	78a	83a
6	11.28	20.07c	72c	60b	26d
7	11.06	10.98l	84b	84a	63b
8	11.18	16.30f	73c	67b	23d
9	11.82	14.73h	74c	68b	51b
10	11.39	11.34l	78c	78a	73a
11	11.51	15.45g	85b	84a	41c
12	11.77	14.10i	91a	80a	63b
13	12.63	13.91i	81c	71b	72a
14	11.02	14.54h	57e	36c	28d
15	10.49	22.85a	35f	22d	32c
16	10.44	12.63j	83b	83a	61b
17	11.21	18.10d	79c	74a	29d
18	13.09	16.95e	83b	77a	10e
19	13.05	14.76h	80c	80a	26d
20	11.68	14.07i	79c	79a	76a
21	12.02	13.93i	83b	81a	64b
22	11.86	14.57h	92a	90a	66b
23	11.77	16.69e	81c	78a	45c
24	11.40	11.95k	78c	64b	58b
25	11.68	12.34j	88a	85a	81a
26	11.72	14.82h	76c	75a	63b
27	11.71	14.44h	80c	71b	67b
28	10.93	14.76h	84b	79a	62b
29	11.49	16.30f	74c	67b	15e
30	11.80	10.34m	80c	78a	70a
Average	-----	14.94	77.30	71.48	51.76
CV(%)	-----	2.66	6.88	8.67	18.20

Averages followed by the same letter in the column are not significant different by Scott-Knott test ($p \leq 0.05$).

TABLE 2 - Chemical characteristics (caffeine, total sugars, ash, ether extract, protein, crude fiber and chlorogenic acid) of seeds from 30 *C. canephora* 'Apoatã' genotypes.

Genotype (Clone)	Caffeine %	Total sugars %	Ash %	Ether extract%	Crude protein %	Crude fiber%	Chlorogenic acids%
1	1.48h	4.24d	3.96a	5.82b	17.38e	12.80e	8.29f
2	1.74f	4.17d	3.88a	5.57b	17.50e	14.03d	7.99g
3	1.97b	3.80e	4.04a	5.24c	17.39e	10.10e	9.40b
4	1.75f	5.03a	4.28a	5.67b	16.59f	12.13e	8.91c
5	1.47h	4.00e	3.45a	6.48a	18.18d	13.46d	7.80h
6	1.72f	4.34c	4.10a	5.23c	14.75g	13.66d	8.65e
7	1.62g	4.24d	3.56a	4.68d	17.39e	13.80d	7.82h
8	1.77e	3.83e	4.20a	4.10e	16.75f	14.56c	8.69e
9	1.60g	4.61b	3.84a	5.38c	18.38d	13.73d	7.47k
10	1.90c	4.67b	4.17a	4.83d	16.62f	13.40d	8.77d
11	1.83d	3.89e	4.13a	5.99b	17.38e	13.60d	8.92c
12	1.73f	4.24d	4.32a	5.68b	17.95d	12.60e	8.04g
13	1.93c	4.32c	4.07a	5.20c	20.19b	14.40c	7.72i
14	2.10a	4.33c	5.96a	4.66d	22.88a	14.50c	7.89h
15	2.06a	4.38c	4.35a	3.85e	20.11b	16.40b	8.78d
16	1.05l	3.61f	3.84a	3.96e	17.85e	14.80c	7.64j
17	1.29k	3.88e	4.08a	5.28c	14.93g	14.46c	7.87h
18	1.61g	4.37c	3.89a	4.84d	17.50e	15.20c	8.81c
19	1.80e	4.17d	4.08a	5.12c	18.54d	15.13c	9.40b
20	1.49h	4.14d	4.45a	4.59d	17.61e	15.46c	8.88c
21	1.48h	3.88e	4.09a	4.37d	14.94g	18.90a	8.74d
22	2.06a	3.86e	4.25a	4.05e	19.41c	14.96c	9.58a
23	1.51h	4.70b	3.69a	3.76e	17.51e	17.13b	7.29l
24	2.00b	4.41c	4.03a	5.62b	17.61e	16.00b	7.47k
25	1.43i	4.42c	3.91a	5.91b	16.40f	15.20c	8.05g
26	1.93c	4.36c	4.31a	5.39c	19.34c	18.73a	8.87c
27	1.39j	4.17d	3.51a	4.13e	17.61e	17.33b	8.84c
28	2.08a	4.11d	3.73a	4.96c	16.19f	16.30b	8.07g
29	1.70f	4.10d	3.90a	5.28c	18.17d	19.53a	7.60j
30	1.82d	4.17d	4.03a	5.34c	19.49c	15.66c	7.03m
Average	1.71	4.22	4.07	5.03	17.75	14.93	8.31
CV(%)	1.39	2.60	15.99	4.32	2.81	4.67	0.60

Averages followed by the same letter in the column are not significant different by Scott-Knott test ($p \leq 0.05$).

TABLE 3 - Pearson correlation coefficient among the analyzed variables (HSW: 100-seed mass; CAF: Caffeine; TS: Total Sugars; ASH: Ash; EE: Ether extract; PT: Protein; CF: Crude fiber; CA: Chlorogenic acid; FGC: First germination count; G: Germination; TZ: Tetrazolium) for seeds from 30 *C. canephora* 'Apoatã' genotypes.

	CAF	TS	ASH	EE	PT	CF	CA	FGC	G	TZ
HSW	0.16^{ns}	-0.18^{ns}	0.09^{ns}	-0.22^{ns}	0.06^{ns}	0.06^{ns}	***0.35****	***-0.64****	***-0.64****	***-0.59****
CAF		0.21^{ns}	***0.45****	0.03^{ns}	***0.45****	-0.06^{ns}	0.25^{ns}	***-0.42****	***-0.33****	-0.05^{ns}
TS			0.09^{ns}	0.14^{ns}	0.08^{ns}	-0.04^{ns}	-0.14^{ns}	-0.14^{ns}	-0.11^{ns}	0.07^{ns}
ASH				-0.11^{ns}	***0.52****	-0.07^{ns}	0.16^{ns}	***-0.48****	***-0.40****	-0.22^{ns}
EE					-0.12^{ns}	***-0.37****	-0.17^{ns}	0.14^{ns}	0.18^{ns}	0.14^{ns}
PT						0.06^{ns}	-012^{ns}	***-0.37****	***-0.34****	-0.01^{ns}
CF							-0.15^{ns}	0.13^{ns}	0.09^{ns}	-0.07^{ns}
CA								-0.08^{ns}	-0.11^{ns}	-0.09^{ns}
FGC									***0.95****	***0.39****
G										***0.41****

*Significant and nsNot significant by the t-test ($p \leq 0.05$).

Such correlation may be associated with protein and caffeine contents, since these two substances negatively affected the germination and the first germination count. Furthermore, protein and caffeine contents were the only components that correlated positively with ash content (Table 2). The negative correlation between physiological quality and caffeine content suggests that this substance may be associated with inhibition of germination and vigor. According to Rosa et al. (2007), the presence of caffeine may cause self-inhibition of coffee seed germination. This fact may explain the low germination and vigor of the genotypes 14 and 24, which showed 2.10 and 2.00% caffeine, respectively. These results corroborate those reported for *C. canephora* 'Apoatã', in which the exogenous application of caffeine reduced the rooting rate, root length and root fresh mass (ROSA et al., 2006).

Despite the negative correlation and behavior of genotypes 14 and 24, the results of genotypes 22 and 28 counteract with the evidences, since they showed high contents of caffeine (2.06 and 2.08%) and high physiological quality (92 and 84% germination), respectively (Table 1). Behavior similar to caffeine occurred with ash and crude protein contents, since there was a negative correlation for these components, but with low intensity, indicating that high ash or protein content does not reflect in low physiological quality for some genotypes. These results suggest the existence of other endogenous or exogenous factors associated with the quality of *C. canephora* 'Apoatã' seeds.

The contents of total sugars, total lipids; crude fiber and chlorogenic acid varied according to the studied genotype (Table 3). However, these constituents did not correlate with the physiological quality of coffee seeds (Table 2).

The slow germination of coffee seeds has been attributed to several probable causes, such as physical or chemical barriers, presence of inhibitors or hormonal balances, and probably all these factors can influence it together. Additionally, seed germination is a complex process in which innumerable metabolic events are involved and several factors act simultaneously, under genetic control and under influence of several external factors (ROSA et al., 2006).

The results of the present study suggest that the physiological quality of *C. canephora* 'Apoatã' seeds varies according to the genotype that originated such seeds. However, the evaluated chemical components did not allow inferring about the origin of such variation.

4 CONCLUSIONS

The physiological quality and chemical composition of *C. canephora* 'Apoatã' seeds vary according to the genotype.

The variation of the physiological quality of *C. canephora* 'Apoatã' seeds is not related individually to caffeine, total sugars, ash, ether extract, crude fiber protein and chlorogenic acid.

Seed batches of *C. canephora* 'Apoatã' from different genotypes contain seeds of different sizes, being indicated the classification before the processing stage in order to prevent mechanical damages.

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INTERCROPPING PERIOD BETWEEN SPECIES OF GREEN MANURES AND ORGANICALLY-FERTILIZED COFFEE PLANTATION

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ABSTRACT: The adequate supply of nitrogen to coffee plantation is one of the main challenges of organic agriculture. The aim of the present study was to evaluate the effect of organic fertilization with two legume species in different intercropping periods on nitrogen nutrition, initial growth and productivity of coffee plantation. The experimental design was in randomized blocks, in 2x4 split-plot factorial design, being that the plot consisted of two intercrops (coffee+jack bean and coffee+hyacinth bean) and the four intercropping periods (30, 60, 90 and 120 days after sowing of the legume), and the subplot by 50% and 100% of fertilization for the coffee plantation. The increase in the intercropping period between legumes and coffee plantation favored a greater increase in height and node number of coffee trees, besides showing higher heights when fertilized with 50% of the recommended dose and intercropped with hyacinth bean. The intercropping with the hyacinth bean resulted in a larger crown diameter of coffee trees in 2010 and a larger diameter accumulated in the two evaluated years. Higher N contents were found in coffee trees fertilized with 100% of the recommended dose. The legumes supplied the nutritional requirements of the coffee harvest fertilized with 50% of the dose. The bean yield of the processed coffee is not affected by the intercropping with the green manures of jack bean or hyacinth bean.

Index terms: *Coffea arabica* cv. Oeiras, *Canavalia ensiformis*, Dolichos lablab, nitrogen cycling, organic fertilization.

PERÍODO DE CONSORCIAÇÃO ENTRE ESPÉCIES DE ADUBOS VERDES E CAFEEIROS ADUBADOS ORGANICAMENTE

RESUMO: O suprimento adequado de nitrogênio aos cafeeiros é um dos principais desafios da agricultura orgânica. O trabalho objetivou avaliar o efeito da adubação orgânica com duas espécies de leguminosas em diferentes períodos de consorciação sobre a nutrição nitrogenada, o crescimento e a produtividade iniciais de cafeeiros. O delineamento foi em blocos casualizados, em esquema fatorial (2x4) com parcela subdividida, sendo a parcela constituída por dois consórcios entre cafeeiros e leguminosas (café+feijão-de-porco e café+lablabe) e os 4 períodos de consorciação (30, 60, 90 e 120 dias após a semeadura da leguminosa), e a subparcela por 50% e 100% da adubação para o cafeeiro. O aumento do período de consorciação entre leguminosas e cafeeiros favoreceu um maior incremento em altura e do número de nós dos cafeeiros, e estes apresentaram maiores alturas quando fertilizados com 50% da dose recomendada e consorciados com lablabe. A consorciação com a lablabe resultou em maior diâmetro de copa dos cafeeiros em 2010 e maior diâmetro acumulado nos dois anos avaliados. Maiores teores de N foram encontrados nos cafeeiros adubados com 100% da dose recomendada. As leguminosas complementaram e supriram as necessidades nutricionais exigidas na colheita do café adubado com 50% da dose. O rendimento de grão do cafeeiro beneficiado não é prejudicado pelo consórcio com os adubos verdes feijão-de-porco ou lablabe.

Termos para indexação: *Coffea arabica* cv. Oeiras, *Canavalia ensiformis*, Dolichos lablab, ciclagem de nitrogênio, adubação orgânica.

1 INTRODUCTION

Chemical fertilizer increases the cost of crop yield and favors the growing demand for biological and renewable origin inputs. Therefore, nutrient cycling in coffee nutrition is becoming increasingly important. In this sense, it is important to study nutritional alternatives aimed to reduce costs and dependence on industrial inputs, without implying significant losses of coffee productivity and quality (VILELA et al., 2011).

Nitrogen from fertilizers applied to the soil can be recovered by the root and shoot systems of the plants or remain in the soil, where it can be immobilized or lost from the soil-plant system (FENILLI et al., 2008), i.e., the efficiency of nitrogen fertilizers is associated with their soil dynamics (PEDROSA et al., 2014). The ability of the coffee tree to acquire nutrients depends on how the nutrient was applied (by organic or mineral), the efficiency of absorption mechanisms and the volume of soil explored by the roots, i.e.,

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the plant's ability to grow and produce well with certain nutrient content of the soil, called use efficiency (AMARAL et al., 2011).

The alternative production pathways aimed at reducing the use of external inputs should be economically viable, being a promising alternative the use of legume phytomass, by reducing some negative effects of continuous monoculture of the soil (ILANY et al., 2010). Moreover, supply of nitrogen in sufficient amounts to crops is one of the main challenges for organic coffee growing because, according to Guimarães et al. (1999), it is necessary to apply 300 kg ha^{-1} $year^{-1}$ N to produce 60 bags ha^{-1}, approximately.

Green manures contribute to the nutrient cycling, both those added by fertilizers and not utilized by the main crop, as well as those from the organic matter (OM) mineralization of the soil (TORRES; PEREIRA; FABIAN, 2008). Nitrogen-fixing legumes can be used as a source of N for coffee crop because their cultivation between the lines of coffee tree allows recycling nutrients by the decomposition of the produced biomatter, as well as the contribution of the OM to the soil. However, organic fertilizers regulated by organic legislation such as manures, organic compounds, bran, meals, among others (RICCI et al., 2005), present a low N concentration from approximately 10 to 50 g kg^{-1}, besides mineralization and complex behavior in the soil.

The nutrient mineralization of green manures should be synchronized as a period of increased nutritional demand of the coffee tree. High mineralization rates before or after this period can promote loss or immobilization of N, with few benefits to the crop. In addition, the growth of green manure may affect the growth and yield of coffee plantation. Therefore, the accumulation of nutrients and the N contribution from the green manures should be associated with the choice of the planting and cutting periods. Therefore, flowering is probably not a good indicator of the cutting season of green manures, since the species flowers at different times under different weather conditions, as well as different mass accumulations in different phenological stages and nutritional demand of coffee trees.

The aim of the present study was to evaluate the influence of the cutting season of legumes jack bean (*Canavalia ensiformis* (L.) DC.) and hyacinth bean (*Dolichos lablab* L.) and organic fertilization on the nutritional status of N, growth and the initial yield of coffee trees.

2 MATERIAL AND METHODS

The experiment was carried out from October 2007 to May 2011 at the Horta Velha experimental field of the Universidade Federal de Viçosa, in Viçosa, MG, Brazil, located at 20°45'14" S and 42°52'53" W, and 650 m altitude. The chemical characterization of the soil before planting and in subsequent years is presented in Table 1.

The experimental design was in randomized blocks, in a ((2x4)+1)x2 split-plot factorial design with five replicates. The plot consisted of two intercrops between coffee and legumes (coffee+jack bean and coffee+hyacinth bean) and four intercropping periods (30, 60, 90 and 120 days after sowing of the legume - DASL), besides a treatment without intercropping, with legumes as a control. The subplot was composed by fertilization with 50% and 100% N dose for the coffee growing. Each subplot consisted of six useful plants.

The transplanting of *C. arabica* cv. Oeiras seedlings was performed in October 2007, spaced 2.80 m between lines and 0.75 m between plants. The coffee was fertilized based on the recommendations of Guimarães et al. (1999), receiving the subplots with 50% and 100% fertilization, respectively (Table 2). The chemical analysis results of the materials used in fertilization are presented in Table 3.

The legumes jack bean (JB) and hyacinth bean (HB) were previously inoculated with the rhizobia strains *Bradyrhizobium* sp. and *Bradyrhizobium elkanii*, respectively, and sown in three lines between the coffee lines, at 1 m from the coffee trees, spaced 0.4 m apart and at the density of six seeds per linear meter. The legumes were cut according to the treatments, and the residues were placed under the canopy of the coffee tree.

Evaluations of coffee vegetative development were performed at the end of the phases of major (March) and minor (September) growth. These data were presented as increment in the period, i.e., the growth of the end date (March 2010) minus the growth of the initial date (September 2009), and the final increment as the sum of the 2009 and 2010 increments.

For evaluation of plant height (PH, cm), a measuring tape was placed parallel to the orthotropic branch of the coffee tree, measuring from the soil surface to the apical bud.

TABLE 1 - Results of routine soil chemical analysis of the experimental area, before the implementation of treatments in October 2007, in the layer 00-20 cm and 20-40 cm, and in the following years, Oct 2008 and Oct 2009, in the layer 00-20 cm.

Year	Treat	pH H_2O	P mg dm^{-3}	K	Ca^{2+} cmol$_c$ dm^{-3}	Mg^{2+}	Al^{3+}	H+Al	EB	CEC(t)	CEC(T)	V %	m	P-rem mg L^{-1}
2007	00-20	6,0	14,8	69	2,0	0,7	0,0	3,96	2,88	2,88	6,84	42	0	24,2
	20-40	5,6	4,4	36	1,1	0,4	0,0	3,14	1,59	1,59	4,73	34	0	21,0
2008	JB30	7,0	149,9	210	4,8	1,5	0,0	0,83	6,84	6,84	7,67	89	0	
	JB60	6,4	105,3	170	3,7	1,3	0,0	1,65	5,43	5,43	7,08	77	0	
	JB90	6,9	127,7	162	4,3	1,5	0,0	0,99	6,21	6,21	7,20	86	0	
	JB120	6,6	85,8	124	3,4	1,2	0,0	1,49	4,92	4,92	6,41	77	0	
	HB30	6,9	102,4	172	4,2	1,4	0,0	1,32	6,04	6,04	7,36	82	0	
	HB60	6,9	73,3	182	4,2	1,4	0,0	0,99	6,07	6,07	7,06	86	0	
	HB90	6,8	117,7	132	3,9	1,4	0,0	1,15	5,64	5,64	6,79	83	0	
	HB120	6,7	105,3	124	3,8	1,4	0,0	1,32	5,52	5,52	6,84	81	0	
	TEST	7,1	201,7	210	5,3	1,5	0,0	0,99	7,34	7,34	8,33	88	0	
2009	JB30	6,4	11,8	97	2,4	1,0	0,0	1,98	3,65	3,65	5,63	65	0	
	JB60	6,3	17,4	59	2,1	0,9	0,0	2,31	3,15	3,15	5,46	58	0	
	JB90	6,9	74,1	93	2,7	1,0	0,0	1,65	3,94	3,94	5,59	70	0	
	JB120	6,4	19,5	54	2,1	0,9	0,0	2,64	3,14	3,14	5,78	54	0	
	HB30	6,6	24,6	83	2,6	1,0	0,0	2,31	3,81	3,81	6,12	62	0	
	HB60	6,6	20,0	97	2,3	1,0	0,0	1,98	3,55	3,55	5,53	64	0	
	HB90	7,0	52,6	113	2,8	1,0	0,0	1,82	4,09	4,09	5,91	69	0	
	HB120	6,7	27,0	71	2,3	0,8	0,0	1,82	3,28	3,28	5,10	64	0	
	TEST	6,6	17,9	72	2,3	0,9	0,0	2,64	3,38	3,38	6,02	56	0	

pH of water, KCl and CaCl2 – 1:2.5 ratio
P – K – Mehlich 1 extractor
Ca – Mg – Al – Extractor : KCL – 1 mol L^{-1}
H + Al – 0,5 mol L^{-1} calcium acetate extractor – pH 7,0
EB = Exchangeable bases
CEC (t) – Effective cation exchange capacity
CEC (T) – Cation Exchange capacity at pH 7,0
V = Base saturation index
m = Alumínio saturation index
P-rem = Phosphorus Remnant

For evaluation of crown diameter (CD, cm), a measuring tape was placed transversely to the orthotropic branch in relation to interline of the coffee tree, measuring the higher distance between the first pair of leaves present in the opposite plagiotropic branches. It was also quantified the number of total nodes (NTN) in a plagiotropic branch in the middle third of the plant. In 2009, the branches chosen in 2008 occupied the lower third of the plant, being replaced by other branches in its middle third. The leaf nitrogen concentration (NC) in coffee plantation was determined in November and March of the years 2008/2009 and 2009/2010 at 30 and 150 DASL, in leaf samples of the 3rd and 4th pairs of the plagiotropic branch present in the middle third of the coffee tree.

The legumes were cut at ground level in a linear area of 1,0 m, and according to the proposed treatments and managements, this sample was weighed and the subsamples were removed. The subsamples were washed in deionized water and dried in a convection oven at 70 °C until constant weight and stored for further determination of N concentration by sulfur digestion, according to Kjeldahl methodology modified by Cotta et al. (2007). Productivity was determined by discounting the area occupied by coffee plantation.

TABLE 2 - Fertilization performed in coffee plantation in the 2008/2009 and 2009/2010 crop years.

Fertilization[1]		Limestone	Thermophosphate	Poultry litter	Castor bean cake
		---------- g $plant^{-1}$ ----------		------- g DM $plant^{-1}$-------	
Planting		50.00	300.00	750.00	---
Mulch	(Dec/Jan 2008)	---	---	325.00[2]	---
	1st year (2008/2009)	---	---	653.25[3]	---
		---	---	---	304.85
	2nd year (2009/2010)	---	---	1044.00	---
		---	---	---	383.24
		---	---	---	304.70

[1] Values calculated considering the recommendation of 300 kg ha^{-1} $year^{-1}$ N (GUIMARÃES et al., 1999);
[2] Applied in two side dressing; [3]Applied in three side dressing.

TABLE 3 - Chemical analysis results of poultry litter (PL) and castor bean cake (CBC) used in basal fertilization of coffee plantation in 2007 and topdressing fertilization in the following years, 2008 and 2009.

Year		N	Y	K	Ca	Mg	Y	CO	C/N	Zn	Fe	Mn	Cu	B	pH	Moisture
		-----------------------%-------------------						(%)		-------------------ppm---------					H_2O	(%)
2007/08	PL	2.73	1.99	1.47	2.84	0.55	0.38	21.05	8.98	461	1413	369	56	87.7	7.02	53
2008/09	PL	1.99	1.44	2.88	3.53	0.64	0.40	20.74	10.42	536	2601	638	63	65.3	7.69	60
2009/10	CM	5.85	0.61	0.88	1.64	0.47	0.55	15.75	2.69	120	9355	216	23	26.6	5.91	12.9
	PL	1.82	2.90	1.84	12.23	0.56	0.79	8.11	4.45	743	1858	503	63	54.4	7.00	42

The coffee yield was evaluated in the harvests performed in March 2010 and May 2011 in all the useful plants in the subplots. The fruits were harvested and weighed, obtaining the cherry coffee yield. The samples were collected and the fruits were dried in a terrace up to 12% moisture, yield data on the coconut coffee (kg ha^{-1}), which were then processed and obtained the processed bean yield (kg ha^{-1}), and the percent yield (%). The productivity (60 bg ha^{-1}) of each year and the average biannual productivity (bg ha^{-1}) were determined with the average productivity of 2010 and 2011.

The data were evaluated through analysis of variance by F test, followed by Dunnett's test (for comparisons with the control) or Tukey test (for comparisons in the factorial), or even by regression analysis of variance, when pertinent, always at 5% probability level. The analyses were performed using the System for Statistical and Genetic Analyses - SAEG (FUNDAÇÃO ARTHUR BERNARDES, 2007). The choice of the regression models was made based on the biological phenomenon, the determination coefficient and the residue analysis at 5% probability level.

3 RESULTS AND DISCUSSION

In the 2009/2010 season, there was effect of the interaction between species and the legume intercropping period on the growth of jack bean and hyacinth bean, justified because the growth of the species were directly related to the growth habit and duration in the field. The accumulation of fresh (FM) and dry matter (DM) in both species increased until the end of the evaluated period, with fitting of quadratic regression models (Figures 1A and B). Such model is because the maximum evaluated period is 90 days, in which the species are at the growth peak and there wasn´t mass losses due to the decreased vegetative part as a function of the flowering.

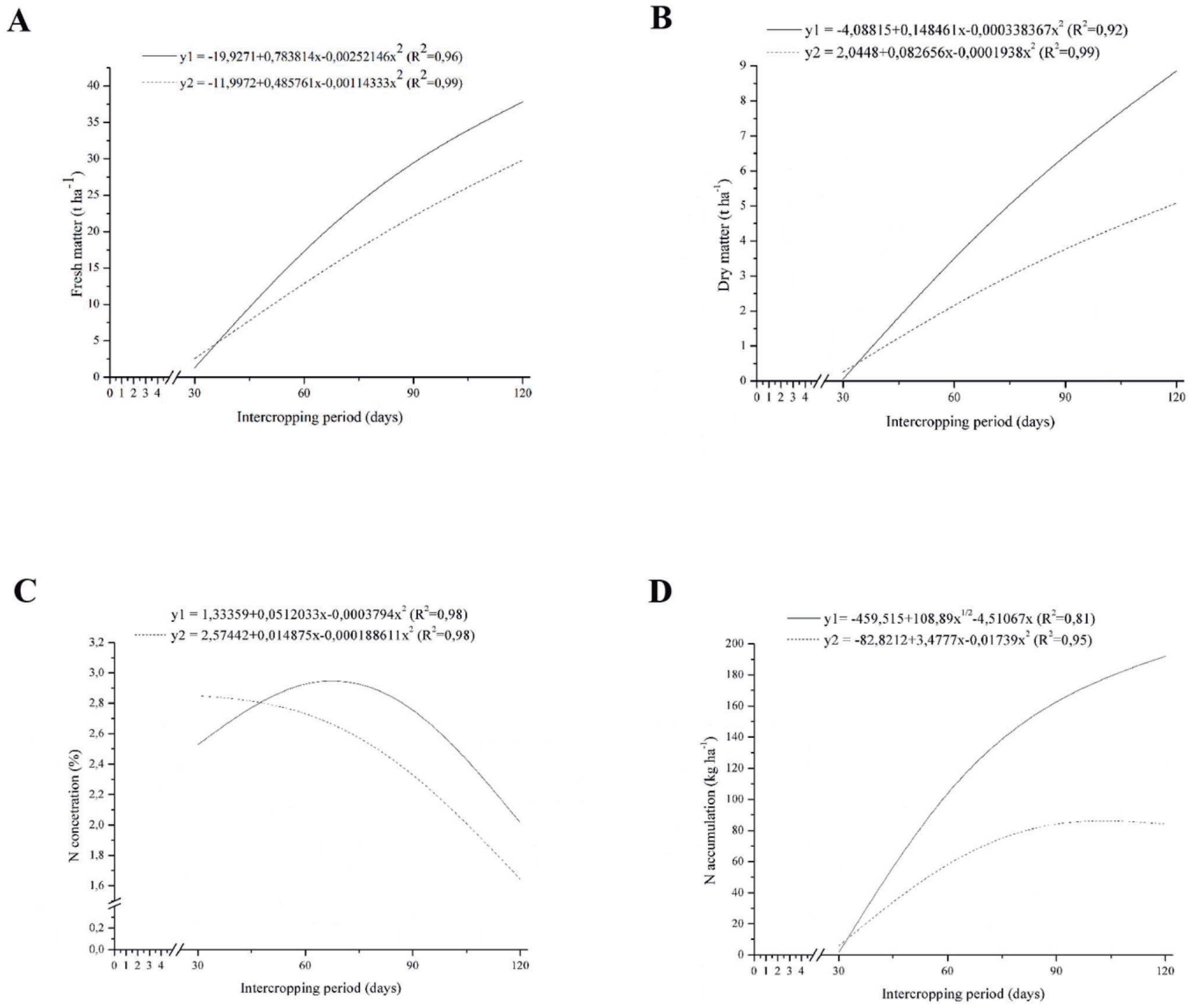


FIGURE 1 - Accumulation of fresh and dry matter (t ha^{-1}, A and B, respectively), concentration (NC %, C) and accumulation of nitrogen (NAC kg ha^{-1},D) in the green manures jack bean (y1) and hyacinth bean (y2) intercropped with coffee trees in 2009/2010.

Jack bean accumulated more mass than hyacinth bean, mainly from 90 DASL, and there was no significant difference ($p \geq 0.05$) between the species in the 30 and 60 DASL periods. This fact is due to the physical characteristics of the species, which can be better distinguished from 60 days, when the stem/leaf ratio of jack bean is increased, thus accumulating more mass.

The DM content in the jack bean was higher than the hyacinth bean at the same cutting dates, probably due to its shorter development cycle, with pod formation already at 90 days, thus increasing its DM content from this date. No flower and hence pod formation were observed in the hyacinth bean until the 120 DASL, the last cutting date. In a study on the intercropping between organic coffee trees and jack bean and hyacinth bean, it was also reported in the first experimental year that the DM accumulation by the jack bean was superior to hyacinth bean, 2.65 t ha^{-1} and 1.89 t ha^{-1}, respectively (MOREIRA et al., 2014), indicating that there is consistency of the result obtained with those found by other authors.

The jack bean showed higher NC in relation to the hyacinth bean at 60, 90 and 120 DASL. The NC in the hyacinth bean decreased over time. With the jack bean happened the opposite, where the NC was increased up to 70 DASL (inflection point), when it went down to the last cutting date (Figure 1C).

The nitrogen accumulation (NAC) in jack bean increased over time, totaling 192 kg ha^{-1} N at 120 days (Figure 1D). The NAC in the jack bean was superior to the hyacinth bean, except at 30 DASL. The highest NAC by hyacinth bean occurred at 100 days, with 91.05 kg ha^{-1} N. There is a report of lower NAC in jack bean (71.52 kg ha^{-1}) at 120 DASL, in an experiment performed in a lower altitude region and intercropped with adult coffee trees (MOREIRA et al., 2014). The weather conditions provided by the highest altitude and mainly the intercropping with younger coffee trees, providing low shade to the jack bean and allowing its full development due to its erect growth habit, resulted in lower competition between green manure and coffee tree, thus favoring the highest yield and NAC of the jack bean in the present experiment.

The N concentration is considered as adequate for coffee tree between 2.6 and 3.0%. In order to reach such concentrations, it is necessary to apply approximately 300 kg ha^{-1} per year of N, with expected yield of 60 bags ha^{-1} (GUIMARÃES et al., 1999). The NAC in jack bean at 120 DASL would be enough to supply the nutritional demand in the first years or to supplement it in subsequent years, assuming that there would be no competition with the coffee tree.

The intercropping period with legumes showed an isolated effect on height and number of nodes of the coffee trees, both in 2009, probably because the development of legumes was more pronounced in relation to coffee tree in the early years, when their size was still low. Legumes influenced the crown diameter individually in 2010 and the final diameter (sum of the increments) in the years 2009 and 2010. The height of coffee trees in 2010 was influenced by interactions between species and intercropping, fertilization and species, and fertilization and intercropping. Therefore, it was observed that the crown and root development of the coffee tree created a competition between these and the green manures, directly influencing the growth of coffee trees. Moreover, there was effect of the interaction between fertilization and intercropping on the diameter and number of nodes in 2010, and the final number of nodes.

The height increase was lower with the increased intercropping period in 2009 (Figure 2A). In 2010, coffee trees intercropped jack bean overcame those with hyacinth bean only at 30 days, being similar in the other intercropping periods (Table 4 and Figure 2B). Vilela et al. (2011) verified that the coffee trees fertilized with legumes showed higher vegetative growth than those that received only nitrogen fertilization with ammonium sulfate, except for the plant height, which was statistically similar in all treatments at the end.

The intercropping between coffee trees and jack bean in 2010 resulted in a smaller height increase up to 70 DASL, while those intercropped with hyacinth bean showed a linear increasing height throughout the intercropping period (Figure 2B).

The hypothesis that the residual effect of green manures, nitrogen immobilized in 2008 and 2009 and subsequently released over time, favored culture of interest may explain the increment presented by height and crown diameter in 2010, regardless of the applied dose (Figures 3A and 3B), being that the longer the intercropping period with green manures, the higher these values.

Coffee trees intercropped with hyacinth bean and fertilized with 50% N dose showed a higher increment in height when compared to those fertilized with 100% dose. However, at the 100% dose there was no significant difference resulting from legume species (Table 4).

The coffee height increment in 2010, with 50% fertilization and intercropping for 30 DASL, was higher when compared to the 100% dose, and did not differ in the other intercropping periods in both doses. The height increment curves in 2010 in relation to the fertilization doses (Figure 3A) showed the same curve pattern of the species (Figure 2B), where for the 50% dose, the growth remained practically stagnant until the 75th day and then increased until the end of evaluations.

The intercropping with the hyacinth bean resulted in a larger crown diameter increment of coffee trees in 2010 and a higher diameter increment accumulated in the two evaluated years (Table 4 and Figure 3B). The fertilizations of 50% and 100% dose did not influence the crown diameter of coffee trees in that same year. In both doses, the crown diameter increment in 2010 followed quadratic model with the increase of the intercropping period (Figure 3B), similar to the behavior in 2009.

Although all coffee trees grew in height and crown diameter in the evaluated period, the reduction of this growth when intercropped with jack bean (JB) can be attributed to the competition with the legume, since it showed rapid initial growth, flowered with about 70 days, thus initiating the production of pods and accumulating more mass than the hyacinth bean, as verified in Figure 1, which resulted in lower competition with the coffee tree.

TABLE 4 - Height increment (cm) in 2010 at each intercropping period and in organic fertilizations of 50% and 100% of the dose; diameter increment in 2010 (Diam 2010, cm) and accumulated diameter in 2009 and 2010 (Acc. diam, cm) of the coffee trees intercropped with jack bean and hyacinth bean for different periods of days after sowing (DAS).

SPECIES	HEIGHT 2010						Diam 2010[1]	Acc. diam
	Intercropping season[1]				Fertilization[2]			
	30 DAS	60 DAS	90 DAS	120 DAS	50%	100%		
Jack bean	30.60 A	27.25 A	28.17 A	31.67 A	28.70a B	30.14aA	11.05 b	60.06 b
Hyacinth bean	23.97 B	29.88 A	32.14 A	36.39 A	32.18a A	29.01aA	15.66 a	65.57a

Averages followed by the same letter on the same column do not differ among themselves by F test ($p \geq 0.05$). Averages followed by the same lowercase letter on the row and capital on the column do not differ among themselves by Tukey test ($p \geq 0.05$).

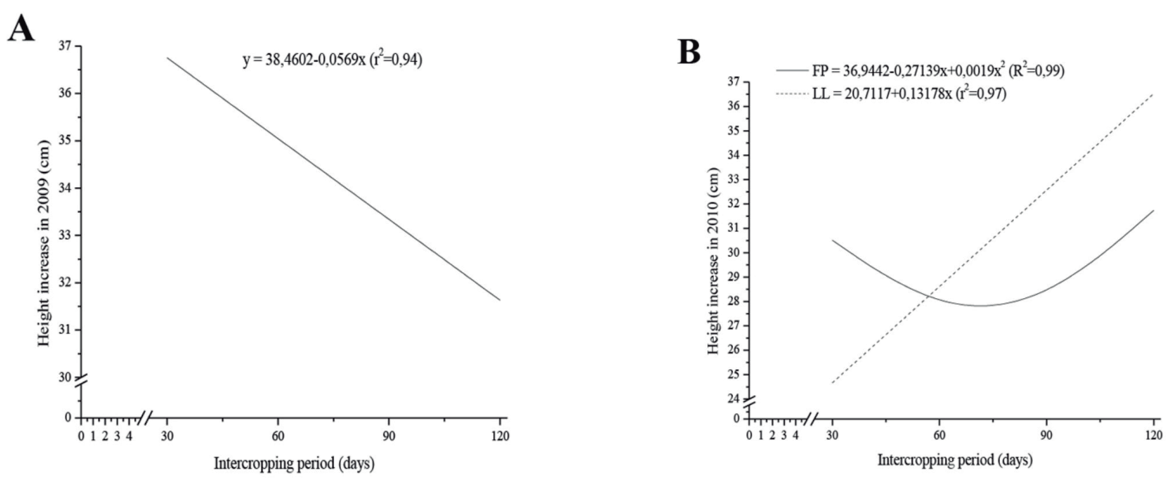


FIGURE 2 - Height increment in 2009 (A) and 2010 (B) of coffee trees, due to the species of intercropped green manure (jack bean and hyacinth bean) at each intercropping period..

Jack bean is a species of tropical and subtropical climate, adapted to practically all types of soils, being considered as very rustic, resistant to high temperatures and drought, with a long annual cycle of 180 days and flowering with approximately 140 days (BARRETO; FERNANDES, 2001). The ideal conditions of JB cultivation may have favored its early flowering.

Moreira et al. (2014) reported that intercropping with hyacinth bean resulted in different effects on adult coffee trees: the longer the intercropping period with the hyacinth bean, the higher the reduction of crown diameter in the 1st year, however, in the 2nd year, the longer the intercropping period with the hyacinth bean, the larger the crown diameter of coffee trees, similar to the result obtained with young coffee trees in this experiment. Such results suggest that miscellaneous effects can be expected in continuous evaluations for a higher number of years. Moreira et al. (2014) observed divergent results between the coffee intercropped with jack bean and hyacinth bean in relation to the intercropping period, the crown diameter of coffee trees was affected negatively by the increased conservation period with hyacinth bean, and the intercropping with jack bean resulted in linear response plateau model.

The legumes did not result in distinct effects on the number of nodes (NN) of coffee trees, in none year ($p \geq 0.05$). In 2009, the NN increased linearly over time, with no significant difference as a function of the fertilization dose (Figure 4A).

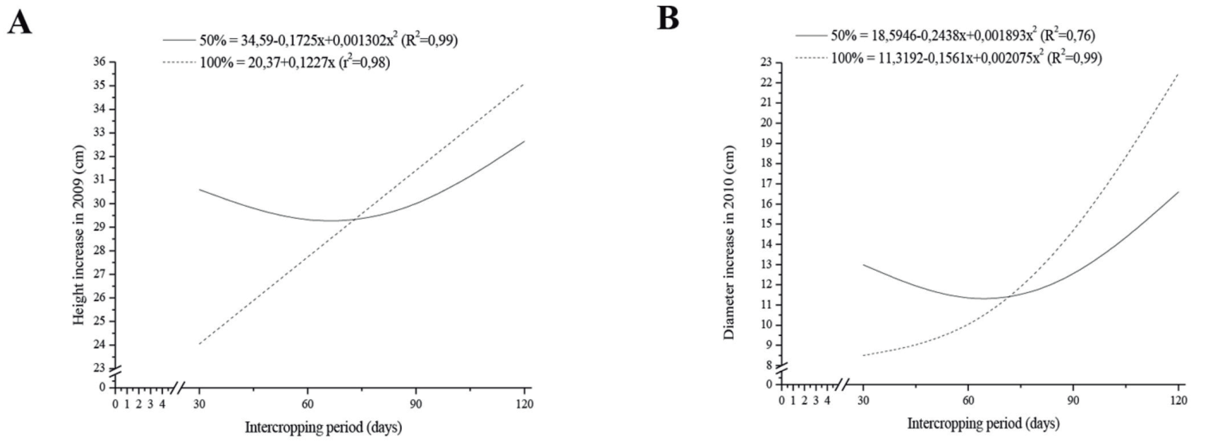


FIGURE 3 - Increment in height and crown diameter in 2010 of coffee plants under 50% and 100% organic fertilization..

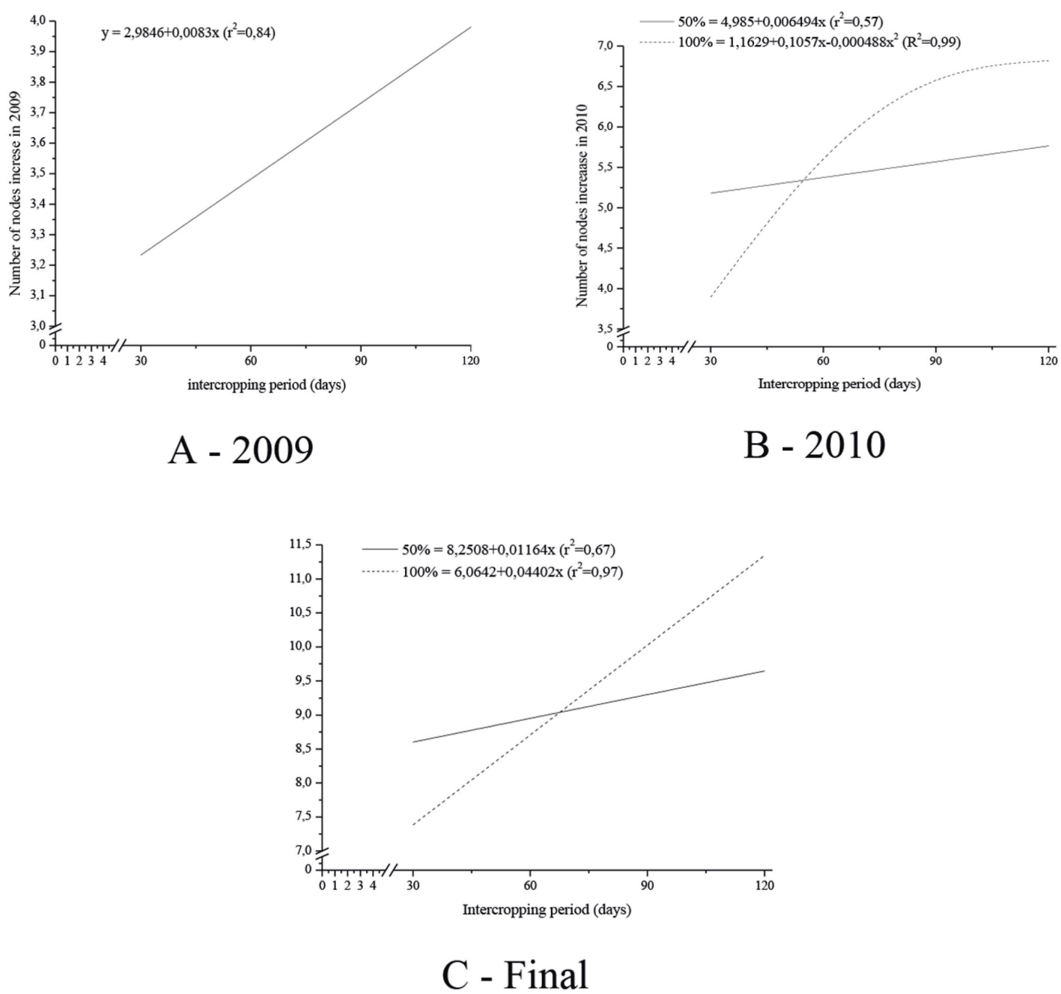


FIGURE 4 - Increment in number of nodes in 2009 (A - average of two doses of fertilization), in 2010 (B) and final increment in the number of nodes (C) of coffee plants at each intercropping period with legumes and under 50% and 100% recommended fertilization. Averages of treatments from two intercropped legumes.

Regarding the increase of NN in 2010, coffee plants fertilized with 50% dose showed a higher increase in the NN up to about 70 DAS, which was overcame by the coffee tree fertilized with 100% dose after this intercropping period (Figure 4B). The accumulated increment in the NN within two years was higher in coffee trees that received the full dose of fertilization (Figure 4C).

In a comparative study between the exclusive supply of biomass of feed peanut or mucuna, it was observed that the legumes showed stem perimeter, crown diameter, number of nodes and leaves similar with one another and higher than those fertilized with ammonium sulfate (VILELA et al., 2011). In another research the biomass of feed peanut promoted increases in crown diameter and volume, height and number of plagiotropic branches (FIDALSKI; CHAVES, 2010). Araújo et al. (2014) observed that initially 30% initial dose of the mineral fertilizer adequately nourished the coffee tree until the beginning of the reproductive period. However, at the end of this period, it became necessary to supplement the fertilization with 584 g plant^{-1} of jack bean biomass. These results demonstrate the beneficial effect of applying legume biomass on the initial growth of the coffee tree. In any case, it should be emphasized that these studies did not deal with intercropping between coffee trees and green manures, but rather the supply of green mass to the coffee tree. Thus, there was no competition among plants.

Leaf NC in coffee plants analyzed at 30 and 150 DASL were influenced only by the intercropping period ($p<0.05$). There was no effect of the intercropping period or the species on the NC when coffee trees were evaluated at 60, 90 and 120 DASL and compared with the average of controls (Table 5).

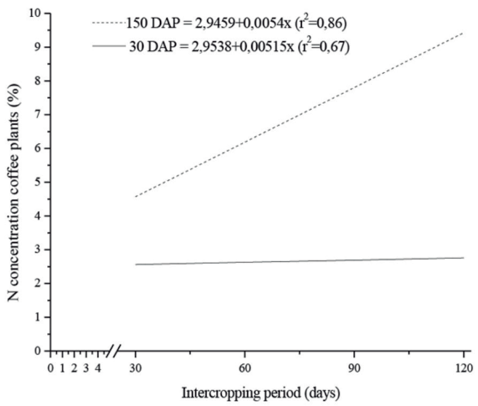
In the analysis performed at coffee plantation in 2008/2009, the NC increased little over time when the legumes were cut at 30 DASL (Figure 5A), which can be attributed to the residual effect of the matter of intercropped legumes in the two previous years. With the cut of legumes at 30 DASL, the intercropping between the coffee tree and the hyacinth bean for 60 and 120 days resulted in a higher average NC (Table 5), and the other treatments did not differ from the average of controls.

In coffee trees evaluated at 150 DASL in 2008/2009 and 2009/2010 crop season, the N concentration increased linearly with the increase of the intercropping period, regardless of the legume species (Figures 5A and B). This result can be explained by the increasing amount of mass and N (Figures 1B and 1D) of legumes supplied to the coffee trees.

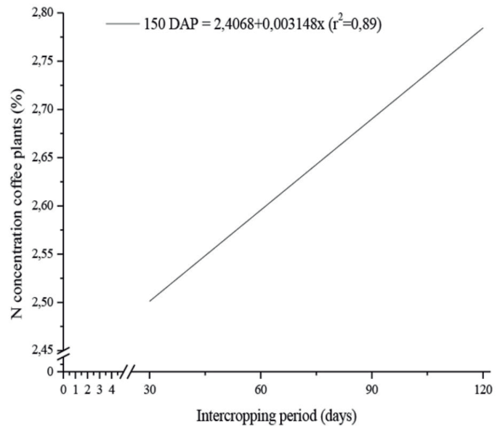
TABLE 5 - Nitrogen concentrations (NC, %) in the coffee tree at 30 and 150 days after sowing of legumes (DASL) jack bean and hyacinth bean cut at 30, 60, 90 or 120 days and the average of controls (50% and 100% fertilization), in the 2008/2009 crop season.

SPECIES	DAYS OF INTERCROPPING	NC 30 DASL (%)	NC 150 DASL (%)
Control		2.49	3.16
Jack bean	30	2.58	3.05
	60	2.57	3.19
	90	2.65	3.54 A*
	120	2.74	3.61 A*
Hyacinth bean	30	2.53	3.14
	60	2.76 A*	3.25
	90	2.56	3.56 A*
	120	2.85 A*	3.44
CV (%)		6.03	6.06

Averages followed by * differ from the control by the Dunnett's test ($p<0.05$).



A - 2008/2009



B - 2009/2010

FIGURE 5 - Leaf nitrogen concentration (NC, %) in the coffee tree after 30 and 150 days after sowing (DAD) of green manures at each intercropping period with legumes (30, 60, 90 and 120 DASL) in the 2008/2009 and 2009/2010 crop season.

In the 2008/2009 crop season, in the evaluation of 30 DASL, the coffee trees presented NC similar to the average of controls (50 and 100%) without intercropping (Table 5). In the same year (2008/2009) at 150 DASL, the coffee trees intercropped with the jack bean for 90 and 120 days and with the hyacinth bean for 90 days showed higher NC in relation to the other intercropping periods and the average of controls (Table 5). These concentrations were above the low level of < 2.50 dag kg^{-1}, established for the coffee tree (GUIMARÃES et al., 1999). Legume cutting at 30 DASL resulted in low mass and N accumulation, i.e., the short intercropping period provided little or no effect on NC of coffee trees evaluated at 30 DASL. However, in the evaluation at 150 DASL, the effects of increased amounts of mass and N provided due to the longer intercropping period, and the longer time of mineralization and uptake of N by coffee trees, resulted in higher NC in the tissues.

In the 2008/2009 crop season, the coffee trees showed NC within the aforementioned range considered as adequate for the region and in values similar or superior to the control without intercropping. The increased NC at the end of the reproductive cycle (150 DASL) when compared with the beginning of the cycle (30 DASL) in the different intercropping periods suggests that the soil supply and N uptake by the roots were sufficient to meet the demands of fruits and leaves. These results suggest a possible lack of competition of the green manure with the coffee tree by nitrogen, besides reflecting the positive effect of intercropped legumes in 2007/2008 crop season.

In 2009/2010, for the leaf N of the coffee tree, there was only a significant effect of the interaction species x intercropping period and fertilization X intercropping period (Figure 5B and Table 6). There was no effect of treatments when coffee trees were evaluated at 60, 90 and 120 days. In the evaluation of coffee trees at 30 DASL, those intercropping with JB had higher NC than those intercropped with hyacinth bean (HB), which was reversed when the coffee trees were evaluated at 150 DASL (Table 6). In both evaluation dates, the coffee trees that received the full-dose fertilization showed higher NC (Table 6).

This result is explained by the mass decomposition and accelerated N mineralization of the HB in relation to the JB, possibly because the JB is a shorter cycle plant with pod formation and a higher lignin content as early as 70 days (BARRETO; FERNANDES, 2001), whereas the HB no flowering was observed until the last cutting date.

The leaf tissue analysis of coffee trees at 26 days after the final cut of the crotalaria showed that in the plots where the legume was cultivated, there was a significant reduction of the accumulated total N concentration, from 2.93 (May/2002) to 3.5 before the crotalaria cultivation (November/2001), being kept below the level considered as critical (3%), possibly due to the greater competition exerted by the legume throughout its development, by the N available in the soil (RICCI et al., 2005).

TABLE 6 - Leaf nitrogen concentration (NC, %) in the coffee tree at 30 and 150 days after the sowing (DASL) of green manures jack bean and hyacinth bean (DASL), and with 50% and 100% of the recommended fertilization in the 2009/2010 crop season.

Variable		NC (%)	
		30 DASL	150 DASL
Species	Jack bean	2.79 a	2.58 b
	Hyacinth bean	2.70 b	2.70 a
Fertilization	50%	2.68 b	2.61 b
	100%	2.81 a	2.68 a

In order to evaluate the effect of species and fertilization, the averages followed by the same letter on the column do not differ among themselves by F test ($p \geq 0.05$).

Productivity was influenced only by the intercropping period, while the average biennial productivity was influenced only by fertilization ($p<0.05$). The productivity of 2010 decreased in a quadratic way due to the increase in the intercropping period with legumes. In 2011, the result was inverse showing a quadratic increase with the increased intercropping period (Figure 6). The average biennial productivity of the coffee trees subjected to 100% fertilization exceeded the productivity of coffee trees that received only 50% of the recommended fertilization, showing 15.422 and 13.906 bg ha^{-1}, respectively.

The yield and productivity of coconut coffee, as well as that of beans harvested in 2010 and the yield of coffee beans in 2011 did not differ statistically from the control fertilized with 50% of the recommended dose ($p \geq 0.05$), regardless of the intercropped legume, intercropping period or fertilization dose.

When evaluated in 2010, the coconut coffee, processed beans and productivity and, in 2011, the processed bean, yield and productivity, besides the average biennial productivity, did not differ statistically from the control at 50% of the recommended dose ($p \geq 0.05$), regardless of the intercropped legume, intercropping period or fertilization dose (Table 7). These results indicate that the legumes supplied the nutritional requirements of coffee trees fertilized with 50% dose, when compared with the control that received 100% fertilization.

Regarding the coffee yield, there was a difference for the green manure factor analyzed separately for the yield obtained in the first stage of the harvest, being that the yield obtained in the absence of green manure was significantly higher than that obtained in its presence, although there was no difference in the final yield (sum of the two steps). The lack of response of the coffee tree in relation to the yield obtained with and without the cultivation of green manure between the lines can be considered as a positive result, since it allows concluding that the cultivation of a green manure associated with the coffee tree did not hindered its yield.

When evaluating the yield in 2010, the 100% control exceeded the intercropping with jack bean at 120 days fertilized with only 50% of the recommended dose, which is 37.78%. Coconut coffee in 2011 presented a significance difference between the 100% control and the intercropping with the hyacinth bean 120 days with 100% dose fertilization, showing average of 2,536.63 kg ha^{-1}, higher than the 890.05 kg ha^{-1} of the control (Table 7).

These results demonstrate the low achieved yields, including controls fed with 50% and 100% of the recommended fertilization, which did not differ from the other treatments, except jack bean intercropped for 120 days and fertilized with 50% of the recommended dose in 2010 when compared to the 100% fertilized control (Table 7). Possibly, the low yield was due to the strong drought together with high temperatures during the months of January and February 2010, period of grain formation, which affected the productivity initially expected (60 bg ha^{-1}, based on a preliminary evaluation in the edges), due to the higher incidence of malformed, immature and defective fruits, increasing the ratio of *in natura* fruits necessary to obtain a processed bag of coffee. Furthermore, the drier climate in the months of August and September 2009 caused premature maturation of the beans (harvest in March and April 2010), further compromising the grain formation process, evidenced by the low yield achieved in 2010.

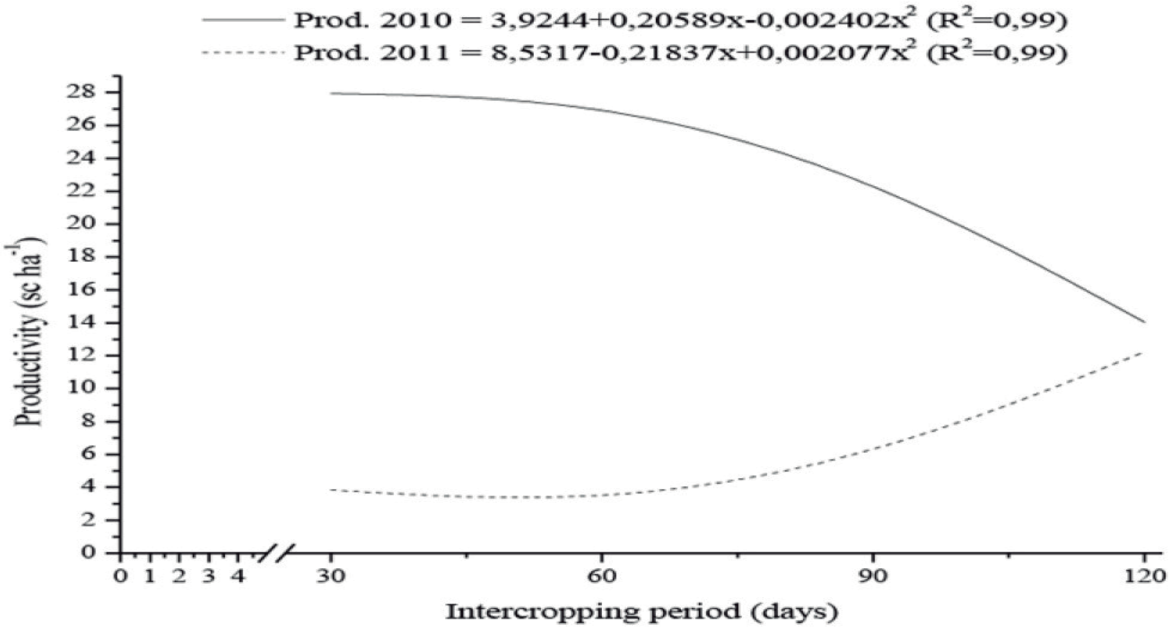


FIGURE 6 - Productivity of coffee plants as a function of intercropping with legumes for different periods (30, 60, 90 and 120 days after showing of the legume) in the crop season 2009/2010 (Prod. 2010) and 2010/2011 (Prod. 2011). Data from two species of legumes and two fertilization doses.

In the literature, there are contradictory reports of the effect of organic fertilization on the productivity of coffee trees, e.g., Malta et al. (2007) observed increase from 33 to 40.8 bg ha^{-1} with pigeon pea, as well as observed by Araujo et al. (2014) with the jack bean. Theodoro, Mendes and Guimarães (2009) verified that coffee productivity was not influenced by applying this legume. However, Moreira et al. (2014) observed that productivity was reduced in the first year for both the jack bean and the hyacinth bean in all evaluated periods, and in the second year, only the intercropping with jack bean for 120 days resulted in reduced coffee productivity. In some cases, the lower productivities were attributed to the greater competition for water, light and nutrients between the legumes and the coffee tree due to the higher matter yield of legumes.

The low productivity in the 2011 harvest was probably affected not only by the negative biennial of coffee, but also due to the severe drought suffered by the crop from the beginning of April 2010, when there is the maturation and bud development phase (April to June). The coffee plantation received below-average rainfall volumes for more than five months, which contributed to a greater leaf fall of plants.

Plants with low leaf area indexes tend to have low yields due to the high abortion rate of pinheads. One hypothesis for higher productivity in 2011 in the 120-day intercropping would be to maintain soil moisture due to green manure cutting and higher soil mulch under coffee plantation. In a research on the nitrogen efficiency fertilization in the intercropping between coffee tree and brachiaria, it was observed that the maintenance of the brachiaria biomatter under the crown of the coffee tree reduced the water loss in the dry months by 49%, favoring the development of cultivated plants (PEDROSA, 2013).

The higher soil mulch increased root density and maintained moisture and hence higher nutrient recovery efficiency, due to the higher yield of surface roots in the coffee trees that received brachiaria biomatter in relation to the control, and a higher recovery of ^{15}N by the coffee tree that received the brachiaria biomatter fertilized with 50% of the recommended dose to the coffee tree (PEDROSA, 2013).

TABLE 7 - Coconut coffee (CC, t ha^{-1}), processed bean (PB, t ha^{-1}), yield (Yld,%), productivity (Pr, bg ha^{-1}) and average biennial productivity (AvBProd, bg ha^{-1}) in the coffee tree fertilized with 100% and 50% fertilization, intercropped with jack bean (JB) and hyacinth bean (HB) under four cutting seasons (30, 60, 90 and 120 DASL) in the 2009/10 and 2010/11 crop season.

SPC	MAN	FERT	CC2010	PB2010	Yld2010	Pr2010	CC2011	PB2011	Yld2011	Pr2011	AvPBrod
		%	t ha^{-1}	t ha^{-1}	%	bg ha^{-1}	t ha^{-1}	t ha^{-1}	%	bg ha^{-1}	bg ha^{-1}
Test		100	3.72 A	1.40 A	37.78 A	23.41 A	0.89 A	0.29 A	34.53 A	4.93 A	14.17 A
Test		50	3.53 A	1.04 A	30.66 A	17.26 A	0.58 A	0.20 A	35.39 A	3.31 A	10.28 A
JB	30	50	3.49 A	1.37 A	38.85 A	22.80 A	0.68 A	0.29 A	36.08 A	4.80 A	13.80 A
	60	50	4.04 A	1.44 A	35.67 A	24.07 A	0.37 A	0.13 A	36.59 A	2.14 A	13.10 A
	90	50	4.09 A	1.56 A	37.59 A	26.03 A	0.49 A	0.16 A	34.53 A	2.66 A	14.35 A
	120	50	3.16 A	0.63 A	18.38 B	10.45 A	1.69 A	0.59 A	34.93 A	9.91 A	10.18 A
	30	100	5.08 A	1.90 A	37.00 A	31.67 A	0.99 A	0.39 A	37.32 A	6.52 A	19.10 A
	60	100	4.00 A	1.21 A	29.30 A	20.12 A	0.76 A	0.26 A	34.47 A	4.29 A	12.21 A
	90	100	3.94 A	1.54 A	37.93 A	25.70 A	1.36 A	0.45 A	34.39 A	7.46 A	16.58 A
	120	100	2.69 A	0.91 A	33.50 A	15.18 A	1.95 A	0.73 A	36.99 A	12.19 A	13.68 A
HB	30	50	4.42 A	1.67 A	37.82 A	27.87 A	0.42 A	0.17 A	36.64 A	2.81 A	15.34 A
	60	50	4.60 A	1.88 A	39.60 A	31.31 A	0.60 A	0.20 A	34.03 A	3.34 A	17.32 A
	90	50	3.54 A	1.25 A	35.47 A	20.75 A	1.03A	0.39 A	39.49 A	6.57 A	13.66 A
	120	50	2.26 A	081 A	33.67 A	13.42 A	2.08 A	0.81 A	35.47 A	13.54 A	13.48 A
	30	100	4.79 A	1.82 A	37.92 A	30.39 A	2.15 A	0.70 A	36.34 A	1.16 A	15.77 A
	60	100	4.69 A	1.93 A	40.67 A	32.09 A	3.75 A	0.13 A	34.43 A	2.14 A	17.11 A
	90	100	3.66 A	1.35 A	36.61 A	22.44 A	0.89 A	0.35 A	39.51 A	5.83 A	14.13 A
	120	100	2.63 A	0.97 A	34.48 A	16.14 A	2.54 B	0.80 A	33.97 A	13.40 A	14.77 A
Averages			3.81	1.39	35.43	23.17	1.02	0.37	35.86	6.10	14.64
CV (%)			22.36	31.70	17.30	31.70	69.23	77.72	15.67	77.72	27.01

Averages followed by the same letter on the column do not differ from the control by Dunnett's test ($p \geq 0.05$).

4 CONCLUSIONS

The jack bean overcomes the hyacinth bean in the yield of fresh and dry matter, N concentration and N accumulation.

The increased intercropping period between legumes and coffee trees favors a greater increase in height and the number of nodes of the coffee plants.

The coffee trees show higher heights when fertilized with 50% of the recommended dose and intercropped with hyacinth bean.

The intercropping with hyacinth bean resulted in a larger crown diameter of coffee trees in 2010 and a larger diameter accumulated in the two evaluated years.

The leaf N concentration at the end of the reproductive cycle (150 DASL) is higher in relation to the beginning of the cycle (30 DASL) for the different intercropping periods.

Higher N contents are found in coffee trees fertilized with 100% of the recommended dose.

The legumes supplement and supply the nutrients required in the harvest of coffee fertilized with 50% dose.

The bean yield of the processed coffee tree is not hindered by the intercropping with the green manures jack bean or hyacinth bean.

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DECOMPOSITION AND NITROGEN MINERALIZATION FROM GREEN MANURES INTERCROPPED WITH COFFEE TREE

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ABSTRACT: The knowledge about the rate of decomposition and nitrogen mineralization of green manures provides synchronization with the higher absorption stage by the coffee tree. The rate of decomposition and nitrogen mineralization varies according to the species of green manure and with the environmental factors. The aim of the present study was to evaluate the decomposition and nitrogen mineralization of two green manures intercropped with coffee trees for three different periods. The experiment was divided into two designs for statistical analysis, one referring to the characterization of plant material (fresh mass, dry matter, dry matter content, nitrogen concentration and accumulation in the jack bean (*Canavalia ensiformis*) and hyacinth bean (*Dolichos lablab*) and another to evaluate the rate of decomposition and N mineralization of these species. The decomposition rate decreased in both species as their growth time increased in the field. The decomposition was influenced by the phenology of green manures. Nitrogen mineralization of the jack bean decreased as the growth period in the field increased and was faster than hyacinth bean only when cut at 60 days. The N mineralization was slower than mass decomposition in both species.

Index terms: *Coffea arabica* cv. Oeiras, *Canavalia ensiformis*, *Dolichos lablab*, decomposition rate, nitrogen cycling.

DECOMPOSIÇÃO E MINERALIZAÇÃO DO NITROGÊNIO PROVENIENTE DE ADUBOS VERDES CONSORCIADOS COM CAFEEIROS

RESUMO: O conhecimento sobre a taxa de decomposição e mineralização de nitrogênio dos adubos verdes possibilita uma sincronia com o estádio de maior absorção pelo cafeeiro. A taxa de decomposição e mineralização de nitrogênio variam com a espécie de adubo verde utilizado e com os fatores ambientais. O objetivo deste trabalho foi avaliar a decomposição e a mineralização de nitrogênio de dois adubos verdes, consorciados com cafeeiros por três períodos diferentes. O experimento foi separado em dois para análise estatística, sendo um referente à caracterização do material vegetal (massa fresca, massa seca, teor de massa seca, concentração e acúmulo de nitrogênio no feijão-de-porco e lablabe) e outro para avaliação da taxa de decomposição e mineralização do N dessas espécies. A taxa de decomposição reduziu em ambas as espécies à medida que se aumentou o tempo de crescimento destas no campo. A fenologia dos adubos verdes influenciou sua decomposição. A mineralização do nitrogênio do feijão-de-porco foi mais lenta à medida que aumentou o período de crescimento no campo e foi mais acelerada que da lablabe apenas quando cortado aos 60 dias, apresentando similaridade aos 90 e 120 dias e a mineralização do N foi mais lenta que a decomposição da massa, em ambas as espécies.

Termos para indexação: *Coffea arabica* cv. Oeiras, *Canavalia ensiformis*, *Dolichos lablab*, taxa de decomposição, ciclagem de nitrogênio.

1 INTRODUCTION

Over 90% nitrogen in soils is in the form of organic N, composed by different molecules, with varying recalcitrance degrees, or as part of living organisms. The N in the organic form is released during the mineralization as inorganic N (NO_3^- and NH_4^+) and, this process is one of the main N sources of the crops (CANTARELLA, 2007).

In the coffee tree, the N concentration is considered as adequate when between 2.6 and 3.0% N in the leaves. To reach such values, annual applications from 175 to 300 kg ha^{-1} N are required in order to produce between 20 and 60 bags ha^{-1} (GUIMARÃES et al., 1999). An alternative to provide this nutrient within the organic management is the green manure with legumes, since it contributes to the nutrition of subsequent crops. However, green manure with legumes intercropped with coffee trees is a challenge to be overcome, considering that despite the great contribution of mass and N, coffee productivity may or may not be benefited by the intercropping (PAULO et al., 2006).

Legumes have is the low C/N ratio when compared to plants from other families. This characteristic, together with the great presence of soluble compounds, favors its decomposition

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and mineralization by soil microorganisms and nutrient cycling (CANTARELLA, 2007).

The efficiency of N recovery by crops is related to the timing between the N released by green manures and the absorption by plants (FONTANETTTI et al., 2006). Therefore, it is essential to know the decomposition dynamics of green manures in order to estimate the best period for mass distribution in the field, aiming at the synchronization between the mineralization time of nutrients to the soil and the greater absorption stage by the plant of interest. The mass decomposition rate varies according to the species (THOMAS; ASAKAWA, 1993) and to the environmental factors such as temperature, humidity, aeration, organic matter content in the soil, which influence the activity of decomposer microorganisms. The jack beans (Canavalia ensiformis (L.) DC. is considered as one of the most suitable green manure species for intercropping, since it accepts partial shading by the main crop. It has rapid initial growth, thus precluding the establishment of invasive species. Another species with high intercropping potential is hyacinth bean (Dolichos lablab L.), which has slow initial growth and high mass accumulation at the end of the cycle, yielding 18-30 tons of fresh mass per year^{-1} (Brazilian agricultural research agency - EMBRAPA, 2004).

In studies on the decomposition of intercropped legumes to coffee plants, it was observed that Pinto peanut (Arachis pintoi Krapov. & W. C. Greg.) chaff increased height, crown diameter, crown volume and number of plagiotropic branches of the coffee tree in relation to nitrogen fertilization (FIDALSKI; CHAVES, 2010). It was also observed that the shoot of the velvet bean (Mucuna pruriens L. DC) contributed to the increase of the stem diameter, number of nodes, crown diameter and number of leaves of the coffee tree (VILELA et al., 2011). These results evidence how the use of green manures such as legumes in coffee growing can provide greater growth and development of the coffee tree.

The aim of the present study was to evaluate the decomposition and nitrogen mineralization of two green manures intercropped with coffee trees for three different periods.

2 MATERIAL AND METHODS

The experiment was carried out at the Research vegetable garden of the Universidade Federal de Viçosa, MG, Brazil, at 20°45'14" S and 42°52'53" W and 650 m altitude, in a soil classified as cambisol. The climate is Cwa according to the Köppen classification.

The soil, under organic fertilization, showed the following chemical characteristics at the beginning of the experiment in the 0-20 cm depth layer: pH (H_2O) = 6.0; Ca = 2.0 mg dm^{-3}; Mg = 0.7 mg dm^{-3}; Al = 0.0 cmol$_c$ dm^{-3}; H+Al = 3.96 cmol$_c$ dm^{-3}; K = 69 mg dm^{-3}; P = 14.8 mg dm^{-3}; cation exchange capacity (CEC) = 68.4%; V = 42%.

Seedlings of *Coffea arabica* L. cv. Oeiras, purchased in a trustworthy commercial nursery, were transplanted on December 10, 2007, at a spacing of 2.80 x 0.75 m, resulting in a population of 4,761 plants ha^{-1}. Basal and topdressing fertilization were based on the recommendations of Guimarães et al. (1999) for coffee tree (Table 1). The topdressings were performed every 30 days in the rainy season with poultry litter and castor bean cake, according to nutritional requirements. Basal fertilization consisted of 3.0 L poultry litter pit^{-1} (750 g DM pit^{-1}), 300 g thermophosphate pit^{-1} and 50 g limestone pit^{-1}. After the setting of seedlings, 325 g plant^{-1} dry matter of poultry litter (5 g plant^{-1} N per application) was applied in two plots, in December and January 2008.

The fertilization of the first year (2008/2009) was performed with poultry litter, applying 653.25 g plant^{-1} dry matter (10 g plant^{-1} N per application) in three plots in November and December 2008 and January 2009, considering that only 70% N would be available. Topdressing fertilizations performed in October, November, December 2009 and January 2010 were calculated according to expected productivity, since the crop showed a yield perspective already in the second year after planting. Through the evaluation of some edge plants, a productivity of 60 bg ha^{-1} was admitted. Following the recommendation of Guimarães et al. (1999), of 300 kg ha^{-1} year^{-1} N, 350 g plant^{-1} fresh mass (304.85 g plant^{-1} dry matter) of castor bean cake was applied in the first plot, totaling 15.15 g N plant^{-1}, since it was considered that 85% N would be available. In the second plot, 1,800 g plant^{-1} fresh mass of poultry litter (1,044 g plant^{-1} dry matter) was applied, totaling 13.3 g N plant^{-1}, considering the availability of 70% N. In the third plot, 440 g plant^{-1} fresh mass of castor bean cake was applied (383.24 g plant^{-1} dry matter), totaling 19.05 g N plant^{-1}, considering the availability of 85% N. In the fourth plot, 350 g plant^{-1} fresh mass of castor bean cake was applied (304.7 g plant^{-1} dry matter), totaling 15.5 g N plant^{-1}, with availability of 85% N.

TABLE 1 - Fertilization performed in coffee plantation in the 2008/2009 and 2009/2010 crop years.

Fertilization[1]		Limestone	Thermophosphate	Poultry litter	Castor bean cake
		---------- g pit^{-1} ----------		------- g DM pit^{-1}-------	
Planting		50.00	300.00	750.00	---
(Dec/Jan 2008)		---	---	325.00[2]	---
Mulch	1st year (2008/2009)	---	---	653.25[3]	---
Mulch		---	---	---	304.85
Mulch	2nd year (2009/2010)	---	---	1044.00	---
Mulch		---	---	---	383.24
Mulch		---	---	---	304.70

[1] Values calculated considering the recommendation of 300 kg ha^{-1} year^{-1} N (GUIMARÃES et al., 1999);
[2] Applied in two plots; [3] Applied in three plots.

The legumes jack bean (*C. ensiformis)* and hyacinth bean (*D. lablab)* were chosen because they showed growth habits and contrasting crop cycles. The legumes were previously inoculated with the rhizobia strains *Bradyrhizobium* sp. and *Bradyrhizobium elkanii*, respectively, and sown in three lines between the coffee lines, spaced 0.4 m apart, at the density of six seeds per linear meter, in October 2008, occupying the entire plot of six useful coffee plants. The legumes were cut 30 days after sowing (DAS) in November 2008, at 60 DAS (Dec 2008), at 90 DAS (Jan 2009) and at 120 DAS (Feb 2009) for the mass characterization (fresh mass, dry matter, dry matter content, nitrogen concentration and nitrogen accumulation). The statistical design consisted of a 2x4 factorial design and five replications. The treatments were two intercrops between coffee and legumes (coffee+jack bean and coffee+hyacinth bean) and four intercropping periods (30, 60, 90 and 120 days after sowing of the legume - DASL). The experiment was arranged in complete randomized block design.

The decomposition experiment followed the complete randomized block in a (2x3) x 9 factorial design. The treatments were two legume species (jack bean and hyacinth bean), three cutting times (60, 90 and 120 DAS) and nine subplots composed by the collection dates (0, 3, 7, 12, 18, 25, 32, 40 and 60 days after legume cutting), with four replicates.

The legumes were sampled in 1,0 m^2, being cut at ground level. The fresh mass of this sample was quantified and 100 g subsamples were taken from this 1,0 m^2 at different cutting dates, according to the treatments.

For the decomposition experiment, there was no collection at 30 DAS because there was little mass available for assembling the nine subplots. Subsequently, the 100 g subsamples were washed in deionized water and placed in a convection oven at 70 °C until constant weight was reached. After this process, the dry matter of samples was determined and ground in a Wiley mill with a 20-mesh sieve and stored for further chemical analyses.

A total of 36 samples (nine dates after cutting and four replicates) of 100 g fresh mass of each legume were collected in every period (60, 90 and 120 DAS) and distributed in the crown projection of coffee plants, in their respective plots. Each sample was covered with a nylon mesh (4 mm^2) and 20 x 20 cm size, which were attached to the ground through wires in order to prevent material loss. The same stem/leaf ratio that green manures were harvested in the field was maintained, i.e. the percentage of stems and leaves in 1,0 m^2 sampled was the same percentage of stem and leaves in the 100 g samples, distributed under the mesh in the cleaned soil. At each collection date, all the material of decomposing green manures remaining on the soil was collected, cleaned of dirt and dried for the laboratory analyses described above.

The variables in green manures were fresh mass (FM) and dry matter (DM), dry matter content (DMC), nitrogen concentration (NC) and nitrogen accumulation (NAC).

The dry matter content (DMC) was calculated by the equation DM x 100/FM. The N concentration was determined by the Kjeldahl method, modified by Cotta et al. (2007), and the N accumulation calculated by the equation NC x DM /100. All calculations were performed considering only the area occupied by the legumes, thus disregarding 50% of the area occupied by coffee trees.

Dry matter and nitrogen concentration were evaluated in the remaining mass of green manures, taken from the soil under mesh at each collection date, and the data were expressed as percentage (%) of the initial mass. The rate of mass decomposition and nitrogen mineralization were determined at each period using the exponential mathematical model described by Thomas and Asakawa (1993):

$$C = Co\ e^{-kt}$$

Where C is the amount of dry matter or nitrogen remaining after the time t, in days; Co is the amount of initial dry matter or nitrogen. The half-life time ($T_{1/2}$), i.e., the time required to lose half of the plant biomass and release half of the nitrogen at the initial time was calculated based on the k values, a constant of the mathematical model, where: $T_{1/2} = \text{Ln } 0.5 / k$.

The decomposition and mineralization data were submitted to analysis of variance and regression at 5% probability level. The analysis were performed using the System for Statistical and Genetic Analyses (FUNDAÇÃO ARTHUR BERNARDES, 2007). The regression models were chosen based on the significance of the regression coefficient using the t test, adopting 5% probability level and the biological phenomenon under study.

3 RESULTS AND DISCUSSION

There was an effect of interaction between species and intercropping period on the variables, FM, DM, DMC, NC and NAC (Table 2).

At 60 days after planting, there was a higher fresh mass accumulation by the jack bean and at 120 days a higher accumulation by the hyacinth bean (Table 3), evidencing a higher initial growth of the jack bean (Figure 1A). Afterwards, an increased growth of the hyacinth bean was observed, overcoming jack bean and showing higher fresh mass accumulation at the final evaluation date at 120 days (Table 3).

The DM accumulation increased over time in both species (Figure 1B), reaching more than 5.0 t ha^{-1} at 120 days, discounting the area occupied by coffee trees (Table 3). The DM accumulation in the jack bean exceeded the hyacinth bean at 60 and 90 days of intercropping (Table 3). The results are different from the ones found by Moreira et al. (2014), which reported a higher DM accumulation of hyacinth bean in relation to jack bean at 90 and 120 days of intercropping with adult coffee trees.The jack bean showed higher DMC than the hyacinth bean at 90 and 120 days of intercropping (Table 3), possibly due to the presence of pods already formed in this species. There was no regression fitting for these data.

Regarding the N concentration, the jack bean exceeded the hyacinth bean only at 60 days of intercropping (Table 3). The adjusted regression models show an opposite performance of the green manure species (Figure 2A). According to Moreira et al. (2014), the N concentrations in jack bean were 3.5, 3.86, 3.10, and 3.05% at 30, 60, 90 and 120 days of intercropping, respectively, similar to the found in the present experiment. For the hyacinth bean, in the same periods, the values found were different, being the concentrations of 3.13, 3.71, 3.41 and 3.03%.

There was increasing N accumulation until the end of the evaluations in both species (Figure 2B). Jack bean grew faster than hyacinth bean and accumulated triple N at 60 days and twice N at 90 days of intercropping (Table 3). Moreover, it produces twice mass and concentrates 1.5 times more N at 60 days, and 1.5 times more mass and concentrates 1.1 times more N at 90 days.

The cutting of green manures in its flowering and pod formation raises the species potential to provide nutrients to the crop. During this period, large amounts of mass accumulate and large amounts of nutrients are recycled. Furthermore, there are no risks for infestation of areas, since the plants are cut before beginning the seed maturation process. However, these results are largely dependent on the growth rate of the species. The earlier and faster growth - such as jack bean - provides a more abundant mass up to 90 days after emergence (MORAES et al., 2008).

At 120 days, there was no statistical difference between the N accumulation in the jack bean and the hyacinth bean (Table 3). A lower value was reported by Moreira et al. (2014), which obtained 111.37 kg ha^{-1} N in the hyacinth bean, also at 120 DAS. This same author reported 71.52 kg ha^{-1} N in the jack bean at 120 days, which is lower than the found.

TABLE 2 -Summary of analysis of variance referring to the fresh mass (FM), dry matter (DM), dry matter content (DMC), nitrogen concentration (NC) and nitrogen accumulation (NAC) of legumes jack bean and hyacinth bean for four periods (30, 60, 90 and 120 days after sowing) in 2008/2009.

F.V.	GL	Mean square				
		FM	DM	DMC	NC	NAC
Species (Sp)	1	2.67	2.63**	17.42**	1.58**	5260.66**
Growing period (G)	3	1566.56**	47.87**	13.53**	0.64**	43926.85**
Sp x G	3	63.19**	1.35*	6.11**	0.94**	2263.26**
Residue	28	448.85	0.43	1.30	0.14	576.63
CV (%)		28.85	27.36	6.59	12.72	32.05

(**) (*) values significant at 1% and 5% probability, respectively, by F test; fresh mass (FM), dry matter (DM), dry matter content (DMC), nitrogen concentration (NC) and nitrogen accumulation (NAC)

TABLE 3 - Accumulation of fresh mass (FM), dry matter (DM), dry matter content (DMC), nitrogen concentration (NC) and nitrogen accumulation (NAC) in the green manures jack bean (JB) and hyacinth bean (HB) cut at 30, 60, 90 and 120 days of intercropping with coffee trees (DAS), in the 2008/2009 crop year.

Cutting (DAS)	FM		DM		DMC		NC		NAC	
	JB	HB	JB	HB	JB	HB	JB	HB	JB	HB
	------------------ $t\ ha^{-1}$ -----------------				------------------- % -----------------				----- $kg\ ha^{-1}$ -----	
30	2.23 A	0.76A	0.42A	0.13A	18.86A	17.51A	2.67A	2.65A	11.17A	3.53A
60	10.60 A	5.27B	1.61A	0.85B	15.20A	16.00A	3.68A	2.40B	59.32A	20.36B
90	17.86 A	13.14A	3.49A	2.12B	19.34A	16.40B	3.45A	3.09A	121.60A	65.68B
120	27.76 B	33.39A	5.10A	5.47A	18.41A	16.63B	2.95A	3.01A	153.39A	164.17A

Means followed by the same letter on the row for each variable and at every date do not differ among themselves by F test (p≥0.05).

The dry matter and N accumulation curves show similar regression models (Figure 1B and 2B), indicating a constant growth up to 120 days of intercropping. Similar pattern of curves indicates the dependence of N accumulation in relation to the accumulated dry matter.

The experiment was performed in the rainy season, favoring the mass decomposition and N mineralization. In both species, the kinetics of the legume decomposition process showed higher rates when cut at 60 days than at 90 and 120 days, according to the values of the constant k (Table 4 and Figure 3A).

When cut at 60 DAS, the jack bean mass decomposed faster than the hyacinth bean, and less sharply when cut at 90 DAS (Figure 3A). At 120 DAS, the inverse was observed, probably due to the presence of pods in the jack bean, which is a material more lignified and therefore more resistant to decomposition, while the hyacinth bean began the flowering at this date.

In all cutting dates and in both species, the average time of 50% mass decomposition (T½) occurred between 9 and 24 days (Table 4), when there is a greater content of soluble compounds that are more labile and easily decomposed.

The environmental factors such as temperature, humidity, aeration and organic matter content in the soil act on soil microorganisms, which are the main agents in the decomposition process. In December 2008, the rainfall was 705 mm, much higher than the 292 mm in January 2009 and 243 mm in February 2009, contributing to a faster decomposition of legumes cut at 60 DAS. The average temperatures found in the months of Dec 2008, Jan 2009 and Feb 2009 were 20.6 °C, 21.3 °C and 19.8 °C, respectively.

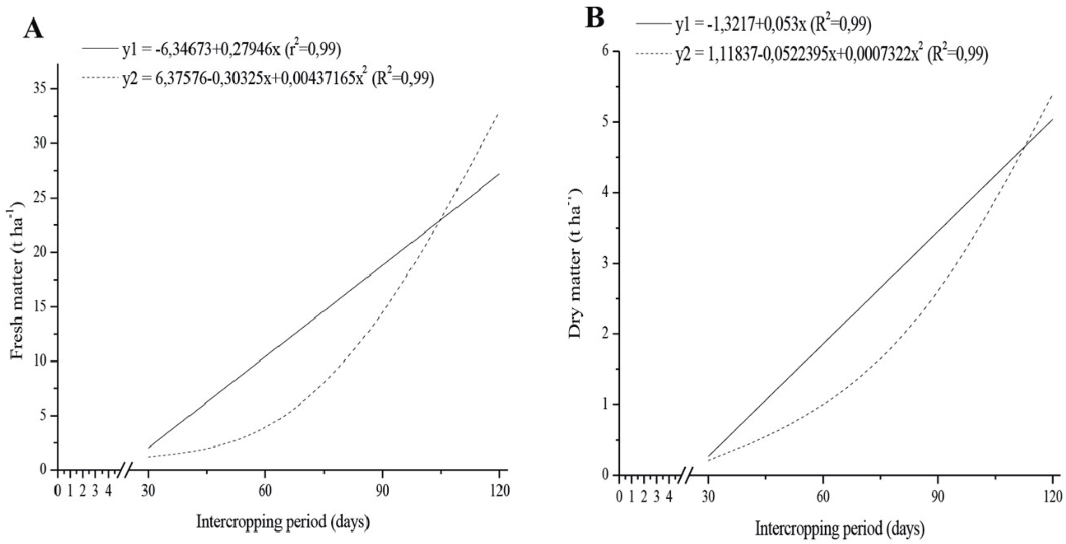

FIGURE 1 - Fresh (FM, A) and dry (B) matter accumulation of the green manures jack bean (y1) and hyacinth bean (y2) intercropped with coffee trees in 2008/2009.

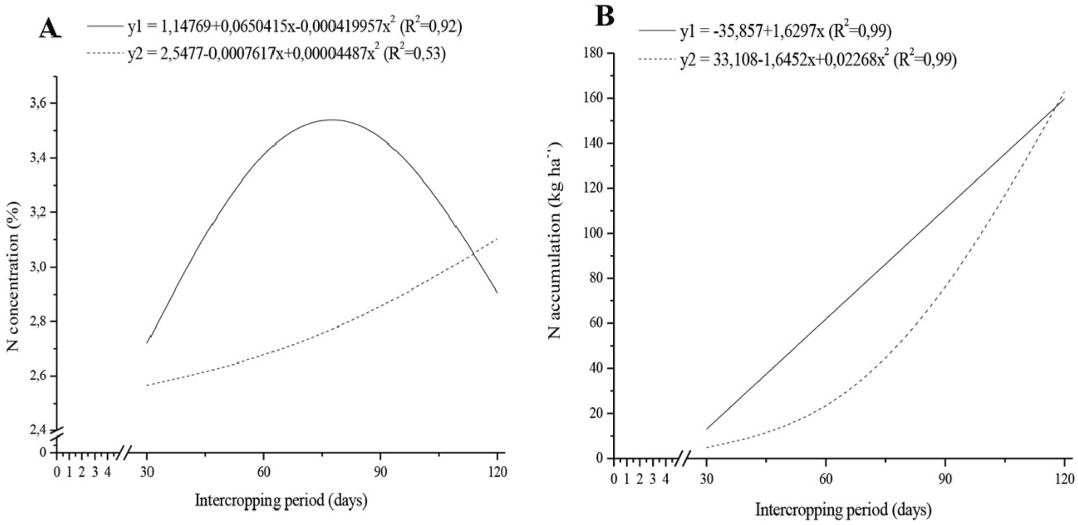

FIGURE 2 - Nitrogen concentration (A) and accumulation (B) in jack bean (y1) and hyacinth bean (y2) intercropped with coffee trees in 2008/2009.

Decomposition is a dynamic process regulated by decomposer organisms in which structure fragmentation, chemical transformation and synthesis of compounds occur simultaneously. For nutrient release to the soil-plant system adequately, not only the amount of residue should be considered, but also its quality, in order to achieve sustainable cropping systems, besides ensuring soil conservation and productivity (CHACÓN et al., 2011).

Whether the environmental factors remain constant, the decomposition of plant tissues depends mainly on the C/N ratio, lignin, cellulose and hemicellulose content (ESPINDOLA et al., 2006). As previously reported, the present experiment was performed in the rainy season with an average temperature of 20.5 °C, which may have contributed to a fast mass decomposition and N mineralization. However, the decomposition of plant materials does not only depend on environmental factors, but also on the management of the mass-producing plant in relation to fertilization and the cutting season.

TABLE 4 - Equations of the estimates of dry matter decomposition and nitrogen mineralization as a function of time (t), with the respective decomposition constants (k), half-life time (T½) and R^2 values, in the jack bean and hyacinth bean cut in the year 2008-2009 at 60 (Dec 08), 90 (Jan 09) and 120 days (Feb 09) after the planting intercropped with coffee trees.

Legume	Cutting (days)	Equation	K	T½	R^2
		Remaining dry matter (%)			
Jack bean	60	$y = 101.50009e^{(-0.07448t)}$	0.0745	9	$R^2 = 0.95$
	90	$y = 99.36339e^{(-0.02961t)}$	0.0296	23	$R^2 = 0.97$
	120	$y = 108.86759e^{(-0.0287t)}$	0.0287	24	$R^2 = 0.92$
Hyacinth bean	60	$y = 95.68082e^{(-0.0835t)}$	0.0835	8	$R^2 = 0.91$
	90	$y = 96.36374e^{(-0.03455t)}$	0.0345	20	$R^2 = 0.90$
	120	$y = 103.73837e^{(-0.0365t)}$	0.0365	19	$R^2 = 0.92$
		Remaining nitrogen (%)			
Jack bean	60	$y = 93.53913e^{(-0.04058t)}$	0.0406	17	$R^2 = 0.85$
	90	$y = 108.27153e^{(-0.02433t)}$	0.0243	28	$R^2 = 0.85$
	120	$y = 97.59175e^{(-0.01659t)}$	0.0166	42	$R^2 = 0.93$
Hyacinth bean	60	$y = 87.33679e^{(-0.02283t)}$	0.0228	30	$R^2 = 0.70$
	90	$y = 88.83899e^{(-0.02565t)}$	0.0256	27	$R^2 = 0.82$

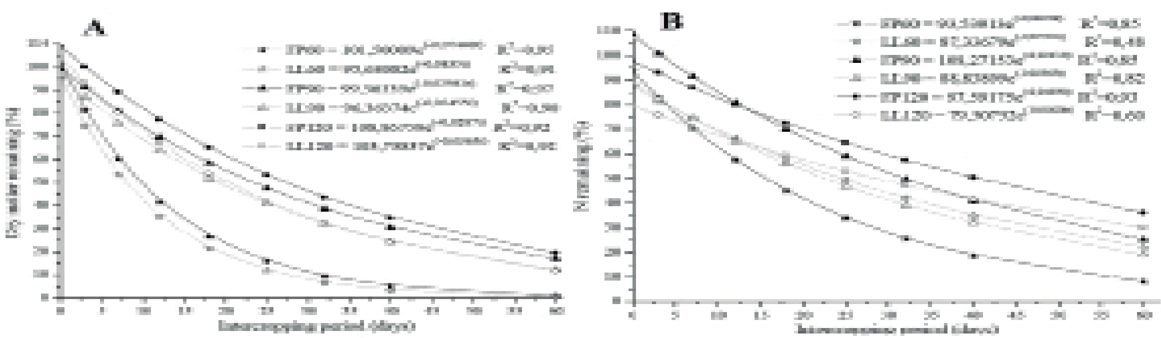

FIGURE 3 - Remaining dry matter (A) remaining nitrogen (B) in the mass of the legumes jack bean (JB) and hyacinth bean (HB) cut at 60 (Dec 08), 90 (Jan 09) or 120 days after sowing (Feb 09) intercropped with coffee trees.

In a study on the N recovery derived from green manure applied to cabbage crop, Aráujo et al. (2011) report that the recovery rate in the soil-plant system varied from 60 to 100%. In addition, this recovery was influenced by the species of green manure, and jack bean was the one that most contributed to the nitrogen nutrition of the cabbage.

The most intense decomposition in the initial phase is also attributed to the water loss and the intense chemical and biochemical oxidation of the less-resistant constituents of the residue, such as hemicellulose, with significant reduction of mass (PEGADO et al., 2008). Thus, the faster decomposition showed by legumes cut at 60 days of planting can also be explained because younger plants are more tender, have lower C:N ratio and lignin content than older plants.

The N mineralization of the jack bean was slower than the hyacinth bean as the legume growth period advanced (Table 4 and Figure 3B). This result can be attributed to the higher precocity of the jack bean, with higher contents of lignin and polyphenols, with shorter cycle and maturation of the plant, presence of pods, thus making the decomposition and the N mineralization slower. The mineralization of the hyacinth bean cut at 60 and 90 DAS was similar to the jack bean, but higher when cut at 120 DAS, probably due to the longer growth cycle evidenced by the absence of flowering up to 120 DAS, and possibly lower lignin content at the beginning of evaluations.

In a study on the brachiaria (*Brachiaria decumbens* Stapf.) biomass decomposition as a nitrogen source in the intercropping with the coffee tree, it was observed that the brachiaria fertilized with nitrogen showed higher decomposition rates of dry matter (DM) at 30, 55 and 85 days after fertilization (DAF) comparatively to residues that did not receive N. Moreover, the decomposition kinetics of the forage biomass for the N rates showed higher rate of decomposition at 30 DAA than at 55 and 85 DAA due to the low lignification of biomass tissues (PEDROSA, 2013). This result shows that the chemical composition of the residue influences the decomposition and N mineralization.

The N mineralization was slower than the mass decomposition, as reported by Oliveira, Gosch and Padovan (2007), These authors reported that the hyacinth bean had a half-life time of 43 days for the mass and 58 days for the nitrogen, in an experiment performed in the state of Tocantins, Brazil. Different results were found by Moreira et al. (2014), in which the nitrogen contained in the legumes was mineralized faster than the mass.

In the jack bean species, the N mineralization was faster than in the hyacinth bean only when cut at 60 DAS. In the other cutting dates (90 and 120 DAS), the T½ was similar for both species. Contrasting results were found by Moreira et al. (2014) in the same year, with T½ (N) valuesof 13, 12 and 16 days for the jack bean and 13, 14 and 17 days for the hyacinth bean, both when cut at 60, 90 and 120 days after planting, although performed in a different site.

Under the conditions of the Viçosa, MG, Brazil, the coffee tree reproductive cycle lasts 224 days and the highest accumulation rates of dry matter, N, P, K, Ca, Mg and S in fruits are observed at the stage of rapid fruit expansion, between 79 and 85 days after anthesis (LAVIOLA et al., 2007). These same authors described that fertilization practices should begin before the onset of the rapid fruit expansion stage, i.e. before 66 days after anthesis, and a higher proportion of macronutrients should be supplied until the end of the rapid expansion stage.

Based on data from Laviola et al. (2007) and in the decomposition data, it can be suggested that the N mineralized in April would be poorly absorbed by the coffee trees. For the Viçosa region, 50% of the nutrients would have to be available to the coffee tree in November, being necessary the cutting of green fertilizers 46 days before, i.e., at the end of September. This practice becomes unviable due to the weather conditions of the region that do not allow planting these legumes with high anticipation.

Therefore, it is recommended that green manures be planted as soon as possible (beginning of the rainfall) and cut 90 days after sowing. Thus, it would be possible to provide part of the nitrogen necessary to the berry formation and maturation phase and for the coffee growth. Therefore, the annual green fertilizers would be used as complementary to the fertilization, either mineral or organic.

When associating the legume decomposition rate, DM yield, N accumulation and mineralization, it could be estimated that two months after cutting, 54,458; 91,018; and 98,066 kg ha^{-1} N would be mineralized from jack bean when cut at 60, 90 and 120 days, respectively (Table 5). For the hyacinth bean, the values would be 15,841; 53,158; and 114,966 kg ha^{-1} N mineralized under the same conditions.

When considering the N contribution (Table 5) of 121.60 kg ha^{-1} by jack bean and 65.68 kg ha^{-1} by the hyacinth bean at 90 days after planting of legumes (January), there would be a mineralization of approximately 55 kg ha^{-1} N by jack bean and 37 kg ha^{-1} N by the hyacinth bean up to 28 days ($T_{1/2}$) after the management, i.e., in February, since the planting occurred in October.

The nutrients not readily released and absorbed by the crop of interest will be stored in the organic matter of the soil and, possibly mineralized and available in the next crop cycle. This reinforces the idea that intercropping green manures between the coffee lines is a viable alternative also to recycle nutrients. In a study on nitrogen fertilization in coffee trees with jack bean biomass, it was related that the higher the volume of residue applied to the soil, the higher the organic matter, Ca^{2+}, SB and CEC contents in the soil (ARAÚJO et al., 2014), strengthening how much green manure can contribute to a better crop development.

TABLE 5 – Estimates of accumulation and mineralization of nitrogen from green manures jack bean and hyacinth bean two months after cutting at 60, 90 and 120 days after sowing.

Legume	Cutting (DAS)	Total N accumulated (kg ha^{-1})	N mineralization (kg ha^{-1})				Total mineralized
			Days after cutting				
			0-15	15-30	30-45	45-60	Up to 60
Jack bean	60	59.32	29.132	13.764	7.488	4.074	54.458
	90	121.60	30.199	27.948	19.402	13.470	91.018
	120	153.39	36.673	25.713	20.049	15.632	98.066
Hyacinth bean	60	20.36	7.734	3.661	2.599	1.846	15.841
	90	65.68	25.966	12.684	8.633	5.876	53.158
	120	164.17	61.893	22.136	17.345	13.591	114.966

4 CONCLUSIONS

The decomposition rate is lower in both green manure species as the cut is delayed in the growing season;

Nitrogen mineralization of the jack bean is slower as the green manure grows for longer periods;

The N mineralization in the jack bean is faster than hyacinth bean only when cut at 60 days, showing similarity at 90 and 120 days.

Green manures should be planted as soon as possible (beginning of the rainfall) and managed 90 days after sowing for greater benefits to the coffee tree.

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DIFFERENT VOLUMES OF TUBES FOR CLONAL PROPAGATION OF *Coffea canephora* FROM SEEDLINGS

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ABSTRACT: The aim in the present study was to evaluate the growth of *Coffea canephora* cv. 'Conilon BRS Ouro Preto' seedlings in different tube volumes. The experiment was performed at Embrapa Rondônia plant nursery in Ouro Preto do Oeste, Rondônia, Brazil, from July to November 2013. The treatments consisted of five tube volumes (50, 100, 170, 280 and 400 cm^3) plus one control composed by polyethylene bags (11 cm width x 20 cm height) with capacity of 770 cm^3. The experimental design was a randomized complete block design with 15 replicates, formed by 15 clones that compose the Conilon 'BRS Ouro Preto' cultivar. The tube volume of 280 cm^3 provide the best vegetative performance of seedlings, similarly to volume of 400 cm^3, thus, the use of larger tubes would not justify. Tubes of 50, 100 and 170 cm^3 produce seedlings with physiological quality similar to the control until 130 days after staking, but may limit the development of seedlings in a longer period.

Index terms: Vegetative propagation, cuttings, Conilon, BRS Ouro Preto.

DIFERENTES VOLUMES DE TUBETES PARA PRODUÇÃO DE MUDAS CLONAIS DE *Coffea canephora*

RESUMO: O objetivo neste estudo foi avaliar o crescimento de mudas de cafeeiros *C. canephora* 'Conilon – BRS Ouro Preto' em diferentes volumes de tubetes. O experimento foi conduzido no viveiro de produção de mudas da Embrapa Rondônia em Ouro Preto do Oeste, Rondônia, de julho a novembro de 2013. Os tratamentos foram cinco volumes de tubete (50, 100, 170, 280 e 400 cm^3) mais uma testemunha constituída por um sacolinhas de polietileno com 11 cm de largura x 20 cm de altura com capacidade para 770 cm^3. O delineamento experimental foi em blocos casualizados com quinze repetições, formadas pelos 15 clones que compõe a variedade 'Conilon - BRS Ouro Preto'. O volume de 280 cm^3 e 400 cm^3 promove o melhor desempenho vegetativo das mudas, semelhantemente ao volume de 400 cm^3, por isso, o uso de tubetes de maiores volumes não se justifica. Tubetes de 50, 100, e 170 cm^3 produzem mudas com qualidade fisiológica semelhante ao controle, até 130 dias após o estaqueamento, mas pode limitar o crescimento das mudas em períodos mais extensos.

Termos de indexação: Propagação vegetativa, estaquia, Conilon, BRS Ouro Preto.

1 INTRODUCTION

The vegetative propagation of *Coffea canephora* Pierre ex A. Froehner is one of the technologies that favored the increasing crop productivity in the recent decades. Based on this propagation method, it is possible to maintain the genetic characteristics of the matrix plant, guaranteeing crop homogeneity in terms of productivity, yield precocity and grains quality, and obtaining larger grains and maturation uniformity, besides allowing the harvesting scheduling using clones with differentiated maturation cycle (AMARAL et al., 2007; CONTARATO et al., 2010; PARTELLI et al., 2006b). Clonal crops also facilitate the realization of cultural practices, especially when planted in the 'in line clone' system (ESPINDULA et al., 2015).

The vegetative propagation by cuttings is a simple technique with high setting rates of seedlings (ANDRADE JÚNIOR et al., 2013), being consolidated as the most used propagation method in the commercial production of *C. canephora* seedlings (ALMEIDA et al., 2011; PARTELLI et al., 2006b). However, there is little progress in relation to the used containers and substrates.

For commercial production of seedlings, polyethylene bags and a mixture of soil and cow dung supplemented with chemical fertilizers (DIAS; MELO, 2009) are usually used. Such way of propagation has high costs with transport and cultural practices, provides propagation of soil pathogens, especially nematodes, and degrades the environment due to large soil movement (VILLAIN et al., 2010).

In contrast, the use of tubes allows forming seedlings in organic substrates, with greater control of nutrition, easiness of management in the nursery, transport and rapid planting (BRAUN et al., 2007; LISBOA et al., 2012). Furthermore,

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the twisting of main roots does not occur in these containers, since they are carried vertically through striations present on the inner walls of the container until the hole in the lower base where the pruning of roots occurs in contact with light and oxygen (AMARAL et al., 2007).

Currently, there are several studies related to the development of coffee seedlings by seed in tubes using commercial substrates (DARDENGO et al., 2013; HENRIQUE et al., 2011; MARANA; MIGLIORANZA; FONSECA, 2008; SILVA et al., 2010; VALLONE et al., 2010). However, for clonal seedlings, few scientific articles descript this method.

Several seedling characteristics are influenced by the container size, such as root and shoot growth, and may affect the percentage of survival in the field and crop productivity (LIMA et al., 2006; VALLONE et al., 2009, 2010). Thus, to optimize the volume of containers in the seedling propagation is essential because larger containers can result in unnecessary labor costs, excessive demand for substrates and transportation, besides occupying a larger area in the nursery, raising production costs (AMARAL et al., 2007; CORREIA et al., 2013; DIAS; MELO, 2009).

In this context, the aim in the present study was to evaluate the growth of *Coffea canephora* cv. 'Conilon BRS Ouro Preto' seedlings in different tube volumes.

2 MATERIAL AND METHODS

The experiment was installed in the experimental field of Embrapa Rondônia, in the municipality of Ouro Preto do Oeste, RO, Brazil (10°45' S, 62°15' W and 245 m altitude). The climate of the region is Aw according to the Köppen classification (tropical rainforest climate) with rainy summer (October to May) and dry winter (June to September). The annual average rainfall was 2,000 mm and annual average temperature of 25 °C.

The cuttings were planted in July 2013 and remained to the nursery until October 2013. The experiment was performed with five treatments consisting of five tube volumes (50, 100, 170, 280 and 400 cm^3) and a control, using polyethylene bags (11 cm width x 20 cm height) with capacity 770 cm^3.

The experimental design was the randomized complete block design with 15 replicates. Each replicate was composed by one of the 15 clones from the *C. canephora* cv. 'Conilon - BRS Ouro Preto'. The cultivar stands out in the yield per area (average of 70 bags per hectare of processed coffee), as well as in the characteristics of its plants, tolerance to the main diseases and to the abiotic stresses of the coffee tree occurring in the state of Rondônia, Brazil (ROCHA et al., 2015). The experimental plot consisted of six plants.

The tubes were filled with a mixture of commercial substrates, while the polyethylene bags used fertilizer-enriched soil. The materials used in the filling of containers had their chemical properties determined prior to the addition of fertilizers (Table 1). The analyses were performed by the chemical analysis laboratory of the Embrapa in the municipality of Porto Velho, RO, Brazil.

The mixture used in the study consisted of the commercial substrates Bioplant® and Vivatto Plus® in the 2.5:1 ratio. The Bioplant® substrate shows in its formulation pine bark, coconut fiber, vermiculite, rice husk and nutrients. In contrast, the Vivatto Plus® consists of ground charcoal, pine bark and peat. The Basacote Plus® controlled release fertilizer was added to the substrate mixture in the proportion of 6 kg m^{-3}. This fertilizer is composed of 16% N, 8% P_2O_5, 12% K_2O, 2% Mg and 5% S.

The mixture of 210 kg soil, 35 kg sand, 1000 g limestone, 1000 g single superphosphate, 200 g potassium chloride and 80 g FTE-BR12 was used to fill the polyethylene bags (control).

The containers were filled with substrate 20 days prior to planting of cuttings and packed in the nursery, irrigated by micro sprinkler systems, combined with an automated timer programmed to maintain humidity at approximately 90% in the first 30 days after planting of cuttings.

In each container, was inserted a vegetative propagule, formed by orthotropic branch segment (cutting) with 4 cm length according to the recommendations proposed by Ferrão et al. (2007). For standardization of the propagule maturity, only the third node, from the apex to the base, of each orthotropic stem was used.

Fertilization and cultural practices were performed according to the crop needs. From the complete emission of the second pair of definitive leaves, 5 g urea dissolved in 10 dm^3 water were applied every 15 days.

The phytosanitary control also occurred every 15 days, alternating the application of systemic fungicide based on tebuconazole prepared at the concentration from 50 cm^3 to 20 L water and a protector based on copper sulphate prepared in the ratio from 100 g to 20 dm^3 water.

TABLE 1 - Chemical properties of substrates formed by the mixture of commercial substrate and soil used in the experiment.

	pH in water	P	K	Ca	Mg	Al+H	Al	OM	V
		mg dm^{-3}			cmol$_c$ dm^{-3}			g kg^{-1}	%
Substrates	5.6	890	0.31	1.54	0.74	1.15	0	99.7	69
Soil	6.2	4	0.37	3.72	1.01	2.97	0	16.5	63

Ca^{2+}, Mg^{2+} and Al^{3+}: extractor KCl 1 mol L^{-1}; P and K: extractor Mehlich^{-1}; H+Al: extractor calcium acetate 0.5 mol L^{-1} at pH 7.0; OM: organic matter; V: base saturation.

After 98 days of the planting of cuttings, the deltamethrin insecticide was applied to control insects at the concentration from 20 cm^3 to 220 dm^3 water.

The seedlings remained growing for 130 days, showing four pairs of fully expanded leaves. Afterwards, the seedling were removed from the tube, washed to remove the substrate and taken to the laboratory to determine the vegetative characteristics.

The evaluated properties were root volume (RV) in cm^3, determined in graduated beaker by displaced volume difference; number of leaves (NL) and number of nodes (NN), determined by direct counting; stem length (SL) in cm, determined by measuring directly the insertion point of the shoot at the stake to the apical meristem; stem diameter (SD) in mm, determined using a caliper at the base of the orthotropic branch, 3 cm above the insertion point of the shoot at the stake.

The materials were taken to the convection oven at 65 °C until reaching a constant mass in order to obtain the root (RDM), stem (SDM) and leaf (LDM) dry mass in g, determined using an analytical balance with a precision of 0.01 g.

It was also determined the shoot dry mass (SHDM), resulting from the sum of the LDM and SDM; total dry mass (TDM), resulting from the sum of the SHDM and RDM; total leaf area (LA) in cm^2, determined through the DDA (Digital Area Determiner) free software (FERREIRA; ROSSI; ANDRIGHETTO, 2008) from digital images and Dickson quality index (DQI), obtained by the formula DQI = [TDM/[(SL/SD)+ (SHDM/ RDM)] (DICKSON; LEAF; HOSNER, 1960). All characteristics were express by one seedling.

Data were subjected to analysis of variance and, when significant effects were detected, regression analyses were performed ($p \leq 0.05$). Data were also subjected to the Dunnett's test ($p \leq 0.05$) for comparison of treatments with the control.

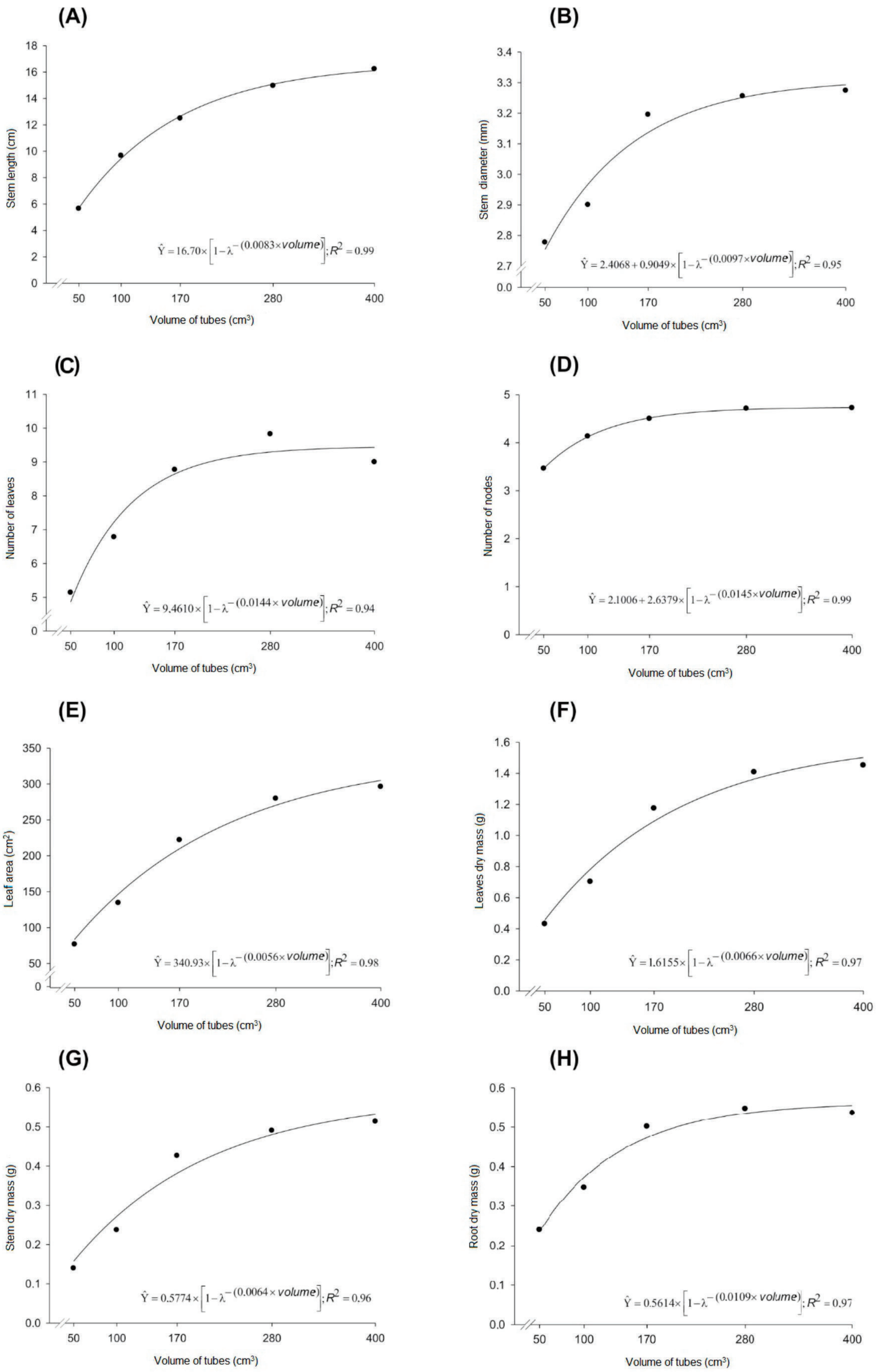
3 RESULTS AND DISCUSSION

All vegetative characteristics were influenced by the studied tube volumes, with exponential trendlines increasing to the maximum point (Figure 1).

There was increase in the vegetative performance of seedlings with the increased tube volume. The growth of plant, shoot and root system as a function of the container volume corroborate with the results reported for *Toona ciliata* M. Roem. (LISBOA et al., 2012), *Cordia trichotoma* (Vell.) Arráb. ex Steud. and *Jacaranda micranta* Cham.(MALAVASI; MALAVASI, 2006), *C. arabica* (VALLONE et al., 2009), *Hymenaea courbaril* L., *Tabebuia chrysotricha* (Mart. ex DC.) Standl.and *Parapiptadenia rigida* Benth. (FERRAZ; ENGEL, 2011), *Ricinus communis* L. (LIMA et al., 2006) and *Pinus taeda* L.(DOBNER JÚNIOR et al., 2013).

Such increase is resulting of a greater area available for root exploration inside the containers, providing a greater development of the root system, greater availability of water and nutrients and better seedling formation, minimizing stress due to lack of water, which can limit the metabolism, influencing the shoot development of the plant (DOBNER JÚNIOR et al., 2013; FERRAZ; ENGEL,2001; MALAVASI; MALAVASI, 2006; STAPE et al., 2010).

The volumes of 50 and 100 cm^3 showed values of stem length (SL), stem diameter (SD), leaf area (LA), leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), shoot dry mass (SHDM), total dry mass (TDM) and Dickson quality index (DQI) similar to the control, while the 170, 280 and 400 cm^3 volumes showed values higher than control. For the root volume (RV), only the volumes of 280 and 400 cm^3 presented results significantly higher than the control (Table 2).


(A)
Stem length (cm)
$\hat{Y} = 16.70 \times \left[1 - \lambda^{-(0.0083 \times volume)}\right]; R^2 = 0.99$
Volume of tubes (cm³)
(B)
Stem diameter (mm)
$\hat{Y} = 2.4068 + 0.9049 \times \left[1 - \lambda^{-(0.0097 \times volume)}\right]; R^2 = 0.95$
Volume of tubes (cm³)
(C)
Number of leaves
$\hat{Y} = 9.4610 \times \left[1 - \lambda^{-(0.0144 \times volume)}\right]; R^2 = 0.94$
Volume of tubes (cm³)
(D)
Number of nodes
$\hat{Y} = 2.1006 + 2.6379 \times \left[1 - \lambda^{-(0.0145 \times volume)}\right]; R^2 = 0.99$
Volume of tubes (cm³)
(E)
Leaf area (cm²)
$\hat{Y} = 340.93 \times \left[1 - \lambda^{-(0.0056 \times volume)}\right]; R^2 = 0.98$
Volume of tubes (cm³)
(F)
Leaves dry mass (g)
$\hat{Y} = 1.6155 \times \left[1 - \lambda^{-(0.0066 \times volume)}\right]; R^2 = 0.97$
Volume of tubes (cm³)
(G)
Stem dry mass (g)
$\hat{Y} = 0.5774 \times \left[1 - \lambda^{-(0.0064 \times volume)}\right]; R^2 = 0.96$
Volume of tubes (cm³)
(H)
Root dry mass (g)
$\hat{Y} = 0.5614 \times \left[1 - \lambda^{-(0.0109 \times volume)}\right]; R^2 = 0.97$
Volume of tubes (cm³)

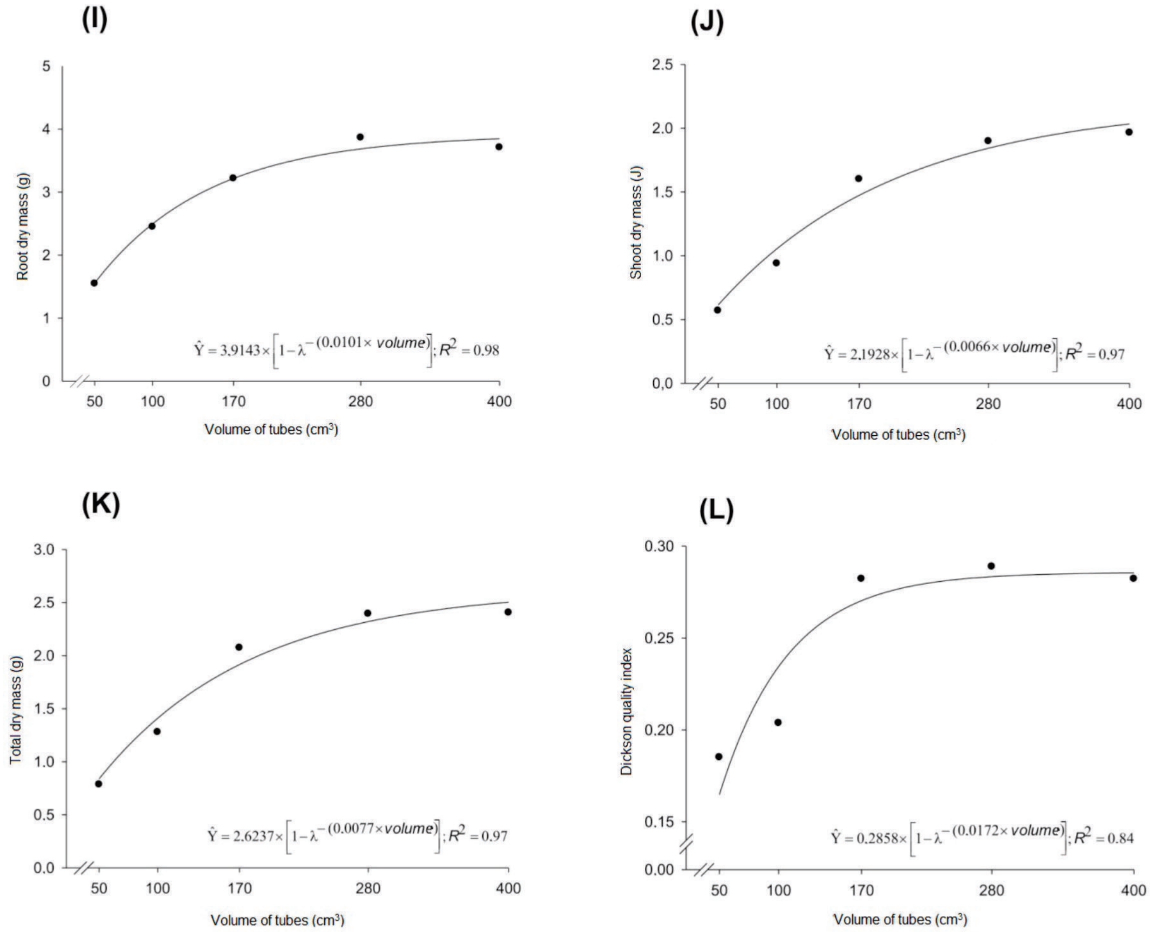


FIGURE 1 - Stem length (cm) (A), stem diameter (mm) (B), number of leaves (C), number of nodes (D), leaf area (cm^2) (g), leaves dry mass (F), stem dry mass (g), root dry mass (g) (H), root volume (cm^3) (I), shoot dry mass (J), total dry mass (g) (K), Dickson quality index (L) of *Coffea canephora* seedlings propagated in different tube volumes. All characteristics are express by one seedling.

The values obtained for stem length (SL) and stem diameter (SD) were higher than the presented by Braun et al. (2007) in *C. canephora* seedlings with 140 days of nursery, and by Dardengo et al. (2013), working with different containers and levels of shading in *C. canephora* seedlings with 160 days, 30 days longer than the seedlings propagated in the present experiment.

The SL and SD are important characteristics to evaluate the quality of seedlings. Seedlings of higher stem diameter show greater capacity for emission of new roots (NOVAES et al., 2002), providing resistance to environmental stress conditions, ensuring higher survival rates and initial development after planting in the field (FREITAS et al., 2005).

The treatments with 170, 280 and 400 cm^3 showed values of RDM, SHDM and TDM higher than the reported by Berilli et al. (2014), working with different substrates in polyethylene bags. The averages obtained for the DQI were between 0.18 and 0.28. The values are close to the cited by Hount (1990) and Marana, Miglioranza and Fonseca (2008), which recommend DQI values above 0.20 as ideal for seedlings. Gomes et al. (2013) stated that this index is efficient to evaluate the quality and robustness of seedlings, incorporating in the calculation values related to the growth and accumulation of dry matter.

The volume vs. control interaction did not influence the NL and NN, but was significant for LA, in which the tubes 170, 280 and 400 cm^3 were superior to the control. It was also possible to observe that this increased LA of seedlings was proportional to the increase in the tube volume (FIGURE 1).

TABLE 2 - Stem length (SL), stem diameter (SD), number of leaves (NL), number of nodes (NN), leaf area (FA), root volume (RV), leaves dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), shoot dry mass (SHDM), total dry mass (TDM), Dickson quality index (DQI) of *Coffea canephora* clonal seedlings grown in different volumes of substrate. All characteristics are express by one seedling.

Volume of tubes	SL	SD	NL	NN	LA	RV	LDM	SDM	RDM	SHDM	TDM	DQI
(cm^3)	(cm)	mm	(un.)	(un.)	(cm^2)	(cm^3)			(g)			
Control	**8.163**	**2.71**	**6.97**	**4.47**	**112.07**	**2.03**	**0.56**	**0.16**	**0.31**	**0.73**	**1.01**	**0.200**
50	5.65^{ns}	2.77^{ns}	5.13^{ns}	3.46^{ns}	76.63^{ns}	1.54^{ns}	0.43^{ns}	0.13^{ns}	0.23^{ns}	0.56^{ns}	0.78^{ns}	0.185^{ns}
100	9.66^{ns}	2.90^{ns}	6.78^{ns}	4.13^{ns}	134.41^{ns}	2.44^{ns}	0.70^{ns}	0.23^{ns}	0.34^{ns}	0.93^{ns}	1.27^{ns}	0.203^{ns}
170	12.49*	3.19*	8.76^{ns}	4.49^{ns}	222.11*	3.21^{ns}	1.17*	0.42*	0.50*	1.60*	2.07*	0.282*
280	14.96*	3.25*	8.99^{ns}	4.71^{ns}	279.71*	3.86*	1.40*	0.49*	0.54*	1.89*	2.39*	0.288*
400	16.23*	3.27*	9.82^{ns}	4.72^{ns}	296.21*	3.70*	1.45*	0.51*	0.53*	1.96*	2.40*	0.282*
Average	11.19	3.01	7.74	4.33	186.86	2.80	0.95	0.32	0.41	1.28	1.65	0.240
CV(%)	26.49	11.26	24.58	14.99	36.48	44.81	42.12	57.42	42.04	45.26	44.38	34.22

*Differ from the control and ^{ns} do not differ from the control by Dunnett's test ($p \leq 0.05$).

The increase in LA provides a greater ability to intercept light, thus promoting plant development (PARTELLI et al., 2006a).

The LA values were also higher than the best values obtained by Dardengo et al. (2013). For the tubes 170, 280 and 400 cm^3, the LA values were higher than obtained by Lemos et al. (2015) in coffee plants subjected to the application of different concentrations of citric acid and phosphorus in the substrate, demonstrating satisfactory seedling growth in the present experiment.

In short, the study results indicate that higher tube volumes can promote a vigorous and balanced development between shoot and root system. On the other hand, Lemos et al. (2015) emphasized that the substrate represents a high value in the production cost. Thus, how the tube of 280 cm^3 showed enough vegetative development of seedlings, the use of larger tubes would not justify.

The container size must be considered too in relation to the time that seedlings will remain in the nursery before the final planting in the field. This is because, even considering that the volumes of 50 and 100 cm^3 did not differ from the control, the permanence of seedlings in these containers for a period superior to the studied could promote delayed growth and development of seedlings in the field.

4 CONCLUSIONS

The tube volume of 280 cm^3 provide the best vegetative performance of seedlings, similarly to volume of 400 cm^3, thus, the use of larger tubes would not justify.

Tubes of 50, 100 and 170 cm^3 produce seedlings with physiological quality similar to the control until 130 days after staking, but may limit the development of seedlings in a longer period.

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AGRONOMIC PERFORMANCE AND ADAPTABILITY OF ARABIC COFFEE RESISTANT TO LEAF RUST IN THE CENTRAL BRASILIAN SAVANNA

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ABSTRACT: Breeding programs and later indication of rust resistant cultivars for different environments and crops systems, in the concept of diseases integrated control, reach out for productivity raising and reduced production costs. The aim of this work was to evaluate the agronomic performance and adaptability of new *Coffea arabica* cultivars and progenies resistant to leaf rust in Central Brazilian Savanna. The experiment has been conducted since 2008 in an experimental area of Embrapa Hortaliças. Twenty three resistant cultivars, four progenies and three susceptible cultivars as controls, were assessed in a complete randomized block design with four replicates. The following traits were analyzed: plant height, stem diameter, canopy projection, number of plagiotropic branches, yield, grains percentage retained in sieves above 17, grain ripening and diseases resistance. Catucaí 2SL, Sacramento and Araponga stood out in vegetative growth. The highest yields are observed for IPR 103, Obatã 1669-20, Palma II, Sabiá 398 and Acauã, with values higher than 60 sacks per hectare. Among all these cultivars is observed high resistance to rust leaf and greater susceptibility to brown eye spot in the cultivar Acauã, for the place and period of evaluation.

Index terms: *Coffea arabica*, adaptability, diseases, productivity, vegetative growth.

DESEMPENHO AGRÔNOMICO E ADAPTABILIDADE DE CAFEEIRO ARÁBICA RESISTENTE À FERRUGEM NO CERRADO DO PLANALTO CENTRAL

RESUMO: O trabalho do melhoramento e posterior indicação de cultivares resistentes à ferrugem para diferentes ambientes e sistemas de cultivo, dentro do controle integrado de doenças, visa aumento de produtividades e redução de custos de produção. Com objetivo de avaliar desempenho agronômico e adaptabilidade de novas cultivares e progênies de café arábica com resistência à ferrugem, nas condições de Cerrado do Planalto Central do Brasil, foi instalado em 2008 um ensaio na área experimental da Embrapa Hortaliças. Os tratamentos foram 23 cultivares e quatro progênies resistentes à ferrugem além de três cultivares suscetíveis, utilizadas como controle. O experimento foi conduzido com o delineamento em blocos ao acaso com quatro repetições e parcelas de 10 plantas. As características avaliadas: altura de plantas, diâmetro de caule, projeção da copa, número de pares de ramos plagiotrópicos, produtividade, porcentagem de grãos retidos nas peneiras acima de 17, maturação dos grãos e incidência e severidade das doenças. As cultivares Catucaí 2SL, Sacramento MG e Araponga MG destacaram-se em crescimento vegetativo. As cultivares com maiores produtividades médias, acima de 60 sc.ha-1, apresentando maior adaptabilidade às condições ambientais são IPR 103, Obatã Vermelho 1669-20, Palma II, Sabiá 398 e Acauã. Para todas estas cultivares observa-se alta resistência a ferrugem e maior suscetibilidade a cercosporiose na cultivar Acauã, para o local e período de avaliação.

Termos para indexação: *Coffea arabica*, adaptabilidade, doenças, produtividade, crescimento vegetativo.

1 INTRODUCTION

Brazil is the world's largest producer and exporter of coffee, with a production of about 49 million bags processed in 2016, 81% of which represented by arabica coffee (*Coffea arabica*). The area cultivated with C. arabica was about 1.76 million hectares, of which 86% is in production and the remaining in stage of growth (COMPANHIA NACIONAL DE ABASTECIMENTO - CONAB, 2016). The crop has potential for expansion in regions such as the savanna of the central plateau, due to favorable weather conditions, topography that allows using machines in the production system, with the possibility of achieving high productivity and quality, besides reducing production costs (FERNANDES et al; 2012).

Coffee leaf rust was found in the country in 1970 and soon spread out to lots of coffee regions. Its damages are mainly indirect ones, resulting in defoliation, smaller setting of flowers, lower setting of pinhead fruits, and drying of plagiotropic branches, compromising in some cases over 50% of the production (GARÇON et al., 2004).

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The disease incidence and severity as well as its damages vary according to the genotype, region, crop year and grain loading causing significant losses (PAIVA et al., 2011).

The resistance factors of coffee trees are SH1 to SH9, in contrast to the respective virulence factors v1 to v9, present individually or in combinations, in 45 identified races around the world. Most of the *C. arabica L*. cultivars derived from the varieties Típica, introduced in Brazil in 1727, and Bourbon are both susceptible to coffee leaf rust (ANTHONY et al., 2001). In the country, cultivars still widely planted as germplasms of Mundo Novo and Catuaí are carriers of the SH5 gene. Thus, the race II with the v5 gene has a greater geographical distribution and is found in all producing states (DEL GROSSI, 2011).

The research and technology transfer from institutions linked to the supply chain have made a number of technologies available that increase productivity and income to the producer. Within the scope of breeding, new cultivars resistant to coffee leaf rust have been released for commercial use, and information on behavior and performance in distinct regions is important for selecting genotypes most adapted to edaphoclimatic conditions and cropping systems (CARVALHO, 2011).

The genotype is considered as adapted when as adapted when it positively assimilates the stimulus from environmental conditions (MARIOTTI et al., 1976), and this adaptation to a specific environment can determine differences among cultivars to be recommended.

Within a concept of integrated diseases control and the use of different methods and alternatives to reduce disease occurrence and losses to the producers, the indication of high yield cultivars with excellent agronomic characteristics and rust resistance for different environments and crop systems aims at reducing production costs and risks to rural workers and the environment, besides increase the income of the coffee grower.

Thus, the aim of the present study was to assess the agronomic performance and adaptability of new *C. arabica* cultivars and progenies resistant to coffee leaf rust, under the savanna conditions of central plateau of Brazil.

2 MATERIAL AND METHODS

The experiment was carried out in the savanna region of the central plateau in 2008, at the Embrapa Hortaliças experimental area, in the DF-158 highway, Gama, DF, Brazil. The area is characterized by the following coordinates and edaphoclimatic conditions: 15°56’00” S, 48°08’00” W, with an altitude of 997.2 m. It is a flat area of dark red latosol with clayey texture and presents an annual average rainfall of 1400 mm, with two typical rainy and dry seasons and annual average temperature of 22 ºC.

The treatments composed by the specific cultivars and progenies and the institutions that developed them are listed in Table 1, with 23 cultivars and four progenies resistant to coffee leaf rust, besides three cultivars susceptible to coffee leaf rust, used as control (Topázio MG 1190, Catuai Vermelho IAC 144, Catuai Amarelo IAC 62).

The experiment was performed with a spacing of 3.50 x 0.7 m in order to replicate the typical spacing of mechanized coffee growing performed in the savanna region. The irrigation system used was sprinkling and the sprinklers were modified as the plants grew. The cultural practices followed the common technical recommendations for coffee growing (fertilization, phytosanitary management, thinning, and mechanical and/ or manual control of weeds). The irrigation was suspended in the period between June 24 and September 4 (deadline), aiming at reaching uniformity of flowering and higher yield of coffee in the cherry stage (GUERRA; ROCHA; RODRIGUES, 2005). The annual phosphorus supply was 300 kg P_2O_5/ha, divided in two thirds after irrigation was restarted in September - after flowering standardization - and one third in December. For the supply of nitrogen and potassium in each crop season, 450 kg/ha of the nutrient were used, divided in four times, the first one after irrigation was retaken and the others starting in December. For micronutrients, 100 kg FTE/ha were used, spread on the soil in December.

The characteristics which were assessed annually were: 1) Plant height: measured in meters, after harvest, from the base to the apical bud of the stem; 2) Stem diameter: measured in millimeters at the plant base, using a caliper; 3) Canopy projection: measured in meters, approximately 1 m from the ground crosswise to the planting line; 4) Number of pairs of plagiotropic branches: sum of all productive branches on the plant faces; 5) Productivity: measured in kilograms of cherry coffee of six plants, with fruits dried up to 12% moisture content and converted into 60 kg bags of processed coffee per hectare (bg/ha).

TABLE 1 - List of *Coffea arabica* cultivars and progenies resistant to coffee leaf rust and controls used in the assay.

Treatment	Cultivar/Progeny	Institution
1	Catucai Amarelo 2SL	PROCAFÉ
2	Catucaí Amarelo 24/137	PROCAFÉ
3	Catucaí Amarelo 20/15 cv 479	PROCAFÉ
4	Catucaí Vermelho 785/15	PROCAFÉ
5	Catucaí Vermelho 20/15 cv 476	PROCAFÉ
6	Sabiá 398	PROCAFÉ
7	Palma II	PROCAFÉ
8	Acauã	PROCAFÉ
9	Oeiras MG 6851	EPAMIG
10	Catiguá MG 1	EPAMIG
11	Sacramento MG	EPAMIG
12	Catiguá MG 2	EPAMIG
13	Araponga MG	EPAMIG
14	Paraíso MG	EPAMIG
15	Pau Brasil MG	EPAMIG
16	Tupi IAC 1669-33	IAC
17	Obatã Vermelho IAC 1669-20	IAC
18	IPR 59	IAPAR
19	IPR 98	IAPAR
20	IPR 99	IAPAR
21	IPR 103	IAPAR
22	IPR 104	IAPAR
23	Catiguá MG 3	EPAMIG
24	Topázio MG 1190	EPAMIG
25	Catuaí Vermelho IAC 144	IAC
26	H419-3-3-7-16-4-1	EPAMIG
27	H419-10-6-2-5-1	EPAMIG
28	H419-10-6-2-10-1	EPAMIG
29	H419-10-6-2-12-1	EPAMIG
30	Catuaí Amarelo IAC 62	IAC

6) classification of beans in sieves: a sample of 300 g went through the set of sieves and the percentage above the sieve 17 was checked; 7) Uniformity of maturation: percentage of cherry and unripe fruits at the harvesting time of plots; 8) Assessment of incidence and severity of coffee leaf rust and brown eyespot were performed every month, from November 2014 to October 2015, collecting four leaf pairs per plant, totalizing 32 leaves per plot. The incidence was determined in percentages, counting the number of infected leaves, and the severity was assessed by the diagrammatic scale for coffee leaf rust (MARTINS et al., 2015) and brown eye spot (SOUZA; MAFFIA; MIZUBUTI, 2012). The disease incidence and severity values were turned into an area under the disease progress curve (AUDPC), according to the formula: AUDPC= $\sum [((y_1+y_2)/2)*(t_2-t_1)]$, where y_1 and y_2

are two consecutive assessments performed at times t_1 and t_2.

The randomized block design was used with four replicates, each plot consisted of a set of 10 plants. For grain yield, a split-plot in time was considered with the genotypes as a plot and the biennium (2010 and 2011, 2012 and 2013, 2014 and 2015) in the subplot. For vegetative growth, a joint data analysis was performed among the years 2010 and 2014. For the AUDPC data, a variance analysis was performed in the 12 months of disease assessment, from November 2014 to October 2015. The research data were assessed through the Sisvar statistical software (FERREIRA, 2011) and the grouping of means of response variables were performed by Scott-Knott test at 5% probability.

3 RESULTS AND DISCUSSION

The result of the analysis of variance for productivity in three biennia showed that all sources of variation were significant at 5% at the F test (Table 2).

In this assay, two genotype groups were evidenced in relation to the productivity of processed coffee beans, in the six assessed harvests (Table 3). The IPR 103 cultivar, with a Catuaí x Icatu genealogy, presented an average of over 65 bags.ha^{-1}, demonstrating high adaptability to environmental conditions. In the first group of cultivars with productivities over 60 bags.ha^{-1} are Obatã Vermelho IAC 1669-20, Palma II, Sabiá 398 and Acauã. Among the higher yield, still intothe first group are Catucaí 2SL, Tupi IAC 1669-33, Araponga MG, IPR 98 and the H419-10-6-2-5-1 progeny.

When the average yield in the six harvests is considered, all genotypes showed values well above the current national average of 22.5 bags. All of them over 37 bags, which is the average for Bahia savannas, the highest values for savanna regions in 2015 (CONAB, 2016). In savanna areas such as the one from the present study,yield and quality can be increased due to weather conditions for a good vegetative and reproductive development of plants. This is possible with high temperatures, higher levels of insolation, low relative humidity at harvest time, beisdes the possibility of using high technological level with inputs, irrigation and mechanization (FERNANDES et al., 2012).

Carvalho et al. (2012) studied these same cultivars in the South and Alto Paranaíba regions of Minas Gerais, Brazil, and concluded that Sabiá 398, Pau Brasil MG 1, Obatã 1669-20, Catucaí Amarelo 24/137 and IPR 103 are the most promising for the assessed region.

In the Brazilian state of Rondônia, with annual average temperature of 26 °C and high rainfall levels, an experiment with average yield of 24.6 bags.ha^{-1} was observed, and the Catucaí Amarelo 24/137 and Obatã Vermelho 1660-20 cultivars stood out as the most productive varieties, with yields of 42.7 and 36.34 bags.ha^{-1}respectively.

The IPR 103 cultivar was also among the most productive in the north of the country, averaging 33 bags.ha^{-1} (TEIXEIRA et al., 2013), and in the South, Alto Paranaíba and Vale do Jequitinhonha regions of Minas Gerais, with averages of 43, 46 and 55 bags.ha^{-1}, respectively (CARVALHO et al., 2012), showing high adaptability to different environments and cultivation conditions.

In relation to genotypes with lower yield, Catucaí Vermelho 785/15 and Catiguá MG 1 showed average productivities with differences above 50%, when compared to the one with best performance. Carvalho et al. (2012) also found lower adaptability of this Catucaí cultivar in all assessed sites in the state of Minas Gerais.

By studying the genotypes x biennium interaction, with data from two consecutive combined harvests, it is possible to ensure greater experimental precision by reducing effects of biennial production in the culture. Regarding the biennials, a higher average yield was observed considering all genotypes in the years 2012/13 and the significant interaction between genotypes and biennia shows differentiated behavior and adaptability in the periods (Table 3).

Thus, it is possible to highlight genotypes that did not show significant differences considering the biennials, such as Paraíso MG, Catiguás MG1 and MG3 and Topázio MG 1190. Also ones with high average yield in the first two biennium and reduction in the third, such as Tupi IAC 1669-33, IPR 98, IPR 59 and Catuaí Vermelho IAC 144. Finally, genotypes that presented higher values for the second biennium, such as IPR 103, Palma II, Catiguá MG2 and Catuaí Amarelo 62.

It is possible to observe that cultivars such as Sabiá 398, although highly biennial, show a high productivity average when considering all years, as well as when analyzing biennia 2 and 3 (Table 3). This kind of analysis allows for a more detailed indication of cultivars according to management systems and the desired exploration period of cultivation. Besides, it is possible to measure the longevity of the genotype yield, thus a longitudinal study is needed.

TABLE 2 - Summary of analysis of variance with means squares for productivity of processed coffee beans.

Source	*DF*	*MS*	*Pr>F*
Genotype	29	524.5*	0.00
Block	3	409.04*	0.006
error a	87	92.38	
Biennium	2	8821.38*	0.0008
error b	6	301.04	
G x B	58	227.97*	0.00
error c	174	79.97	

*Significant at 5% probability at F test.

TABLE 3 - Average yield of six years and per biennium, in 60 kg bags of processed coffee beans per hectare, of the 30 *Coffea arabica* genotypes under savanna conditions of the central plateau of Brazil.

Cultivar/Progeny	B1	B2	B3	Average
Catucai Amarelo 2SL	49.9 bB	73.2 aA	55.1 aB	59.43 a
Catucaí Amarelo 24/137	48.6 bA	53.3 bA	36.3 bB	46.06 b
Catucaí Amarelo 20/15 cv 479	50.7 bA	60.2 bA	40.7 bB	50.53 b
Catucaí Vermelho 785/15	42.9 bA	44.8 bA	32.1 bB	39.93 b
Catucaí Vermelho 20/15 cv 476	49.3 bB	58.9 bA	42.1 bB	50.10 b
Sabiá 398	44.3 bC	78.8 aA	62.8 aB	61.96 a
Palma II	47.8 bB	89.9 aA	48.3 aB	62.00 a
Acauã	58.6 aB	80.6 aA	45.2 bC	61.46 a
Oeiras MG 6851	55.5 aA	64.3 bA	44.1 bB	54.63 b
Catiguá MG 1	36.4 bA	49.3 bA	44.8 bA	43.50 b
Sacramento MG	42.0 bB	54.5 bA	39.4 bB	45.30 b
Catiguá MG 2	39.7 bB	63.4 bA	40.1 bB	47.73 b
Araponga MG	58.5 aB	72.3 aA	45.9 bB	58.90 a
Paraíso MG	43.1 bA	50.2 bA	51.8 aA	48.36 b
Pau Brasil MG	39.7 bB	59.5 bA	44.9 bB	48.03 b
Tupi IAC 1669-33	61.6 aA	68.4 bA	48.0 bB	59.33 a
Obatã Vermelho IAC 1669-20	62.3 aB	80.8 aA	47.5 bC	63.50 a
IPR 59	53.1 bA	59.8 bA	39.0 bB	50.63 b
IPR 98	63.3 aA	60.9 bA	44.6 bB	56.37 a
IPR 99	48.5 bB	60.6 bA	41.2 bB	50.10 b
IPR 103	63.3 aB	78.8 aA	53.7 aB	65.40 a
IPR 104	48.9 bA	58.8 bA	51.8 aA	53.17 b
Catiguá MG 3	46.1 bA	50.4 bA	44.8 bA	47.00 b
Topázio MG 1190	46.1 bA	56.1 bA	41.8 bA	48.00 b
Catuaí Vermelho IAC 144	52.9 bA	58.1 bA	39.2 bB	50.06 b
H419-3-3-7-16-4-1	58.8 aA	61.1 bA	40.1 bB	53.33 b
H419-10-6-2-5-1	53.5 bA	54.8 bA	65.3 aA	57.87 a
H419-10-6-2-10-1	37.9 bB	52.8 bA	53.6 aA	48.11 b
H419-10-6-2-12-1	42.4 bB	59.5 bA	59.8 bA	53.90 b
Catuaí Amarelo IAC 62	41.1 bB	59.4 bA	46.8 bB	49.20 b
Average	49.5 B	62.4 A	46.2 B	52.7

*Averages followed by same lowercase letter on the column and capital on the row belong to the same group statistically at Scott-Knott test. B1: 2010/11 biennium; B2: 2012/13 biennium; B3: 2014/15 biennium.

According to an analysis of variance for percentage of beans classified in sieves above 17 and for fruit maturation, all sources of variation were significant at 5% at the F test. In the classification of sieves, it was observed that some genotypes showed retention averages of beans higher than 50%, including those that also had high yields, such as Obatã 1669-20 and Tupi 1669-33. (Table 4).

In coffee breeding programs, a genotype with high productive capacity and a higher percentage of beans classified in higher sieves is desirable (FERREIRA et al., 2005).

The separation through the classification by sieves improves the quality of the final product due to the greater uniformity of beans. In a study by Carvalho et al. (2012), a higher quantity of beans classified in high sieves was also observed, as well as high productivity for the Obatã IAC 1669-20 cultivar.

The maturation uniformity of fruits from the cultivars was assessed, highlighting the percentage of fruits in the cherry and green stages at harvest time (Table 4). The values for cherry fruits were high, varying from 55% to 80%, indicating variability in the closure of the phenological cycle of each genotype, as well as flowering uniformity with the use of controlled water stress, which is crucial to guarantee a higher number of fruits in this stage. Higher percentages were observed for the IPR 98, IPR 59 and Catiguá MG 3 cultivars, with values above 80%. The Palma II, Sabiá 398, Oeiras and CatucaíAmarelo20/15 cv 479 cultivars presented high percentage of unripe fruits (above 28%), evidencing a behavior of late genotypes in relation to the others. A higher amount of harvested unripe fruits can affect the quality of the beverage because it shows different chemical composition from fruits in advanced stages of maturation (ANGÉLICO et al., 2011).

In the analysis of variance for vegetative growth considering five years of cultivation from the year 2010, a significant effect for genotypes and years, was observed in all response variables. A significant interaction was only detected for stem diameter (Table 5).

The different genotypes showed average plant height ranging from 1.99 to 2.25 m (Table 6). The cultivars that stood out for this characteristic were Catucaí 2SL, Sacramento MG, IPR 103 and Araponga MG. For the diameter of the orthotropic branch, the genotypes showed average values ranging from 49.37 to 64.34 cm, highlighting Sacramento MG, Obatã 1669-20 and Catucaí 2SL (Table 6).

For the number of pairs of plagiotropic branches, the genotypes showed averages ranging from 55.2 to 61.7, with Araponga MG, Sacramento MG and Topázio 1190 standing out. Regarding canopy projection, average values from 90.4 to 102.4 cm were found. Catucaí 2SL, Sabiá 398, IPR 99, IPR 103, Acauã, Sacramento MG and Obatã stood out with values higher than 100 cm.

When considering vegetative growth, it is possible to highlight some cultivars assessed for these characteristics, such as Catucaí Amarelo 2SL, Sacramento MG and Araponga MG. However, it is necessary to emphasize that high vegetative development does not imply in high yield, since Sacramento MG, in the assessed environmental and technological conditions, was found in the group with the highest values of height, stem diameter, number of pairs of plagiotropic branches and canopy projection, despite showing one of the lowest values for average yield, with 45.3 bags. ha-1. On the other hand, the IPR 103 and Obatã 1669-20 cultivars were included in the group with the highest values of average yield in the six years, and also with high average values of height and canopy projection.

A more detailed study of genetic and phenotypic correlations between yield and vegetative growth characteristics is needed in order to obtain a better understanding on the behavior of genotypes. Freitas et al. (2007) observed a negative correlation between the number of plagiotropic branches and the canopy diameter. Thus, a plant with high productivity, with a large number of branches in the horizontal position and reduced canopy projection could be used in a density system. For the present study, some of these characteristics were observed for Palma II, but further researches are necessary in order to study the performance of this cultivar in other management and farming systems.

The evaluation of diseases under the studied environment conditions showed variability of resistance and susceptibility among the cultivars. The values for the assessment of the disease progress over the studied period (AUDPC) were estimated for the incidence and severity of diseases. According to analysis of variance, the source of variation genotypes was significant at 5% at the F test (Table 7).

TABLE 4 - Averages of the percentage of beans retained in sieves above 17, percentage of beans in the cherry stage and the percentage of unripe beans for the 30 *Coffea arabica* genotypes in savanna conditions of central plateau.

Genotype	S>17	Cherry	Green
Catucaí 2SL	49.2 a	76.8 a	14.4 c
Catucaí 24/137	34.0 c	64.6 c	14.6 c
Catucaí 20/15 cv 479	43.8 b	64.4 c	28.0 a
Catucaí 785/15	46.4 a	69.9 b	10.0 c
Catucaí 20/15 cv 476	49.2 a	67.2 c	23.5 b
Sabiá 398	30.0 c	60.2 d	33.5 a
Palma II	35.7 c	57.3 d	34.3 a
Acauã	30.1 c	72.3 b	16.8 c
Oeiras MG	39.6 b	54.6 d	30.4 a
Catiguá MG 1	42.2 b	60.8 d	23.3 b
Sacramento MG	16.5 c	79.0 a	12.5 c
Catiguá MG 2	25.1 c	76.3 a	16.0 c
Araponga MG	39.1 b	77.3 a	13.8 c
Paraíso MG 419-1	27.1 c	77.3 a	14.8 c
Pau Brasil MG	30.1 c	76.4 a	13.5 c
Tupi 1669-33	53.1 a	77.9 a	12.6 c
Obatã 1669-20	51.9 a	70.0 b	20.8 b
IPR 59	44.2 b	80.4 a	10.8 c
IPR 98	31.6 c	80.5 a	10.8 c
IPR 99	46.9 a	70.3 b	20.5 b
IPR 103	46.2 a	70.0 b	22.5 b
IPR 104	50.9 a	78.8 a	11.0 c
Catiguá MG3	39.9 b	80.0 a	9.40 c
Topázio 1190	34.8 c	72.7 b	17.8 c
Catuaí 144	42.7 b	71.7 b	16.7 c
H419-3-3-7-16-4-1	46.4 a	73.3 b	13.5 c
H419-10-6-2-5-1	20.8 c	71.6 b	19.8 b
H419-10-6-2-10-1	15.9 c	66.3 c	25.6 b
H419-10-6-2-12-1	19.8 c	77.0 a	13.5 c
Catuaí 062	44.7 b	71.6 a	21.8 b

*Averages followed by same lowercase letter on the column belong to the same group by Scott-Knott test.

TABLE 5 - Summary of analysis of variance with mean squares of the variables: plant height, stem diameter (Diam.), number of pairs of plagiotropic branches (NPP) and canopy projection (CP).

Source	DF	Height	Diam.	NPP	CP
Year	4	22.86*	12304.3*	7080.5*	1686.1*
Rep (Year)	15	0.035*	111.9*	28.99*	792.24*
Genotypes	29	0.105*	187.17*	53.5*	171.9*
A x G	116	0.017	40.13*	16.27	108.05
Error	435	0.017	26.5	15.22	104.24

*Significant at 5% probability at F test.

TABLE 6 - Average values of plant height, stem diameter, number of pairs of plagiotropic branches (NPP) and canopy projection (CP) for the 30 *Coffea arabica* genotypes under savanna conditions of central plateau.

Genotype	Height (m)	Diameter (mm)	NPP	CP (cm)
Catucaí 2SL	2.25 a	61.69 a	55.2 c	102.4 a
Catucaí 24/137	2.12 b	54.49 c	57.7 c	94.5 b
Catucaí 20/15 cv 479	2.01 c	49.37 d	56.7 c	99.5 a
Catucaí 785/15	2.13 b	57.79 c	57.3 c	98.1 a
Catucaí 20/15 cv 476	2.08 c	56.38 c	55.6 c	97.2 a
Sabiá 398	2.11 b	51.97 d	59.5 b	102.3 a
Palma II	2.16 b	54.62 c	59.8 b	91.9 b
Acauã	2.09 b	57.19 c	56.8 c	100.8 a
Oeiras MG	2.13 b	55.15 c	58.3 b	94.3 b
Catiguá MG 1	2.02 c	56.89 c	57.1 c	95.6 b
Sacramento MG	2.23 a	64.34 a	61.7 a	100.2 a
Catiguá MG 2	2.17 b	60.16 b	58.5 b	96.7 b
Araponga MG	2.21 a	59.73 b	61.7 a	97.5 a
Paraíso MG 419-1	2.00 c	55.74 c	58.9 b	99.4 a
Pau Brasil MG	1.99 c	55.49 c	55.9 c	93.6 b
Tupi 1669-33	2.00 c	53.82 c	56.7 c	97.7 a
Obatã 1669-20	2.09 b	62.18 a	56.4 c	100.5 a
IPR 59	2.11 b	57.40 c	57.7 c	97.9 a
IPR 98	2.08 b	55.91 c	57.7 c	96.3 b
IPR 99	2.16 b	54.94 c	58.3 b	101.6 a
IPR 103	2.22 a	54.37 c	58.7 b	101.1 a
IPR 104	2.11 b	54.68 c	58.4 b	99.6 a
Catiguá MG3	2.04 c	56.08 c	55.9 c	94.7 b
Topázio 1190	2.14 b	59.05 b	60.4 a	95.6 b
Catuaí 144	2.13 b	55.90 c	59.0 b	92.9 b
H419-3-3-7-16-4-1	2.12 b	56.73 c	56.6 c	92.9 b
H419-10-6-2-5-1	2.07 c	54.63 c	57.6 c	90.4 b
H419-10-6-2-10-1	2.01 c	56.09 c	57.9 c	94.8 b
H419-10-6-2-12-1	2.03 c	55.37 c	56.3 c	93.4 b
Catuaí 062	1.99 c	53.04 d	55.8 c	99.8 a

*Averages followed by same letter on the column belong to the same group by Scott-Knott test.

TABLE 7 - Summary of analysis of variance with mean squares of area under the disease progress curve (AUDPC) for brown eye spot incidence (BEI), incidence of coffee leaf rust (LRI), brown eye spot severity (BES) and coffee leaf rust severity (LRS).

Source	DF	BEI	LRI	BES	LRS
Genotype	29	4247473*	944964*	10493*	7.8*
Block	3	3496037*	73137	8552*	0.87
Error	87	908544	135247	2436	1.08

*Significant at 5% probability at F test.

For the source of variation genotype, all response variables were significant. For coffee leaf rust, low severity values were observed, thus generating low AUDPC values. The susceptible Catuaí Amarelo IAC 62 cultivar showed the highest values of coffee leaf rust incidence and severity. Among the genotypes considered as tolerant or resistant, symptoms were observed, with spores, in Catucaí Amarelo 2SL, Catucaí Vermelho 785/15, Paraíso MG, IPR 59 and in the progenies H419-3-3-7-16-4-1, H419-10-6-2-5-1 and H419-10-6-2-10-1 (Table 8).

Higher values for coffee leaf rust incidence were observed from May to July, with highest disease occurrence in June.Susceptible cultivars behaved as classified, with a high incidence in Catuaí Amarelo IAC 62, with percentages higher than 41%. For genotypes considered as tolerant or resistant, the incidence values were below 25%. These genotypes with symptoms are derived from Icatu (Catucaí cultivars) and Timor Hybrid (Paraíso MG cultivar and progenies), both with *C. canephora* Pierre ex A. Froehner in their composition.

The resistance genes SH1 to SH9 interact with virulence genes v1 to v9 of the *Hemileia vastatrix* pathological agent. Genes SH1, 2, 4 and 5 have been identified in pure *C. arabica* from Ethiopia. The SH3 gene is cited as derived from *C. liberica* and the SH genes 6, 7, 8 and 9 from *C. canephora*. The SH gene series ensures complete resistance under homozygous conditions and when specific to the corresponding rust species/ gene. When the genes are broken, the plants show incomplete or partial resistance to the disease (SERA et al., 2010).

Carvalho (2011), in a study performed in producing regions of Minas Gerais, observed high susceptibility to coffee leaf rust for Oeiras derived from Timor Hybrid, showing values similar to controls. The Catiguá MG1, Catiguá MG3, Sacramento MG, Araponga MG, Paraíso MG and Pau Brasil MG cultivars showed severity in intermediate indexes and Catiguá MG2 showed high resistance, with zero infection for all the evaluation sites. In the present study, among these cultivars mentioned above, sporulation symptoms were observed in Pau Brasil MG and also high resistance for Catiguá MG2.

In the Brazilian state of Paraná, Del Grossi (2011) identified cultivars derived from “Catucaí” germplasm as susceptible or with partial resistance levels. The author observed that in varieties from the Timor Hybrid such as Oeiras 6851, Acauã, Araponga MG, IPR 99, Obatã 1669-20, Tupi IAC 1669-33 and Sabiá 398, partial resistance were observed. The cultivars with complete resistance at the evaluated sites were Catiguá MG1 and MG2, IPR 59, 98 and 104, Palma II, Sacramento MG, Pau Brasil MG, and the progenies Paraíso H-419-10-6-2-5-1, H-419-10-6-2-10-1 and H-419-10-6-2-12-1. When comparing with the present study, no symptoms were observed for the cultivars cited with partial resistance in the south of the country.

In the case of brown eye spot, a higher AUDPC was observed for incidence and severity in the Acauã cultivar, differing statistically from the other genotypes. It was followed by a group with IPR 98, IPR 99, IPR 59, Catucaí Vermelho 785/15, Catuaí Vermelho IAC 144, H419-3-3 -7-16-4-1, Sacramento MG 1, Topázio MG 1190, Catucaí Vermelho 20/15 cv 476, Paraíso MG 1 and Araponga MG. The IPR 103, Catiguá MG1 and MG3 cultivars showed the lowest absolute AUDPC values for disease incidence and severity (Table 8). Carvalho (2011) also found lower AUDPC values for Catiguá MG3 in some sites of Minas Gerais, Brazil. It should be noted that low disease incidence and severity, as in these Catiguá cultivars, with high resistance to coffee leaf rust and greater tolerance for the brown eyespot of coffee, do not imply in the higher yield found in the present study.

TABLE 8 - Area under the disease progress curve (AUDPC) for brown eye spot incidence (BEI), coffee leaf rust incidence (LRI), brown eye spot severity (BES) and coffee leaf rust severity (LRS) for the 30 *Coffea arabica* genotypes in savanna conditions of central plateau.

Treatment	Cultivar/Progeny	BEI	LRI	BES	LRS
1	Catucaí Amarelo 2SL	1866 a	436 a	146 a	5.1 b
2	Catucaí Amarelo 24/137	2116a	0 a	152 a	0 a
3	Catucaí Amarelo 20/15 cv 479	2147 a	0 a	175 a	0 a
4	Catucaí Vermelho 785/15	2866 b	436 a	187 b	4.4 b
5	Catucaí Vermelho 20/15 cv 476	2522b	0 a	194 b	0 a
6	Sabiá 398	1430 a	0 a	126 a	0 a
7	Palma II	1648 a	0 a	107 a	0 a
8	Acauã	6402 c	0 a	340 c	0 a
9	Oeiras MG 6851	1527 a	0 a	124 a	0 a
10	Catiguá MG 1	924 a	0 a	99 a	0 a
11	Sacramento MG 1	2831 b	0 a	220 b	0 a
12	Catiguá MG 2	1120 a	0 a	124 a	0 a
13	Araponga MG 1	2455 b	0 a	194 b	0 a
14	Paraíso MG 419-1	2490 b	186 a	212 b	2.5 b
15	Pau Brasil MG 1	1804 a	0 a	156 a	0 a
16	Tupi IAC 1669-33	1854 a	0 a	152 a	0 a
17	Obatã Vermelho IAC 1669-20	1836 a	0 a	149 a	0 a
18	IPR 59	3084 b	31 a	226 b	0.33 a
19	IPR 98	3430 b	0 a	209 b	0 a
20	IPR 99	3360 b	0 a	230 b	0 a
21	IPR 103	1010 a	0 a	93 a	0 a
22	IPR 104	2151 a	0 a	166 a	0 a
23	Catiguá MG 3	1027 a	0 a	100 a	0 a
24	Topázio MG 1190	2553 b	125 a	193 a	2.4 b
25	Catuaí Vermelho IAC 144	2860 b	746 a	217 b	9.4 b
26	H419-3-3-7-16-4-1	2836 b	375 a	214 b	5.6 b
27	H419-10-6-2-5-1	2151 a	63 a	175 a	1.3b
28	H419-10-6-2-10-1	1806 a	374 a	145 a	5.0 b
29	H419-10-6-2-12-1	1929 a	0 a	170 a	0 a
30	Catuaí Amarelo IAC 62	1900 a	2555 b	152 a	56.3 c

*Averages followed by same letter on the column belong to the same group by Scott-Knott test.

Considering the brown eye spot of coffee, two peaks occurred in February and another in July, coinciding with the period of granulation and pre-harvest of coffee fruits, demonstrating the relationship with the crop load. These two disease peaks were also found by Custódio et al. (2014), in the months of March and June of 2005 and 2006, in Lavras-MG county. The disease occurrence in the periods near the harvest can be related to the plant's nutritional imbalance to the detriment of the end of the bean filling, leaving the plant more susceptible to the pathogen attack (CARVALHO, 2011; CUSTÓDIO et al., 2014).

According to the results, cultivars with considerable yield and susceptible to pathogens in the assessed environment could be recommended by using fungicide control, together with the adequate use of mineral nutrition, possibly providing better yields than obtained in the present research. However, in order to reduce production costs and risks to rural workers and to the environment, and still possibly increasing the income, there are options of cultivars with high yield, good vegetative growth and high resistance to diseases, mainly coffee leaf rust for the edaphoclimatic conditions of the central savanna region.

4 CONCLUSIONS

The Catucaí 2SL, Sacramento MG and Araponga MG cultivars stood out in vegetative growth in the savanna conditions of central plateau. Cultivars with the highest average yield, above 60 bg.ha-[1], IPR 103, Obatã Vermelho 1669-20, Palma II, Sabiá 398 and Acauã showed greater adaptability to the environmental conditions. Among all these cultivars is observed high resistance to rust leaf and greater susceptibility to brown eye spot in the cultivar Acauã, for the place and period of evaluation

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SOIL CARBON STOCKS CULTIVATED WITH COFFEE IN THE BRAZILIAN SAVANNA: EFFECT OF CULTIVATION TIME AND USE OF ORGANIC COMPOST

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ABSTRACT: Land-use change (LUC) is one of the main responsible for the loss of soil organic matter (SOM) in the form of CO_2 to atmosphere. The aims of the present study were i) evaluate soil C stocks due to coffee cultivation time after LUC and ii) evaluate the use of the organic compost from the by-product of bean processing as a source of SOM. The study was performed in dystrophic red latosol in the municipality of Patrocínio, MG, Brazil. Two evaluations were performed; i) three coffee (*Coffea arabica* L. var. Icatú Vermelho) growing areas with different implantation times (8, 15 and 37 years) in relation to Cerrado *stricto sensu* (reference); and ii) area cultivated with coffee (*C. arabica* var. Bourbon Vermelho) that received organic compost for four years. Soil was sampled in layers 0-5, 5-10 and 10-20 cm. In the first study, the C stock (0-20 cm) was higher under native vegetation (67 Mg C ha^{-1}) in relation to the coffee growing (63 Mg C ha^{-1}), however, did not differ significantly and showed subtle loss rates of 0.12; 0.06 and 0.02 Mg C ha^{-1} $year^{-1}$ for 8, 15 and 37 years, respectively. In the second study, the organic compost applied to the soil increased the C stock (0-20 cm) to 4.6 Mg C ha^{-1} and showed an accumulation rate of 1.15 Mg C ha^{-1} $year^{-1}$. Thus, it is concluded that C stocks is reduced in the soil due to LUC, however, the application of organic compost increased the supply of organic material, favoring the maintenance and even increasing the stock in the soil.

Index terms: Coffee growing time, *C. arabica* (L.) var. Icatú Vermelho, *C. arabica* (L.) var. Bourbon Vermelho, organic compost, Cerrado biome.

ESTOQUES DE CARBONO DO SOLO CULTIVADO COM CAFÉ NO CERRADO: EFEITO DO TEMPO DE CULTIVO E USO DE COMPOSTO ORGÂNICO

RESUMO: A mudança de uso da terra (MUT) é um dos principais responsáveis pela perda de matéria orgânica do solo (MOS) na forma de CO^2 para atmosfera. Os objetivos deste estudo foram; i) avaliar os estoques C do solo devido ao tempo cultivo de café após a MUT e; ii) avaliar o uso do composto orgânico, oriundo do subproduto do beneficiamento dos grãos como fonte de MOS. O estudo foi realizado em Latossolo Vermelho distrófico em Patrocínio (MG). Duas avaliações foram realizadas; i) avaliaram-se três áreas cultivadas com café (*Coffea arabica* L. var Icatú vermelho) com diferentes tempos e implantações (8, 15 e 37 anos) comparadas ao Cerrado *stricto sensu* (referência) e; ii) avaliou-se área cultivada com café (*C. arabica* L. var Bourbon vermelho) que recebeu durante quatro anos o composto orgânico. O solo foi amostrado nas camadas 0-5, 5-10 e 10-20 cm. No primeiro estudo, o estoque de C (0-20 cm) foi maior no Cerrado (67 Mg C ha-1) comparado ao cultivo do café (63 Mg C ha^{-1}), contudo, não diferiram significativamente e, apresentaram sutis taxas de perdas de 0,12; 0,06 e 0,02 Mg C ha^{-1} ano^{-1} para 8, 15 e 37 anos, respectivamente. No segundo estudo o composto orgânico aplicado ao solo aumentou o estoque de C (0-20 cm) em 4,6 Mg C ha^{-1} e, apresentou taxa de acúmulo de 1,15 Mg C ha^{-1} ano^{-1}. Assim conclui-se que a MUT promove a redução nos estoques de C no solo, contudo, a aplicação de composto orgânico aumentou a oferta de material orgânico favorecendo a manutenção e, até mesmo aumentando o estoque no solo.

Termos para indexação: Tempo de cultivo do café, *C. arabica* (L.) var. Icatú vermelho, *C. arabica* (L.) var. Bourbon vermelho, composto orgânico, Bioma Cerrado.

1 INTRODUCTION

Coffee represents more than 8% of the world's permanent crops, with more than 10 million hectares of land dedicated to its production. It is one of the most traded commodities, sustaining the income of about 25 million people (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS - FAO, 2016). Currently, there are in Brazil approximately 280 thousand producers and the 2016 harvest had more than 2 million hectares (~3/4 *Coffea arabica*) with production of 50 million (~80% *C. arabica*) processed bags (COMPANHIA NACIONAL DE ABASTECIMENTO - CONAB, 2016).

The expansion of Brazilian coffee production in the Alto Parnaíba region of Minas Gerais state, Brazil, occurred in areas previously occupied by native vegetation of the Cerrado biome. Land-use change (LUC) comprises the

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conversion of areas with native vegetation to productive systems and is the main responsible for the change in soil organic matter (SOM) dynamics and changes in soil carbon (C) stock (LAL, 2008).

When considering only the topsoil, the C stock (~800 Pg of C) corresponds almost to the same amount present in the atmosphere (CERRI et al., 2009). During the conversion process from natural ecosystems to agricultural ones, losses occurring in C stocks-SOM promote the C-CO_2 transfer to the atmosphere (LAL, 2007).

The loss of soil C can be attributed to the reduced organic material inputs, the increased decomposition rate of plant residues and the effects of management practices that can reduce the physical protection of the SOM in soil aggregates (CERRI et al., 2009; LAL, 2008). Thus, the mineralization rate of the different C compartments in the soil is increased as a function of the interactions with the promoted changes in the chemical, physical and biological attributes of soil (LAL, 2008).

According to Karp et al. (2015), after loss of C soil stock due to LUC, the recovery capacity of the SOM can be between 25 and 50% lower than the initial amount. However, the recovery potential is related to the history of the area, the environmental conditions related to climate (BERNOUX et al., 2006) and soil type (SIQUEIRA NETO et al., 2010), management (BAYER et al. , 2006), besides especially the time and maintenance of the system (CORBEELS et al., 2016).

A study performed in Brazil with the coffee crop indicated a 33% reduction in soil C when compared with native vegetation in the 0-10 cm layer, as well as significant changes in the environmental services, in the functions and quality of the SOM (MARCHIORI JÚNIOR; MELO, 2000). On the other hand in the study by Pavan and Chaves (1996), the higher the planting density of the coffee plantation, the higher the soil C stock. Whereas the results found by Rangel et al. (2008), the soil C stock was not altered by the spacing between the plants. Additionally, in interline of the coffee plantation were found values of C stock similar to the verified in the crown projection.

The studies that evaluate soil C stocks in the coffee crop are scarce and present quite contrasting results in the literature due to natural factors (climate, soil, relief, cultivation area, etc.) and variety of management (species, cultivars, spacing, pruning, irrigation, use of correctives and fertilizers, etc.). Moreover, given the growing international requirements for sustainable crops based on product life-cycle analyses, the economic, social and even historical-political importance of culture are considered. In this way, the hypothesis of this study was that the cultivation time after LUC, as well as the supply of organic material in crop management can recover (totally or partially) the C stocks of coffee plantations in the Cerrado biome. The objective was to evaluate the influence on soil C due to the coffee cultivation time after the LUC in the Cerrado biome and to evaluate the use of the organic compost (processed by-product of beans) as a source of organic material in the coffee crop management.

2 MATERIAL AND METHODS

Characterization of study areas

The sampled areas are located in Boa Vista Farm, at Rodovia MG 188, km 16, rural area of the municipality of Patrocínio, Minas Gerais state, Brazil. The climate is type Cwa (Köppen classification) - high-altitude humid subtropical, with temperature between 7 °C and 35 °C and rainfall above 1,300 mm. The soil was classified as dystrophic red latosol (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA, 2013).

The first study evaluated three coffee (*Coffea arabica* L. var. *I*catú Vermelho) growing areas with different implantation ages, being 8, 15 and 37 years after native vegetation conversion. For reference, a legal reserve area was taken with approximately 4 ha composed of native vegetation contiguous to the coffee growing areas. The area with native vegetation was classified as Cerrado *stricto sensu*, even with signs of degradation (BASTOS; FERREIRA, 2012).

The conversion of native vegetation to coffee cultivation was performed by cutting and burning the vegetation. Briefly, trees with potential for exploitation were removed, such as posts or for coal manufacturing. Then, the remaining phytomass was felled using two tractors with a chain attached to them. The fallen material remained on the ground until dry, when it was “windrowed” (formation of piles with dry plant material) and burned. After the second “windrowing” and burning of the remaining plant material, the area was prepared using deep plowing (~30 cm) and the manual harvesting of remaining stems and roots of larger diameter. Approximately six months before planting of coffee seedlings, the first soil correction with dolomitic limestone (~2 Mg ha^{-1}) was performed with a leveling harrow. After this period, grooves were opened with application of natural phosphate and nitrogen and potassium fertilizer, as recommended by soil analysis and subsequent planting of seedlings.

Evaluation of soil C stocks

The selected areas to evaluate the effect of coffee cultivation time have 10.1, 5.9 and 13.8 ha, respectively for the times 8, 15 and 37 years, spacing of 3.8 x 0.6 m, the management of spontaneous vegetation between the lines was performed through brushcutter four times a year. The physical-chemical characterization of the soil in these areas is shown in Table 1.

The second study evaluated the effect of the organic compost application in an area of 10.1 ha cultivated for 12 years with coffee (*C. arabica* var. *Bourbon Vermelho*) with spacing of 4.0 x 0.5 m, which in the last four years received 5 Mg ha^{-1} year^{-1} of organic compost in approximately one third of the total cultivated area (3.42 ha). In the total area, the control of the spontaneous vegetation was performed with brushcutter four times a year and brushing (collecting the plant residues from the soil surface in the crown projection of plants) in the period prior to harvesting. The physical-chemical characterization of the soil in these areas is shown in Table 2.

The applied organic compost was composed of coffee husks after the wet fruit processing, coffee husk after processing of beans and crushed plant residues derived from pruning, these materials were mixed and remained in the barnyard at rest for a period between six and eight months until application in the field. The compost was always applied in the crown projection of plants. The characterization of the organic compost is presented in Table 3.

Soil sampling and laboratory analyses

Soil samples were collected at 15 random points in the areas without line discrimination (crown projection) or between the lines of the coffee plantation. At each point, undisturbed samples were collected with a 5 x 5 cm (99.4 cm^{-3}) stainless steel cylinder in the layers 0-5, 5-10 and 10-20 cm. In the Laboratory of Environmental Biogeochemistry (CENA - USP), samples were weighed (total mass), then air dried and passed through a 2 mm sieve. Bulk density (Bd) was determined after discarding the gravimetric moisture in 5 g aliquots of soil, dried for 48 h in ovens at 105 ^{o}C. The total C content was determined in the elemental analyzer LECO© CN-2000® (St. Joseph, Michigan).

TABLE 1 - Physical and chemical characterization of the soil for the 0-20 cm layer of the savanna native vegetation and cultivated with coffee aged 8, 15 and 37 years at Boa Vista Farm in the municipality of Patrocínio, Minas Gerais state, Brazil.

Areas	pH	Clay	avail.-P	K^+	Ca^{2+}	Mg^{2+}	E	BS%
	$CaCl_2$	g kg^{-1}	mg dm^{-3}	mmol$_c$ dm^{-3}				%
Cerrado	4.4	485.3	2.3	1.2	2.1	1.6	61.1	8.0
Coffee 8 years	5.3	507.4	17.9	2.7	22.8	10.2	69.9	51.1
Coffee 15 years	5.9	514.6	22.3	3.5	24.6	13.6	73.9	56.4
Coffee 37 years	5.3	513.9	34.4	4.4	23.3	14.8	73.9	57.5

avail.-P = available phosphorus; E = potential cation exchange capacity; BS% = base saturation.

TABLE 2 - Physical chemical characterization of the soil for the 0-20 cm layer of the areas with and without organic compost application cultivated with coffee at Boa Vista Farm in the municipality of Patrocínio, Minas Gerais state, Brazil.

Area	pH	Clay	avail.-P	K^+	Ca^{2+}	Mg^{2+}	E	BS%
	$CaCl_2$	g kg^{-1}	mg dm^{-3}	mmol$_c$ dm^{-3}				%
Without compost	5.2	596.3	26.4	2.7	22.3	11.8	76.5	48.1
With compost	5.5	595.7	32.5	3.4	27.9	14.7	81.3	56.6

avail.-P = available phosphorus; E = potential cation exchange capacity; BS% = base saturation.

TABLE 3 - Chemical characterization of the organic compost applied in the area cultivated with coffee at Boa Vista Farm in Patrocínio, MG, Brazil.

Properties	Content (g kg^{-1})
Total carbon	419.6
Total nitrogen	9.0
C:N ratio	46.6
Phosphorus (P_2O_5)	0.4
Potassium (K_2O)	2.1
Calcium	3.8
Magnesium	0.9
Sulfur	0.9

Statistical calculations and analyses

The C stocks were calculated from the total C contents, the bulk density values and the sampled soil layers, following Equation 1 presented by Bernoux et al. (1998):

$$S = Bd \times h \times C \quad (1)$$

where S is the soil carbon stock converted into hectare (Mg ha^{-1}); *Bd*, bulk density (g cm^{-3}); *h*, the thickness of the sampled layer (cm); and *C*, the soil C content (g kg^{-1}).

The C stocks were corrected for the soil mass of the reference area (Cerrado), since the bulk density between the coffee cultivated areas showed a significant difference in relation to the area with native vegetation. However, it was not necessary to correct the values for the second study, since no significant differences were found among the bulk density values. The calculation used for correction was presented by Fernandes and Fernandes (2013) (Eq. 2):

$$S_c = \Sigma^{n-i} S + \{M_{ai} - (\Sigma^n M_a - \Sigma^n M_r)\} C_i \quad (2)$$

where S_c is the S stock corrected by the soil mass (Mg ha^{-1}); Σ_{ni} *S* is the sum of the layer stocks, without the last sampled layer; M_{ai} is the soil mass of the last sampled soil layer; $\Sigma^n M_a$ is the sum of the total mass of sampled soil; $\Sigma^n M_r$ is the sum of the reference soil mass; and C_i is the C content in the last sampled layer.

The annual rate of change in soil C stock was estimated based on changes in C stocks over time in relation to the reference area (Eq. 3).

$$\Delta S = \frac{\sum (S_f(A) - S_i(A))}{T} \quad (3)$$

where: ΔS is the soil C stock variation (Mg ha^{-1} $year^{-1}$); *A* is considered as the evaluated system; $S_f(A)$ is the C stock at the final time (Mg C) of the system *A*; S_i *(A)* is the C stock at the initial time (Mg C) in the reference area; and *T* is the time (years).

The results of the first and second study were compared separately. The results were subjected to analysis of variance (ANOVA) in order to obtain the significant differences by the ANOVA procedure and the averages were compared by Tukey test at 5% probability level to characterize the differences among the sampled areas.

In the first study, the bulk density was compared for the C stock correction by the soil mass of the reference area (Cerrado), as well as to determine the least significant difference (LSD) among the C contents at each layer and the comparison among corrected C stocks between the different coffee cultivation times (8, 15 and 37 years) and the reference area (native vegetation). In the second study, the results of bulk density, the determination of the LSD among the C contents at each layer and the comparison between the corrected C stocks between the area with compost application and the reference area, i.e. without compost application.

3 RESULTS AND DISCUSSION

Soil carbon content

The soil C contents for both studies showed the highest values in the top layer, decreasing with increasing depth (Figure 1A and B).

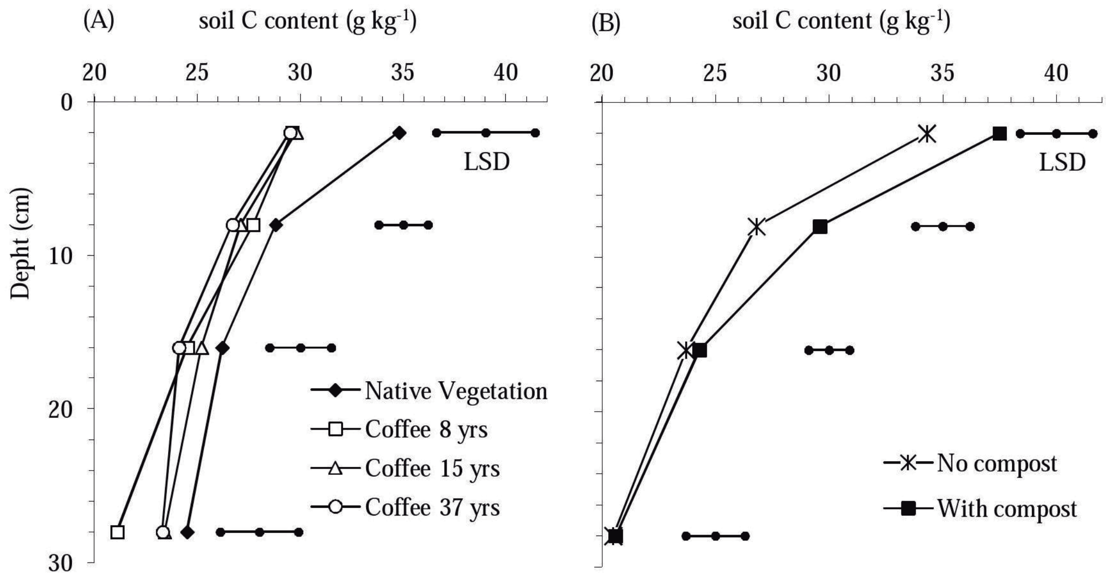

FIGURE 1 - Carbon contents (g kg^{-1}) in the 0-20 cm soil layer (A) for the Cerrado and in areas with different coffee cultivation times; (B) without and with application of the organic compost at Boa Vista Farm in the municipality of Patrocínio, Minas Gerais state, Brazil. Values represent the average (n = 15); the horizontal bars represent the least significant difference (LSD) obtained in the Tukey test ($p < 0.05$).

This behavior is characteristic of latosols in which there is no constant turnover from the topsoil (SIQUEIRA NETO et al., 2010).

The maintenance of high C contents in the top layer is justified by the deposition/contribution of organic materials on the soil surface. This contribution is due to the fall of leaves, both by the coffee and by the savanna vegetation, as well as by the renovation of the root system of plants that usually show greater biomass in the soil surface, searching for elements derived from the nutrient cycling. In coffee growing areas, there is still the deposition of the organic material from the spontaneous vegetation between the rows of crop, ploughed periodically. Alcântara and Ferreira (2000), in an experiment with 18 years of data collection, observed that the spontaneous vegetation, always ploughed in the coffee between the lines of the coffee increased the SOM and improved its soil physical and chemical attributes.

In a study performed by Siles, Harmand and Vaast (2010), 50% biomass of fine roots were found in the first 30 cm of soil and, therefore, the C contribution by the roots can be up to 30% higher in relation to the contribution of the shoot deposition. According to the authors, this occurs because biomass of the root system shows residence time 2.4 times higher than the C derived from the shoot.

In the study of the effect of coffee cultivation time in relation to native vegetation (Figure 1A), the highest C contents were verified in the Cerrado ($p < 0.05$), mainly in the topsoil (0-5 cm) while the different times of coffee implantation did not show significant difference in soil C contents ($p > 0.05$).

Regarding the study that evaluated the effect of the organic compost application (Figure 1B), the soil C contents for the 0-10 cm layer were significantly higher with the compost application ($p < 0.05$) however there was no significant difference ($p > 0.05$) for the 10-20 cm layer.

Bulk density

The lowest soil density values were verified in the Cerrado (Table 4), while significantly higher density values were observed for coffee with 8 and 15 years of implantation. On the other hand, the lowest density among coffee growing areas was verified in the area with 37-year coffee (0.96 g cm^{-3}). In the 10-20 cm layer, there was no difference among the coffee growing areas, regardless of the implantation time of the culture.

The cultivation time was a favorable factor for this parameter probably due to the high volume of fine roots present in older coffee plantations, thus providing greater soil aggregation and hence better structure and porosity.

TABLE 4 - Average bulk density (g cm^{-3}) for Cerrado and in areas with different coffee cultivation times at Boa Vista Farm in the municipality of Patrocínio, Minas Gerais state, Brazil.

Area	Bulk density (g cm^{-3}) †		
	0-5 cm	5-10 cm	10-20 cm
Cerrado	0.97 b	1.00 b	0.99 b
Coffee 8	1.02 a	1.05 a	1.06 a
Coffee 15	1.03 a	1.07 a	1.05 a
Coffee 37	0.96 b	1.04 ab	1.04 a

†Average values of bulk density (n = 15) followed by the same letter among the different coffee cultivation times and Cerrado did not show statistically significant difference by Tukey test ($p < 0.05$).

The bulk density is influenced by SOM, since this is the greatest conditioning agent of soil physical attributes such as aggregation and aeration (SILVA et al., 2006).

In the study with and without organic compost application, no significant difference ($p > 0.05$) was observed among the bulk density for the sampled layers (Table 5).

In general, in different coffee growing areas, for soils from the Cerrado, the values verified in the literature were well above the verified in the present study. Cortez et al. (2010) found values between 1.71 and 1.76 g cm^{-3} for the coffee cultivated in soil from the Cerrado biome, while Alcântara and Ferreira (2000), in a long-term experiment using brushcutter to control invasive plants in the interlines, showed values between 1.29 and 1.41 g cm^{-3}. Silva et al. (2006) obtained values from 1.38 to 1.55 g cm^{-3} in coffee area with application of herbicides to control invasive plants between the lines.

Soil C stocks

Soil C stocks for the 0-20 cm layer between the native vegetation area and the cultivated areas with different coffee implantation times did not differ significantly ($p > 0.05$). However, it is possible to verify lower average values in the C stocks with the increase of coffee cultivation time (Figure 2A).

The shrub vegetation, typical from the Cerrado biome, mainly with plants physiognomy is characterized by a low ratio between the shoot and the root system, i.e., these types of plants have a woody, robust and abundant root system, precisely adapted to the occurrence systemic natural fires (GRACE et al., 2006) and lack of water. In this way, the occurrence of burning of the natural vegetation and subsequent deposition of the partially burned material and coal fragments in a natural ecosystem, i.e., without soil turnover, allows a large quantity of fragmented organic material with a high C:N ratio remaining in the soil (CORBEELS et al., 2016). This cycle, repeated for a long time, leads to physical and chemical (humification) and microbiological (decomposition/mineralization) transformation processes in this organic material and hence the C accumulation in the form of SOM.

In areas with different coffee cultivation times, the lower average values of C stocks may be related to the SOM loss of the conversion process from native vegetation to agricultural system. The phytomass was initially discharged and burned during the conversion of areas, then the deep soil turnover was performed in several operations and finally the inputs (i.e. limestone and fertilizer) were applied. This sequence of operations is quite aggressive to the soil and hence tends to reduce the content of SOM (PAUSTIAN et al., 2016).

Moreover, it should not also be disregarded that after LUC operations, the coffee cultivation, due to its perennial nature, does not require constant soil turnovers, as occurs in annual crops. Thus, the development of root system of the crop, as well as the spontaneous vegetation between the lines of cultivation can provide conditions for a new arrangement of the soil minerals and formation of new macro-aggregates and hence the soil and porosity restructuring. Not only due to the root system, but also to the contribution of leaves and branches of the plants and the phytomass contribution of the spontaneous vegetation, ploughed periodically.

TABLE 5 - Average bulk density (g cm^{-3}) for the area without and with organic compost application at Boa Vista Farm in the municipality of Patrocínio, Minas Gerais state, Brazil.

Area	Bulk density (g cm^{-3}) †		
	0-5 cm	5-10 cm	10-20 cm
Without compost	1.00 ns	1.06 ns	1.05 ns
With compost	0.98	1.06	1.06

†Average values of bulk density (n = 15) without and with organic compost application did not show statistically significant difference by Tukey test (*p <0.05*); ns = not significant.

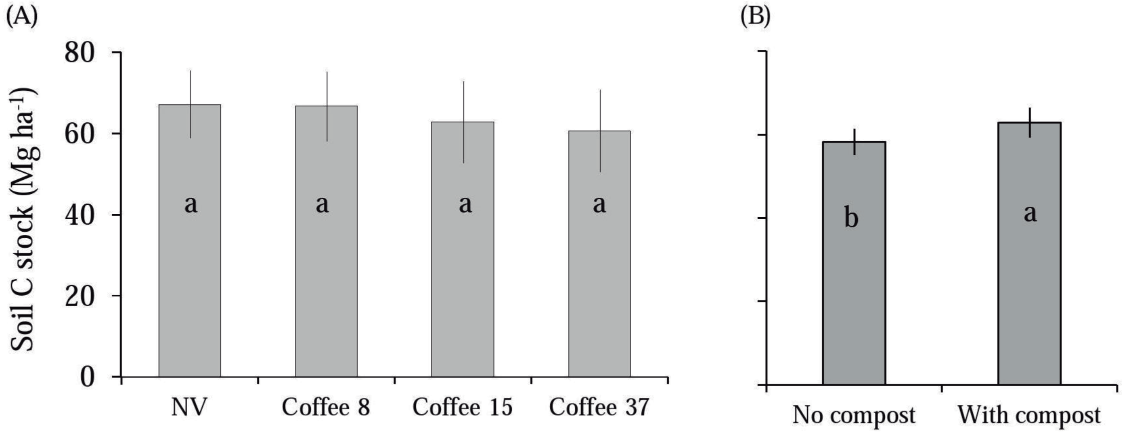

FIGURE 2 - Carbon stocks (Mg^{-1}) in the 0-20 cm soil layer (A) for the Cerrado and in areas with different coffee cultivation times; (B) without and with application of the organic compost at Boa Vista Farm in the municipality of Patrocínio, Minas Gerais state Brazil. Values represent the average (n = 15) ± standard deviation; the same lowercase letters within each study did not differ significantly by Tukey test (p < 0.05).

In the study performed by Marchiori Junior and Melo (2000), the layers 0-10 and 10-20 cm were reduced by 33 and 10%, respectively, in the soil C stock cultivated with coffee for 18 years in relation to the native vegetation cover. On the other hand, the results found by Grebim (2010), evaluating the C stock in coffee crops with 10 and 30 years in Cerrado biome soils, observed an increase of 25 and 43% in relation to the native vegetation. Rangel et al. (2008) observed that the coffee cultivation for 11 years led to increased C stocks in the planting line, however, they observed a reduced crown projection of the coffee plantation. These results, when integrated by area and compared to the native vegetation, did not show significant difference.

In the study by Hergoualc'h et al. (2012), a stock of C above 100 Mg ha^{-1} was verified in the 0-40 cm layer in coffee grown under conventional system, i.e., using brushcutter in the management of invasive plants in the interline. This result, when compared to coffee cultivation under agroforestry system, showed a significant difference only in the 0-10 cm layer (+2.4 Mg ha^{-1}), which was not significant for the whole sampled layer. In this same study, the authors report that the coffee crop stored in the litter and in the root system approximately 6 Mg ha $^{-1}$ of C, which later will be decomposed and partly incorporated in the soil.

The highest C loss rate in the soil, even without significant differences in relation to Cerrado, was verified in the area cultivated for eight years (-0.12 Mg C ha^{-1} year $^{-1}$) which was exponentially decreasing over the years (Figure 3). Therefore, after 15 years of cultivation, the rate was -0.06 Mg C ha^{-1} $year^{-1}$ and -0.02 Mg C ha^{-1} $year^{-1}$ after 37 years.

In a study performed on coffee crops in Costa Rica, Hergoualc'h et al. (2012) verified reduction in soil C stock of -0.43 Mg C ha^{-1} $year^{-1}$ for coffee under conventional management with three years. On the other hand, the C stock for coffee in an agroforestry system showed a small accumulation rate of 0.09 Mg C ha^{-1} $year^{-1}$. However, Guimarães et al. (2014) found increments by 20 and 27% (0-20 cm) in coffee areas under agroforestry system after 20 years of implantation, which varied according to the tree species. In this study, the C accumulation rate was estimated between 0.8 and 1.1 Mg C ha^{-1} $year^{-1}$.

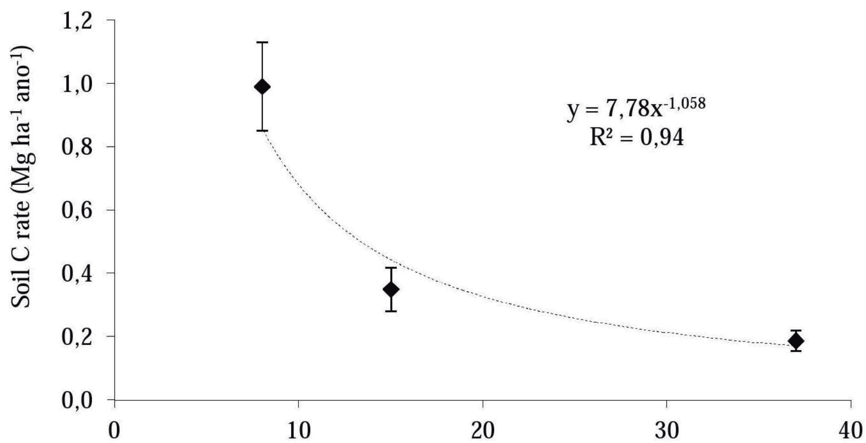

FIGURE 3 - Carbon loss rate (Mg ha^{-1} year^{-1}) in the soil for coffee growing areas with different coffee cultivation times in relation to native savanna vegetation at Boa Vista Farm in the municipality of Patrocínio, Minas Gerais state, Brazil.

The longest implanted area (37 years) showed the lowest loss in C stocks (0.2 Mg C ha^{-1} year^{-1}; Figure 3) reflecting in dynamic equilibrium, where the C loss in the system is compensated by the entry of organic material derived from both coffee and phytomass of the invading plant of interlines. This low change rate in soil carbon over time after LUC may be related to the presence of more recalcitrant fractions of the organic material, e.g., organic polymers such as lignin, suberins, resins and waxes (SILVA; MENDONÇA, 2007). In coffee cultivation, the entry of C in the soil occurs mainly by leaf deposition, mortalities and root exudation. During decomposition, most will be emitted as CO_2, while approximately lower than 20% will remain in the soil (THEODORO; MENDES; GUIMARÃES, 2009).

These results evidence that the higher C loss rate occurs in the initial cultivation period (Figure 3), i.e., closer to the LUC. However, as discussed previously, the sequence of operations during conversion from native vegetation to farming systems promotes high loss of SOM. Thereby, there is the possibility that the C loss occurred to the detriment of the LUC and not necessarily from the new farming system. In other words, the coffee cultivation in clayey soil and influenced by the climate of the Cerrado biome reached a steady state, in which the input of organic matter and the decomposition would be in dynamic equilibrium with the mineralization of the SOM. In this respect, there are no changes in the soil C stocks with the coffee cultivation time (Figure 2A) and therefore the C loss rate did not change effectively with LUC time, since the SOM already had been lost and hence the loss rate was only diluted according to the evaluated times.

In the second study, the application of the organic compost increased the soil C stock by 10%, from 58 to 63 Mg C ha^{-1} ($p < 0.05$; Figure 2b). Thus, the application of the organic compost in four years showed accumulation rate of 1.15 Mg C ha^{-1} year^{-1} in relation to the situation without the compost application. The study by Guimarães et al. (2014) showed a 20% increase in soil C stock (0-20 cm) in organic coffee cultivation that received green manure and jack-bean (*Canavalia ensiformis* (L.) DC.) in relation to conventional cultivation, with 11-year accumulation rate estimated at 1.7 Mg C ha^{-1} year^{-1}. According to Cerri et al. (2009), the main factors determining the soil C accumulation or loss rate are the quantity, quality and positioning of the organic matter contribution, as well as weather conditions, soil type (SIQUEIRA NETO et al., 2010), soil management and other cultural practices, besides the time of implantation and maintenance of the cropping system (CORBEELS et al., 2016).

4 CONCLUSIONS

The land-use change (LUC) from native vegetation to coffee cultivation reduced soil C stock by 10% and, for the present study conditions, it can be verified that soil C loss occurred due to LUC operations and not by the coffee cultivation;

The soil C loss rate showed that the soil C stock after the losses due to LUC with the cultivation time reached the state in which the organic matter contribution and the decomposition are in dynamic equilibrium with the mineralization of the SOM;

The application of the organic compost derived from the coffee processing favored the maintenance and even the increase of soil C stock by 10% over a four-year period.

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CHARACTERIZATION OF COFFEE CULTIVARS LEAF RUST-RESISTANT SUBJECTED TO FRAMEWORK PRUNING

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ABSTRACT: The goal of our work was to evaluate physiological and agronomic traits, as well as the relationship between these traits in coffee cultivars coming from a germplasm supposedly resistant to leaf rust, and their response to framework pruning. The experiment was conducted at the Federal University of Lavras in randomized blocks with three replicates, with spacing of 3.5 x 0.7 m and plots of 12 plants. An amount of 25 coffee cultivars was evaluated, from which 23 were considered resistant and two susceptible to leaf rust. Traits analyzed were the plagiotropic branch length and number of nodes, net photosynthetic rate, transpiration rate, water use efficiency, fluorescence and chlorophyll index, leaf area index, leaf rust incidence and yield. *Catucaí Amarelo 20/15* cv *479*, *Araponga MG1* and *Tupi IAC 1669-33* cultivars show highly responsive to framework pruning. These cultivars have high yield associated to high net photosynthetic rate, water use efficiency and low transpiration rate. Moreover, the last two cultivars show a low incidence of leaf rust. The *Acauã* cultivar has a good response to framework pruning, showing high yield associated to lower incidence of leaf rust. *Catucaí Vermelho 785/15* cultivar is not responsive to framework pruning because show lower yield, high incidence of leaf rust, low vegetative growth and low water use efficiency.

Index terms: *Coffea arabica* L., *Hemileia vastatrix*, pruning.

CARACTERIZAÇÃO DE CULTIVARES DE CAFEEIROS RESISTENTES À FERRUGEM SUBMETIDAS À PODA TIPO ESQUELETAMENTO

RESUMO: Objetivou-se avaliar características fisiológicas e agronômicas, bem como a relação entre elas em cultivares de cafeeiros oriundos de germoplasma supostamente resistente à ferrugem e sua resposta à realização da poda tipo esqueletamento. O experimento foi instalado na Universidade Federal de Lavras, em blocos casualizados, com três repetições, no espaçamento de 3,5 x 0,7m e parcelas de 12 plantas. Avaliou-se 25 cultivares de cafeeiro, sendo 23 supostamente resistentes e 2 consideradas suscetíveis à ferrugem. Analisou-se comprimento de ramo plagiotrópico e número de nós; taxa fotossintética líquida; taxa transpiratória; eficiência de uso da água; fluorescência e índice de clorofila; índice de área foliar, incidência de ferrugem e produtividade. As cultivares Catucaí Amarelo 20/15 cv 479, Araponga MG1 e Tupi IAC 1669-33 mostram-se altamente responsivas à poda de esqueletamento por apresentarem alta produtividade aliada à alta taxa fotossintética, eficiência no uso da água e baixa taxa transpiratória. Além disso, as duas últimas cultivares apresentam baixa incidência de ferrugem. A cultivar Acauã apresenta boa resposta à realização dessa poda apresentando alta produtividade associada à menor incidência de ferrugem. A cultivar Catucaí Vermelho 785/15 não é responsiva à poda tipo esqueletamento, por apresentar menor produtividade, além de alta incidência de ferrugem, baixo crescimento vegetativo e baixa eficiência no uso da água.

Termos para indexação: *Coffea arabica L., Hemileia vastatrix,* poda.

1 INTRODUCTION

Although Brazil is the world's largest producer of coffee, it is known that the average crop yield is low (CAIXETA et al., 2008). One of the reasons for this is the presence of coffee rust (*Hemileia vastatrix* Berk. & Br.), which is the main phytosanitary problem of the coffee plantation today, causing economic losses to coffee growers (BARBOSA; SOUZA; VIEIRA, 2010; BRITO et al., 2010; REZENDE et al., 2013). An alternative for the management of the disease is the use of resistant cultivars.

Leaf rust-resistant coffee plants have been shown as the best option for disease management (ZAMBOLIM; VALE, 2003). However, farmers and technicians have observed that leaf rust-resistant coffee plants, despite having high yield in the first year, have reduced their vegetative vigor over the years, leading to yield loss.

Thus, the lack of scientific knowledge reinforces the need to perform studies related to the restoration of the productive capacity of these materials. The use of pruning, especially framework pruning is a viable technique for

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recovering the vegetative vigor of these plants over the years.

Framework pruning is a technique that consists of the removal of a large terminal portion of all plagiotropic branches and is considered a relatively drastic operation because it reduces a large portion of shoot and consequently of root system (QUEIROZ-VOLTAN et al., 2006). Therefore, for the adequate application of this technique, it is necessary to associate the use of appropriated cultivars with a correct management in order to increase yield, in the short term, in relation to the free growth.

Therefore, the use of techniques to improve conventional selection methods of coffee plants is extremely important, favoring the identification of cultivars that are more productive and responsive to management practices, especially pruning usually employed in crop management.

It should also be considered that physiological studies have been highlighted as important ways for optimizing breeding studies (BATISTA et al., 2010). Moreover, agronomic traits associated with physiological methods allow identifying cultivars with favorable aspects to growth and development vegetative and productive.

Thus, the goal of our work was to evaluate physiological and agronomic traits, as well as the relationship between them in coffee trees cultivars originating from germplasm supposedly resistant to leaf rust and their response to framework pruning.

2 MATERIAL AND METHODS

The experiment was conducted at the Department of Agriculture, Federal University of Lavras, MG, Brazil, from August 2014 to July 2016.

Physiological and agronomic traits were evaluated in 25 Coffea arabica L. cultivars developed by the main genetic improvement programs in Brazil. The selected cultivars developed by PROCAFÉ with their respective source materials were: Catucaí Amarelo 2 SL (Icatu x Catuaí), Catucaí Amarelo 24/137 (Icatu x Catuaí), Catucaí Amarelo 20/15 cv. 479 (Icatu x Catuaí), Catucaí Vermelho 785/15 (Icatu x Catuaí), Catucaí Vermelho 20/15 cv. 476 (Icatu x Catuaí), Sabiá 398 (Catimor x Acaiá), Palma II (Catimor x Catuaí), Acauã (Sarchimor x Mundo Novo). The selected cultivars developed by EPAMIG were Oeiras MG 6851 (Caturra Vermelho (CIFC 19/1) x Timor Hybrid 832/1), *Catiguá MG 1* (Catuaí Am. IAC 86 x Timor Hybrid 440-10), *Sacramento MG 1* (Catuaí Verm. IAC 81 x Timor Hybrid 438-52), *Catiguá MG 2* (Catuaí Am. IAC 86 x Timor Hybrid 440-10), *Araponga MG 1* (Catuaí Am. IAC 86 x Timor Hybrid 446/08), *Paraíso MG 1* (Catuaí Am IAC 30 x Timor Hybrid 445-46), *Pau Brasil MG 1* (Catuaí Verm. IAC 141 x Timor Hybrid 442-34*), Catiguá MG 3* (Catuaí Am. IAC 86 x Timor Hybrid 440-10) e *Topázio MG 1190* (Mundo Novo x Catuaí). The selected IAC cultivars were *Tupi IAC 1669-33 (Sarchimor)*, *Obatã IAC 1669-20* (Sarchimor x Catuaí) e *Catuaí Vermelho IAC 144* (Mundo Novo x Caturra). Finally, the cultivars developed by IAPAR were *Iapar 59* (Sarchimor 1669), *IPR 98* (Sarchimor 1669 selection), *IPR 99* (Catuaí x Icatu), *IPR 103* (Catuaí x Icatu) and *IPR 104* (Catuaí x Icatu).

From these cultivars, 23 were coming from a germplasm supposedly resistant to leaf rust (*Hemileia vastatrix* Berk. & Br.) and two are susceptible commercial cultivars (*Topázio MG 1190* and *Catuaí Vermelho IAC 144*), considered as control.

A randomized block design was used with three replicates and plots of 12 plants. Spacing was 3.5 m between rows x 0.70 m between plants.

Framework pruning was performed in September 2014. Posteriorly, the reduction of orthotropic stem was made at 2 meters of soil, with a single budding top at the terminal portion of plants.

To evaluate the physiological traits were used leaves in the third node from the apex of the branch, in the middle third of the plant. They were free from pest and disease attack, nutritional deficiencies and environmental stresses. The evaluations were performed nine months after framework pruning in June 2015, at the end of the vegetative period, beginning at 8 a.m. and ending at 11 a.m.

For the physiological analysis of gas exchanges, a portable infrared gas analyzer (IRGA LICOR - 6400XT) was used. The net photosynthetic rate (A-μmol m^{-2} s^{-1}) and the transpiration rate (E-μmol m^{-2} s^{-1}) were evaluated under artificial light (1000 μmol m^{-2} s^{-1}). Water use efficiency (WUE) was calculated using the A/E ratio (SILVA et al., 2010).

Leaf area index (LAI) was determined according to the methodology proposed by Barbosa et al. (2012).

The plagiotropic branch length (cm) was evaluated in June 2015, at the end of the period of vegetative development and differentiation of buds for later production. An evaluation was performed using a graduated ruler by measuring three branches (lower, middle and upper third) on each side of the plant, with measures from the apex to the base of the branch developed after pruning, disregarding the first plagiotropic branch.

Leaf rust incidence was evaluated monthly through leaf sampling collected in the middle third of the third and fourth pairs of leaves from the plagiotropic branches, totaling 100 leaves per plot from December 2015 to March 2016. It was determined as a percentage, counting the number of leaves with sporulated pustules.

Harvesting was performed in the first production after framework pruning in all plants. It was made the measured in liters of harvested coffee and divided by the number of plants to obtain the average production (liters/plant). There was extrapolation (liters of coffee harvested/plot) and then conversion to 60 kg bags of processed coffee/ha through actual yield, calculated according to Moraes (2013) using a sample of four liters of coffee.

The statistical analyses were performed using the R software version 3.3.1(R CORE TEAM, 2016).

3 RESULTS AND DISCUSSION

For net photosynthetic rate (TABLE 1), the results showed superiority of the *Catucaí Amarelo 2 SL*, *Catucaí Vermelho 20/15* cv. *476, Oeiras MG 6851*, *Catiguá MG 2*, *Paraíso MG 1* and *Tupi IAC 1669-33* cultivars. *Catucaí Amarelo 24/137*, *Catucaí Amarelo 20/15* cv. *479*, *Catucaí Vermelho 785/15*, *Acauã, Sacramento MG 1*, *Araponga MG1*, *IPR 99*, *IPR 104,* and *Catuaí Vermelho IAC 144* cultivars even though belonging to the second largest group of average photosynthetic rate, showed sufficient/high values for coffee trees, since these plants show low photosynthetic efficiency in relation to most woody plants (CANNELL, 1985).

The lowest transpiration rates were observed in *Catucaí Amarelo 2 SL*, *Catucaí Amarelo 24/137*, *Catucaí Amarelo 20/15* cv. *479*, *and Catucaí Vermelho 20/15* cv. 476, *Sabiá 398, Oeiras MG 6851*, *Catiguá MG 1*, *Araponga MG 1*, *Paraíso MG 1*, *Obatã IAC 1669-20*, *IPR 99*, *Topázio MG 1190* and *Catuaí Vermelho IAC 144* (TABLE 1). On the other hand, the highest averages were obtained by *'Acauã'* and '*Catucaí Vermelho 785/1*' (TABLE 1). Transpiration is the loss of water vapor by plants, occurring mostly through the diffusion of water vapor through the stomata. In situations of water abundance, there is high water loss by transpiration, since water supply is constant, which is advantageous for the production of photoassimilates. However, when soil water is less abundant, the stomata will open less or remain closed to avoid plant dehydration (TAIZ; ZEIGER, 2013).

The plant efficiency in managing water loss while allowing sufficient CO_2 absorption for photosynthesis can be determined by water use efficiency (WUE). The highest WUE values were obtained by *Catucaí Amarelo 24/137*, *Catucaí Vermelho 20/15* cv. *476*, *Sabiá 398* and *Topaz MG 1190* (TABLE 1). The WUE consists of the ratio between the net photosynthetic rate and the transpiration rate, i.e., plants with greater WUE produce more dry matter in relation to transpired water (RAMALHO et al., 2013). Carvalho et al. (2014) also observed that *Catucaí Amarelo 2 SL* cultivar showed high WUE due to its lower transpiration rate, resulting in a lower water loss in relation to the amount of dry matter produced.

Cultivars *Catucaí Amarelo 2 SL*, *Catucaí Amarelo 24/137*, *Catucaí Amarelo 20/15* cv. *479*, *Catucaí Vermelho 20/15* cv. *476*, *Oeiras MG 6851*, *Araponga MG1*, *Paraíso MG 1*, *IPR 99* and *Catucaí Vermelho 20/15* cv. *476* were in the two groups of cultivars with higher WUE. They were also in the two groups with higher net photosynthetic rate and in the group with lower transpiration rate in relation to others cultivars (TABLE 1). However, *Sabiá 398*, *Catiguá MG 1* and *Topázio MG 1190* showed high WUE mainly due to their low transpiration rate, despite having low net photosynthetic rates (TABLE 1). It is worth noting that *Catucaí Vermelho 785/15* and *Acauã* showed low WUE due to their high transpiration rates, despite obtaining high net photosynthetic rates. This is also true for *Palma II*, *Pau Brasil MG1*, *Obatã IAC 1669-20*, *Iapar 59*, *IPR 98*, *IPR 103* and *Catiguá MG 3*, but only because of the low net photosynthetic rates (TABLE 1).

Some cultivars showed higher leaf area indexes, for example, *Catucaí Amarelo 2 SL*, *Catucaí Amarelo 24/137*, *Catucaí Amarelo 20/15* cv. *479*, *Catucaí Vermelho 20/15* cv. *476*, *Sabiá 398, Palma II*, *Catiguá MG 1*, *Paraíso MG 1*, *Pau Brasil MG 1, Obatã IAC 1669-20*, *IPR 99*, *IPR 103*, *IPR 104* and *Topázio MG 1190* (TABLE 1).

TABLE 1 - Averages of cultivars for the characteristics: net photosynthetic rate (A), transpiration rate (*E*), water use efficiency (WUE), leaf area index (LAI), plagiotropic branch length (PBL), yield and leaf rust incidence (LRI) of 25 coffee cultivars after framework pruning in Lavras, MG, Brazil.

Cultivar	A	*E*	WUE	LAI	PBL	Yield	LRI
Catucaí Amarelo 2 SL	10.71 a	0.96 d	11.46 b	4.09 a	49.17 a	72.30 b	43.20 a
Catucaí Amarelo 24/137	8.85 b	0.72 d	12.64 a	4.34 a	54.33 a	67.43 b	38.00 a
Catucaí Amarelo 20/15 cv 479	8.55 b	0.78 d	11.18 b	4.56 a	43.33 b	104.20 a	20.33 c
Catucaí Vermelho 785/15	8.21 b	2.41 b	3.61 c	3.36 b	35.67 b	33.63 d	32.40 b
Catucaí Vermelho 20/15 cv 476	10.07 a	0.83 d	12.41 a	4.59 a	52.33 a	49.87 c	42.13 a
Sabiá 398	7.10 c	0.56 d	13.04 a	4.30 a	51.83 a	66.07 b	21.40 c
Palma II	5.57 c	1.58 c	3.69 c	4.33 a	44.00 b	81.30 b	0.73 d
Acauã	8.77 b	3.37 a	2.95 c	3.99 b	36.83 b	93.43 a	3.07 d
Oeiras MG 6851	9.88 a	1.06 d	10.02 b	3.92 b	42.50 b	69.93 b	36.27 b
Catiguá MG 1	6.96 c	0.82 d	10.00 b	4.16 a	45.50 a	68.60 b	0.00 d
Sacramento MG 1	8.74 b	1.33 c	6.61 c	3.87 b	47.50 a	46.70 c	0.67 d
Catiguá MG 2	10.17 a	1.20 c	9.33 b	3.93 b	45.67 a	77.83 b	0.00 d
Araponga MG 1	8.35 b	0.80 d	10.54 b	3.92 b	40.33 b	96.90 a	3.00 d
Paraíso MG 1	9.86 a	0.94 d	10.61 b	4.07 a	42.33 b	77.63 b	0.13 d
Pau Brasil MG 1	7.85 c	1.76 c	4.30 c	4.11 a	50.17 a	74.93 b	0.00 d
Tupi IAC 1669-33	10.45 a	1.26 c	8.60 b	3.67 b	41.83 b	105.10 a	0.27 d
Obatã IAC 1669-20	5.91 c	1.00 d	5.99 c	4.19 a	41.17 b	56.23 c	1.07 d
Iapar 59	5.60 c	1.48 c	4.59 c	4.02 b	31.67 b	68.63 b	0.00 d
IPR 98	5.98 c	1.17 c	5.34 c	3.99 b	39.00 b	60.50 c	0.00 d
IPR 99	8.05 b	0.97 d	8.97 b	4.34 a	46.33 a	71.50 b	0.00 d
IPR 103	6.97 c	1.65 c	4.41 c	4.18 a	45.30 a	72.23 b	32.00 b
IPR 104	8.19 b	1.86 c	4.80 c	4.38 a	45.33 a	78.93 b	0.00 d
Catiguá MG 3	4.77 c	1.17 c	4.19 c	3.76 b	42.67 b	55.73 c	0.00 d
Topázio MG 1190	6.82 c	0.45 d	15.79 a	4.22 a	38.33 b	69.70 b	39.47 a
Catucai Vermelho IAC 144	8.89 b	0.84 d	9.97 b	3.66 b	41.33 b	46.73 c	41.33 a

Means followed by the same letter in columns do not differ by the Scott-Knott test at 5% probability.

According to Rezende et al. (2014), leaf area is related to yield crop. The estimated leaf area index is a central component of crop growth models, as well as for yield prediction (POCOCK; EVANS; MEMMOTT, 2010; WHITE et al., 2010). The results of our work corroborate partially with those found by these authors, since the cultivar *Catucaí Amarelo 20/15* cv. *479* showed higher leaf area index values and yield, showing that this parameter is a good indicator for predicting the yield of this cultivar. For the cultivars *Catucaí Amarelo 2 SL*, *Catucaí Amarelo 24/137*, *Catucaí Vermelho 20/15* cv. *476*, *Sabiá 398*, *Catiguá MG 1*, *Pau Brasil MG 1*, *IPR 99*, *IPR 103* and *IPR 104*, the leaf area index was directly related to the growth of plagiotropic branches (TABLE 1).

Plagiotropic branch length was higher in the following cultivars: *Catucaí Amarelo 2 SL*, *Catucaí Amarelo 24/137*, *and Catucaí Vermelho 20/15* cv. *476*, *Sabiá 398*, *Catiguá MG 1*, *Sacramento MG 1*, *Catiguá MG 2*, *Pau Brasil MG 1*, *IPR 99*, *IPR 103* and *IPR 104* (TABLE 1).

Carvalho et al. (2010) found that phenotypic traits such as number of plagiotropic branches, plant height and plagiotropic branch length showed high correlation with yield. These results do not corroborate with those observed in our work, once cultivars with great plagiotropic branch length showed low relationship with the highest yield observed (TABLE 1). This may occur because most of the cultivars with great plagiotropic branches had a higher leaf area index (TABLE 1), indicating an investment in vegetative growth in detriment to the reproductive growth.

For the variable yield (TABLE 1), four groups were designed. The ones with higher values for response to framework pruning were *Tupi IAC 1669-33*, *Catucaí Amarelo 20/15* cv. *479*, *Araponga MG 1* and *Acauã,* with 105.10, 104.20, 96.20 and 93.43 bags.ha^{-1}, respectively. They were followed by *Catucaí Amarelo 2 SL*, *Catucaí Amarelo24/137*, *Sabiá 398*, *Palma II*, *Oeiras MG 6851*, *Catiguá MG1*, *Catiguá MG2, Paraíso MG1*, *Pau Brasil MG1*, *Iapar 59*, *IPR 99, IPR 103, IPR 104* and *Topázio MG 1190* cultivars, which also showed satisfactory yield (TABLE 1). It was found that some cultivars obtained little response to this pruning, with lower yield, such as: *IPR 98*, *Obatã IAC 1669-20*, *Catiguá MG 3*, *Catucaí Vermelho 20/15* cv. *476*, *Catuaí Vermelho IAC 144*, *Sacramento MG 1* e *Catucaí Vermelho 785/15*, with yield of 60.50, 56.23, 55.73, 49.87, 46.73, 46.70, and 33.63 bags.ha^{-1}, respectively (TABLE 1).

The performance of certain cultivars after framework pruning was already evaluated in some studies. Carvalho et al. (2013) observed a satisfactory response to this pruning in progenies derived from the cross between *Mundo Novo* and *Catuaí*. Silva et al. (2016) analyzed the recovery capacity of four and a half years old coffee cultivars after framework pruning and verified that the *Sabiá 398*, *Topázio MG1190* and *Catiguá MG3* highlighted in the first biennium after pruning.

Carbon availability from the photosynthetic process for plant growth can be increased due to increasing photosynthesis depending on nutrient availability and the growth capacity of each species (KIRSCHBAUM, 2011). Photoassimilates produced along this process can be mainly redirected to the growth of reproductive organs such as beans (DING et al., 2007), resulting in higher yield and/or directed to vegetative organs such as leaves, stems and roots (COVRE et al. 2016), reflecting higher vegetative growth.

A different behavior of redirecting photoassimilates was observed in the cultivars that showed high net photosynthetic rates (TABLE 1). According to Covre et al. (2016), the reproductive growth of Coffea canephora limited the vegetative growth. The results found in the present work corroborate with this assertion for cultivars with the largest yield, *'Acauã'*, *'Araponga MG 1'* and *'Tupi IAC 1669-33'*, which showed lower vegetative growth, with small plagiotropic branch length and leaf area index in relation to others cultivars. Thus, it can be suggested that these cultivars may be a good option for the zero-crop system, in which cultivars are pruned again after harvesting, since they would possibly exhibit low yields in the following year due to their low vegetative growth.

The cultivar *Catuaí Amarelo 20/15* cv. *479*, which belongs to the group with higher yield, also obtained higher average values for leaf area index (TABLE 1). Therefore, this cultivar can be a good cultivar for management in which a programmed pruning system or pruning in longer cycles is used due to high vegetative growth combined with yield.

The cultivars that showed lower yield were: *Catucaí Vermelho 785/15*, *Catucaí Vermelho 20/15* cv. *476*, *Sacramento MG1*, *Obatã 1669-20*, *IPR 98*, *Catiguá MG 3* and *Catuaí Vermelho IAC 144* (TABLE 1). When was compared the net photosynthetic rate (A) with vegetative growth (PBL and LAI) and yield, it was found that, for these cultivars, targeting of photoassimilates may have predominated for vegetative organs. This is true, for example, for *Catucaí Vermelho 20/15* cv. *476*, *Sacramento MG1* and *Obatã 1669-20.* In addition, the photoassimilates production may have be insufficient for vegetative growth and a satisfactory yield, which is the case of *Catucaí Vermelho 785/15*, *IPR 98*, *Catiguá MG 3* and *Catuaí Vermelho IAC 144* cultivars.

Campostrini and Maestri (1998) performed studies comparing photosynthesis and yield of five coffee genotypes (*C. canephora*), observed that all genotypes showed the same photosynthetic efficiency, but obtained different yield levels, showing that the difference between these two variables may not be correlated.

Carvalho et al. (2012) found that, among leaf rust-resistant coffee plants, the *Catucaí Vermelho 785/15* cultivar showed yield below 44.9% in relation to the average of four crops from superior cultivars in the studied sites, and were not pruned. Such research corroborates with the results obtained in the present work, being that this cultivar showed a decreased yield of 66% in relation to the average of the group from superior cultivars after the first production after pruning.

For the leaf rust incidence (%), four groups were formed. *Catucaí Amarelo 2SL* (43.20%), *Catucaí Amarelo 24/137* (38.00%), and *Catucaí Vermelho 20/15* cv. *476* (42.13%) showed incidence equal to the susceptible patterns Topázio MG 1190 (39.47%) and Catuaí Vermelho IAC 144 (41.33%) (TABLE 1), evidencing the breakdown of their resistance by physiological races of fungi prevalent in the region.

Other cultivars, also considered as leaf rust-resistant, although not resembling the susceptible patterns, showed high disease incidence: *Catucaí Vermelho 785/15* (32.40%), *Oeiras MG* 6851 (36.27%), *IPR 103* (32.00%), *Sabiá 398* (21.40%) and *Catucaí Amarelo 20/15* cv. *479* (20.33%) (TABLE 1).

Cultivars from the *Catuaí* group, carrying only the SH 5 gene, are susceptible to the disease (SHIGUEOKA et al., 2014). Thus, some resistance gene of *Catucaí* ("Icatu" x "Catuaí") cultivars, different from SH 5, was completely broken by some *H. vastratrix* race (SERA et al., 2010).

There are also reports of the occurrence of resistance breakdown by new races in cultivars previously considered as leaf rust-resistant, including those originated from Catimor germplasm (VARZEA et al., 2002). Carvalho (2011) verified that the *Oeiras MG 6851* cultivar, released as leaf rust-resistant, show high susceptible to the disease, in addition to high deterioration and lower vegetative vigor.

Plants from the '*Híbrido de Timor*' have at least the major genes SH 5 to SH 9 (BETTENCOURT; LOPES; PALMA, 1992). Besides these ones already identified, it is likely that other genes will be present in these genotypes (VARZEA; MARQUES, 2005), conferring greater resistance to the materials coming from this crossbreed.

Observing the relationship between leaf rust-incidence and yield in coffee can be suggested that even cultivars that showed high or low disease incidence obtained different yields (TABLE 1). This fact can be explained due the fact that most part of studied materials showed leaf rust-resistance genes. Therefore, the leaf rust-incidence (fungal sporulation) may have occurred when the fruits already showed satisfactory fruiting filling, not influencing the leaf area index that could compromise the photoassimilates production that would be directed to fruit development. The high disease incidence affects mainly the production of the following year, since the loss of leaves decreases photoassimilates production and consequently the yield. This fact was verified in the present work, in which the annual yield was not compromised.

4 CONCLUSIONS

Cultivars such as *Catucaí Amarelo 20/15* cv. *479*, *Araponga MG1* and *Tupi IAC 1669-33* are highly responsive to framework pruning because they show high yield associated to high net photosynthetic rate and low transpiration rate. Moreover, the last two cultivars have a low leaf rust-incidence. The *Acauã* cultivar shows a good response to this pruning, showing high yield associated to the lower leaf rust-incidence.

Catucaí Vermelho 785/15 cultivar is not responsive to framework pruning showing lower yield, besides high leaf rust-incidence and low vegetative growth.

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CHARACTERIZATION OF THE COFFEE FRUIT DETACHMENT FORCE IN CROP SUBJECTED TO MECHANIZED HARVESTING

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ABSTRACT: In order to adjust the coffee harvester and to assist in deciding either whether or not to make a second pass of the harvester, fully or selectively, it is necessary to know some crop parameters. The aim of the present study was to evaluate the coffee fruit detachment force in the green and cherry ripeness, under different plant positions and in four evaluation periods, throughout the harvest period between the first and second pass of harvester. The cultivar used was the Catuaí Amarelo IAC 144 aged eight years in spacing 3.8 x 0.9 m. Detachment force was determined by sampling using a portable digital dynamometer. The green ripeness stage showed superior detachment force than the cherry for all evaluation periods. The fruit detachment force for the green and cherry ripeness showed a decreasing behavior during the evaluation period, since the difference between the detachment forces of these fruits increased, thus guiding the type of harvest to be performed. Beyond the fruit detachment force difference, other parameters such as fruit ripening rate and crop load were essential for harvest management. Significant variations were identified in the fruit detachment force positioned in different parts of the coffee tree branches. The results also reinforce the relevance of characterizing the coffee fruit detachment force for harvester adjustments and management of the selective mechanized harvesting.

Index terms: *Coffea arabica L.*, selective mechanized harvesting, ripeness.

CARACTERIZAÇÃO DA FORÇA DE DESPRENDIMENTO DOS FRUTOS DE CAFEEIROS EM LAVOURA SUBMETIDA À COLHEITA MECÂNICA

RESUMO: Para adequação das regulagens de colhedoras de café e auxiliar na decisão sobre se fazer uma segunda passada da colhedora, de forma plena ou seletiva, é necessário conhecer alguns parâmetros da cultura. Este trabalho foi conduzido com o objetivo de avaliar a força de desprendimento dos frutos de café nas maturações verde e cereja, em diferentes posições na planta e em quatro épocas de avaliação, compreendidas no período de colheita entre a primeira e segunda passada da colhedora. A cultivar utilizada foi a Catuaí vermelho IAC 144, com 8 anos de idade, no espaçamento 3,8 x 0,9 m. A determinação da força de desprendimento foi realizada através de amostragem utilizando um dinamômetro digital portátil. O estádio de maturação verde apresentou força de desprendimento superior ao cereja, para todas as épocas de avaliação. A força de desprendimento dos frutos para as maturações verde e cereja apresentou comportamento decrescente ao longo do período de avaliação, já a diferença entre as forças de desprendimento desses frutos aumentaram, orientando assim no tipo de colheita a ser realizada. Além da diferença na força de desprendimento dos frutos, outros parâmetros como proporção da maturação dos frutos e carga pendente da lavoura se apresentaram essenciais para o gerenciamento da colheita. Foi possível identificar variações significativas na força de desprendimento dos frutos posicionados em diferentes partes dos ramos do cafeeiro. Os resultados reforçam ainda a importância da caracterização da força de desprendimento dos frutos de café para ajustes da colhedora e gerenciamento da operação de colheita seletiva mecânica.

Termos para indexação: *Coffea arábica L.*, colheita seletiva mecanizada, maturação.

1 INTRODUCTION

The coffee is noteworthy worldwide for its socioeconomic importance in the most diverse sectors, being a product present for domestic consumption (FERREIRA JÚNIOR et al., 2016). Coffee growing is highly relevant for the Brazilian economy (SILVA et al., 2015) and, according to Trabaquini et al. (2010), is considered the base of the economy of several municipalities and regions of the country, although its cultivation has a high production cost (RIBEIRO et al., 2009).

The low labor availability for coffee cultivation, especially for the harvesting process that requires a great variety of services available in a short period (SILVA et al., 2014), the search for reducing the operating costs and improving the quality of final product have strengthened the use of mechanized harvesting, with more than one pass of harvester seeking the selectivity of harvested fruits (CUNHA et al., 2016; OLIVEIRA et al., 2007a; SILVA et al., 2000).

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In the selective harvesting, it is sought to collect only ripe fruits, leaving the green fruits in the plant. It requires higher operating speed and hence allows greater effective field capacity (CUNHA; SILVA; DIAS, 2016).

Selective mechanized harvesting of coffee provides batches that are more homogeneous, with greater maturation uniformity, favoring the postharvest process and allowing best final quality of the product.

According to Ferraz et al. (2012), one of the major difficulties for producers is determining the appropriate time to begin the harvest due to the plant shape, ripeness uniformity and the high water content of fruits, precluding the mechanized operation once the fruit is collected by vibration.

According to Silva et al. (2010), the fruit detachment force differs between green and cherry fruits, among cultivars and throughout the maturation period. Silva et al. (2013) showed that this force is an objective parameter that indicate the best time to start harvesting and a possible parameter for selective or full mechanized harvest management of the coffee plantation. Such detachment force is measured based on Hooke's Law, correlating the deformation of bodies with the force exerted on it, so that the force is proportional to the displacement from its equilibrium point (SILVA et al., 2010).

The mechanized harvesting of coffee is based on the vibration of harvester shank in contact with branches and fruits of the coffee tree. The inertial forces are applied to the fruit and overcome the stem attachment forces, resulting in the fruit detachment (ARISTIZÁBAL; OLIVEROS; ALVARES, 2003; OLIVEIRA et al., 2007b; SOUZA; QUEIROZ; RAFULL, 2006).

For Coelho et al. (2016), the natural frequencies of fruit-stem and fruit-stem-branch systems show a decreasing trend in response to the evolution of maturation process. The same authors state that the process of selective harvesting by mechanical vibration may become impossible when there is overlap of natural frequencies relatively to the green and ripe phases due to the variation in the physical and mechanical properties of the fruit peduncle system.

Ferreira Júnior, Silva and Ferreira (2016) reinforce the importance of understanding the behavior of harvest systems, i.e., the mechanical components of the harvester responsible for the transmission of vibration to the coffee fruits.

The knowledge on the trajectory performed by the coffee harvester shanks, besides their vibration amplitudes, effectively contributes to a better harvester adjustment (FERREIRA JÚNIOR; SILVA; FERREIRA, 2016). However, in order to develop efficient harvesters, it is necessary to understand the dynamic behavior of plant or parts to be harvested.

The present study aimed to evaluate the detachment force of coffee fruits (green and cherry) throughout the harvest period between the first and second pass of harvester and under different positions of the fruit in the plant, aiming to obtain information that aid in the management of selective mechanized harvesting of coffee.

2 MATERIAL AND METHODS

The experiment was performed during the 2016 harvest at Bela Vista Farm in the municipality of Nepomuceno, southern of the state of Minas Gerais, Brazil in a coffee area of 2.6 ha, whose geographical coordinates of the center area are 21°21'29.64" S, 45°17'34.53" W, and 958 m altitude. The cultivar used in the evaluations was the Catuaí IAC 144 (*Coffea arabica* L.), planted in January 2008 with 3.80 m spacing between streets and 0.90 m between plants. The average height of plants was 2.20 m and average canopy width of 1.10 m.

Generally, the mechanized harvest with self-propelling harvester is used in the property, performing two or more passes of the harvester in a same plot. The ripeness of fruits is the criterion used to decide when to start the first and second pass of the harvester.

The sampling for determination of crop load was performed in five points distributed within the area, containing five plants from a same line every plot. The manual harvest was performed on cloth, followed by the average volume of fruits harvested in liters per plant for each point and later the average between the crop load of five points. The ripening rate for each sample was obtained by taking two 0.5 L samples of fruits harvested at each point (CARVALHO et al., 2003; SILVA, 2008; SILVA et al., 2015), separating the green, cherry, and raisin and/or dried fruits , Subsequently, the average of those ripeness were performed for the 10 collected samples. Although raisin and dried fruits are from different ripeness stages, they are considered as buoyant fruits in the postharvest process and they easily detach from the branches during harvesting, thus being added and quantified as a single ripeness (raisins and/or dried).

Before the first pass, the crop had an average crop load of 7.6 L per plant and ripeness of 42.5% green, 23.7% cherry and 33.8% raisins and dried fruits. On the second pass of the harvester, the crop showed an average crop load of 4.0 L per plant and ripeness of 10.9% green, 52.8% cherry and 36.3% raisins and dried fruits.

The evaluations occurred for 29 days between the first and second pass of the harvester, and were divided into 7-day intervals, called evaluation periods, being the periods 1, 2, 3 and 4 corresponding to days July 14, July 21, July 28 and August 3, respectively.

The experimental design was the completely randomized design (DIC) within a single plot, in random plots containing five plants. A split-plot in time was designed, being two positions and two ripeness types with 20 repetitions each.

For each plant, the coffee fruit detachment force (FDF) was measured for green and cherry ripeness. The FDF was determined using a Portable Digital Dynamometer manufactured and marketed by the company Instruterm, model DD 200.

The determination of the FDF of green and cherry fruits, as well as the behavior of this force in fruits from different parts along the plant height become essential for harvester adjustments in the selective mechanized harvesting.

Thus, the FDF of each demarcated plant was performed in two parts of the plant: upper middle (U) and lower middle (L) of the plant. These parts were taken on two sides of the plant: the east and the west side of the same (perpendicular to the planting line). Moreover, the FDF of eight coffee fruits per plant were evaluated, being two green fruits and two cherry fruits both in the upper middle and in the lower middle of the plant.

During the first three evaluations, a difference in the volume of fruits that remained in the primary and secondary branches after the first pass of harvester was observed. Therefore, the FDF (green and cherry) was evaluated only in the last collection period (4), under the same conditions (U and L parts of the plant), but in the fruits of the primary (P) and secondary (S) plagiotropic branches.

The data collected in the field were organized in a spreadsheet in order to determine the average and the coefficient of variation of the FDF replications, within each evaluated ripeness stage.

The analyses were performed in a split-plot in time with the R statistical software (R CORE TEAM, 2016). The statistical model for the split-plot design in CRD for the FDF variable is given by (HINKELMANN; KEMPTHORNE, 2008):

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \gamma_{l(ij)} + \delta_k + \alpha\delta_{ik} + \beta\delta_{jk} + \alpha\beta\delta_{ijk} + \varepsilon_{ijk}, \quad (1)$$

where,

y_{ijk} is the observed value of the detachment force variable of the *i*-th position in the *j*-th ripeness stage in the *k*-th evaluation period in the *l*-th repetition, with *i=1,2 , j=1, 2, k=1,2,3,4* and *l=1,2,...20*;

μ is a constant inherent to all the observations;

α_i is the effect of the *i*-th position;

$\beta_{ik}\ \beta_{ik}\beta_j$ is the effect of the *j*-th ripeness stage;

$\alpha\beta_{ij}$ is the effect of the position x ripeness stage interaction;

$\gamma_{l(ij)}$ is the experimental error at plot level;

δ_k is the effect of the *k*-th evaluation period;

$\alpha\delta_{ik}$ is the effect of the position x evaluation period interaction;

$\beta\delta_{jk}$ is the effect of the ripeness stage x evaluation period interaction;

$\alpha\beta\delta_{ijk}$ is the effect of the position x ripeness stage x evaluation period interaction;

ε_{ijkl} is the experimental error at subplot level.

3 RESULTS AND DISCUSSION

The results of the FDF effect for the green and cherry ripeness in the lower and upper positions referring to the four evaluation periods are presented in Table 1. No significant difference was observed in the interaction between ripeness stage (R) x position (P) and evaluation period (EP), with p-value=0.9620 as well as for the double interactions ripeness stage (R) x position (P), with p-value=0.2611; ripeness stage (R) x evaluation period (EP), with p-value=0.3140; and position (P) x evaluation period (EP), with p-value=0.8170. There was no significant difference between the positions with p value=0.0929; for the ripeness stage, there was a significant difference, with p-value <2 x 10-16; finally, there was a significant effect for each evaluation period, with p-value=7.51 x 10-10 for the FDF variable of Coffea arabica cv. Catuaí Vermelho (Table 1).

TABLE 1 - Effect of FDF on different ripeness stages (green and cherry) and positions in the plant (lower and upper) for the cultivar Catuaí Vermelho referring to the four evaluation periods.

Factor		Evaluation period 1	2	3	4	Overall average[1]
Ripeness (R)	Green (G)	8.32	8.38	7.08	7.04	7.71a
	Cherry (C)	5.52	5.08	3.46	3.00	4.27b
	Force difference (FD)	2.8	3.3	3.62	4.04	3.44
Position (P)	Lower (L)	6.76	6.75	5.05	4.73	5.82 a
	Upper (U)	7.09	6.72	5.50	5.32	6.15 a
Evaluation period (EP)[2]		6.92 a	6.73 b	5.27 c	5.02 d	

Significance levels of the F test (p-values)

Factors	F	P-Value
R	305.47	$<2 \times 10^{-16*}$
P	2.89	0.0929[ns]
EP	16.71	$7.51 \times 10^{-10*}$
R x P	1.28	0.2611[ns]
R x EP	1.19	0.3140[ns]
P x EP	0.31	0.8170[ns]
R x P x EP	0.09	0.9620[ns]

[1]Averages followed by different letters on the columns are statistically different by Tukey test (P<0.05). [2]Averages followed by different letters on the rows are statistically different by Tukey test (P<0.05). [ns]: not significant at 5% by F test; [*]: significant at 5% by F test.

It can be verified that the average detachment force between the green and cherry ripeness stages differed significantly by Tukey test. The green ripeness stage showed a higher average FDF value in relation to the cherry, corroborating with the results obtained by Silva (2008, 2012) and Silva et al. (2010, 2013, 2016).

Silva et al. (2010) evaluated the FDF of the coffee tree for five periods along a harvest and observed that the average detachment force of green and cherries fruits was 9.6 N and 6.36 N, respectively, for the same cultivar (Catuaí Vermelho 144). The detachment forces found in the present study showed lower average values (around 2 N) than the found by Silva et al. (2010) for both ripeness evaluated (Table 1). This may have been a consequence of different climate conditions, the flowering or collection season, plant nutritional status and small variation of the dynamometer position in relation to the sampled fruit (Silva et al., 2013, 2016).

The average FDF value for each evaluation period throughout the evaluation periods reduced from 6.92 N to 5.02 N, according to the Tukey test (Table 1).

In Figure 1 is shown the average FDF values for green and cherry ripeness stages and the difference with each other throughout the evaluation periods.

Despite the non-significance of the ripeness stage x evaluation period interaction, a greater reduction in the average value of the force between the evaluation periods 2 and 3 was observed in Figure 1, decreasing from 8.37 to 7.08 N for the green and from 5.08 to 3.46 N for the cherry fruits.

In Table 1 is presented that green and cherry FDF values decreased throughout the evaluation periods, reducing from 8.32 to 7.04 N for green and from 5.52 to 3.00 N for cherry ripeness. The FDF difference between the green and cherry ripeness showed increasing values during the evaluation periods due to the lower ripening rate of green fruits in relation to the cherries. This behavior is evidenced in Figure 1.

It is worth pointing out that, among the performed evaluations, the evaluation period 4 showed a higher average value in the difference between green and cherry FDF (4.04 N), a behavior that according to Silva et al. (2016) enhances the selective and mechanized harvesting, since this parameter becomes a selectivity criterion between the fruit ripeness, favoring the removal of cherry fruits of the plant.

Such criterion can aid in the difficulty faced by coffee growers in defining the best time to start the harvesting, cited by Ferraz et al. (2012). Other situations that can be favored, in which the coffee growers also present difficulties, is in defining for full or selective harvesting and in defining how many times the harvester must pass in the crop.

Silva (2008), through experimentation, defined as a parameter to aid in the decision for full or selective harvesting, the average value of the detachment force difference between green and cherry fruits, being 3.0 N the parameter value of difference; if the difference found is above this value, selective harvesting is recommended, otherwise, full harvesting is indicated.

In the present study, evaluation periods 2, 3, and 4 showed average values in the FDF difference above 3.0 N (Table 1) and, based on the Silva parameter (2008), a selective harvesting would be indicated for these three evaluations.

Taking into account that the average value of the difference between green and cherry FDF increased throughout the evaluation periods (Figure 1), other parameters that supported the decision-making were the rate of green fruits present in the crop at that time and the crop load. At evaluation period 4, although the force difference between the ripeness was 4.04 N, the crop showed 10.2% green fruits and 75.4% ripe fruits for an average crop load of 3.6 L per plant, being not viable for the producer to perform a selective harvesting in the second pass of the harvester, thus opting for the full harvest.

In the condition of few green fruits as presented in the evaluation period 4, a second pass of the harvester selectively would tend to leave few fruits in the plant for the third pass, which could not be profitable.

Thus, besides studying the difference in the detachment force between green and cherry fruits, other factors such as ripening rate and crop load should also be considered in decision-making for more than one pass of the harvester.

This information is extremely important for the management of mechanized harvesting of coffee, since it can be correlated with the recommendation results of mechanized harvesting based on the dynamic behavior of the vibrating shanks of the harvester, such as the results found by Ferreira Júnior, Silva and Ferreira (2016), showing differences in the ranges reached by vibrating shanks, varying the oscillator cylinder vibration, cylinder brake torque and shank length along this cylinder.

Souza et al. (2005) report that the influence of the ripeness stage on fruit detachment period indicates that the vibration time is a parameter that should be considered in the selective harvesting of coffee fruits.

In the selective mechanized harvesting, it is common to remove the shanks from part of vibrating cylinders precisely at the height when the plant has greater amount of green fruits, avoiding to harvest these fruits and seeking to harvest the maximum of cherry fruits. However, when fruit ripeness is non-uninform along the plant, this practice becomes unviable. The results of the present study indicated that it was not necessary to remove the shanks from the cylinders, since there was no significant difference of FDF between the upper and lower parts of the plant (Table 1).

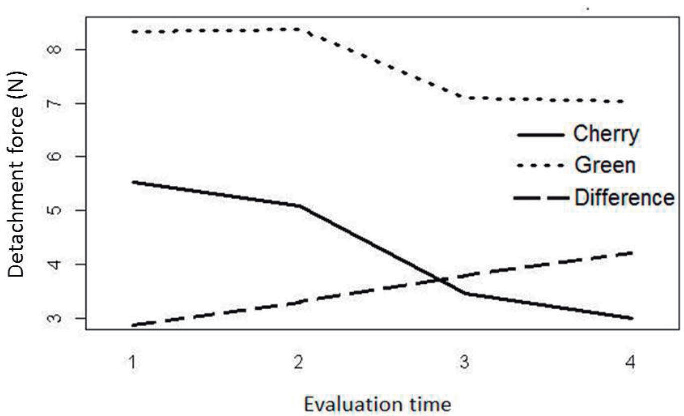

FIGURE 1 - Behavior of green and cherry FDF and the difference of such force among the evaluated stages throughout evaluation periods.

The FDF behavior is characterized in Table 2, showing average values for each ripeness stages in the studied plant positions and the difference in the average FDF value between the green and cherry ripeness stages.

The FDF difference between ripeness is presented in detail for the upper and lower parts of the plant, observing an increase throughout the evaluated periods (Table 2).

Important recommendations for the selective or full mechanized harvesting of coffee, such as the orientation of the arrangement of vibrating shanks along the cylinder and the shank sizes, can be influenced by characterizing the FDF throughout the plant.

When evaluating the FDF in first- and second-order plagiotropic branches (PB), there was no significant difference between the U and L positions (P), with p-value=0.09499, and for the effect of ripeness stage (R), there was significant difference with p-value $<2 \times 10^{-16}$. However, no significant difference was found for the position (P) *x* ripeness stage (R) interaction, with p-value=0.3257. For the effect of plagiotropic branches (PB), there was significant difference, with p-value=0.000591. No significant difference was found for the position (P) x plagiotropic branch (PB) interaction, with p-value=0.414946, nor for the ripeness stage (R) x plagiotropic branch (PB) interaction, with p-value=0.731095. There was also no significant difference for the triple interaction position (P) x ripeness stage (R) x plagiotropic branch (PB), with p-value=0.743464. Data are presented in Table 3.

The results showed that the second-order plagiotropic branches showed fruits with higher average values in the detachment force (Table 3), i.e., greater detachment resistance, being statistically different by Tukey test. On the other hand, the fruits from the first-order branches showed the lowest values of FDF.

In the green ripeness, the forces were 6.53 N and 7.54 N for fruits from the first- and second-order branches, respectively. In the cherry ripeness, the forces were 2.52 N and 3.36 N for fruits from the first- and second-order branches, respectively.

The characterization of green and cherry FDF in the different studied plant positions (L and U) and the average force difference between ripeness stages is generally presented in Table 4.

It was observed that these FDF differences between green and cherry ripeness exceeded the parameter value of 3.00 N suggested by Silva (2008) in both evaluated branches (F and S) and plant position (upper and lower) (Table 4).

The FDF behavior in the first- and second-order order branches for the upper and lower parts is shown in Figure 2.

It is also possible to verify that the higher FDF were obtained for fruits positioned in second-order branches and the smaller forces were obtained in the first-order branches (Figure 2).

There is coffee fruit detachment when the inertial forces resulting from movement in the fruit become greater than the tensile strength necessary to cause detachment (PARCHOMCHUK; COOKE, 1971).

TABLE 2 - Average FDF values of Catuaí cultivar in the green and cherry ripeness stages, at upper and lower plant positions and average value of the force difference between ripeness for the four evaluation periods.

	Evaluation period			
Ripeness / Plant position	1	2	3	4
Green / Upper	8.53	8.43	7.51	7.47
Green / Lower	8.13	8.32	6.67	6.60
Cherry / Upper	5.66	5.00	3.49	3.16
Cherry / Lower	5.39	5.18	3.44	2.85
Force difference between the green and cherry stages positioned in the upper part	2.87	3.43	4.02	4.31
Force difference between the green and cherry stages positioned in the lower part	2.74	3.14	3.23	3.75

TABLE 3 - Effect of the FDF of coffee from the Catuaí Vermelho cultivar at different ripeness stages (green and cherry), plant positions (lower and upper) and in the different plagiotropic branches.

Factor		Plagiotropic branch		Overall average[1]
		Primary	Secondary	
Ripeness (R)	Green (G)	6.53	7.54	7.04a
	Cherry (C)	2.52	3.36	2.94b
	Force difference (FD)	4.01	4.18	4.99
Position (P)	Lower (L)	4.36	5.07	4.71 a
	Upper (U)	4.69	5.83	5.26 a
Plagiotropic branch (PB)[2]		4.52 b	5.45 a	

Significance levels of the F test (p-values)

Factors	F	P-Value
R	158.069	$<2 \times 10^{-16*}$
P	2.860	0.09499^{ns}
PB	12.859	0.000591^{*}
R x P	0.978	0.3257^{ns}
R x PB	0.119	0.731095^{ns}
P x PB	0.672	0.414946^{ns}
R x P x PB	0.108	0.743464^{ns}

[1]Averages followed by different letters on the columns are statistically different by Tukey test (P<0.05). [2]Averages followed by different letters on the rows are statistically different by Tukey test (P<0.05). ^{ns}: not significant at 5% by F test; *: significant at 5% by F test.

TABLE 4 - Average detachment force of coffee fruits from the Catuaí cultivar in the green and cherry ripeness stages, at the upper and lower middle position and in the first- and second-order plagiotropic branches.

Ripeness / Plant position	Plagiotropic branch	
	First (F)	Second (S)
Green / Upper	6.90	8.05
Green / Lower	6.16	7.05
Cherry / Upper	2.49	3.62
Cherry / Lower	2.56	3.10
Force difference between the green and cherry stages positioned in the upper part	4.41	4.43
Force difference between the green and cherry stages positioned in the lower part	3.60	3.95

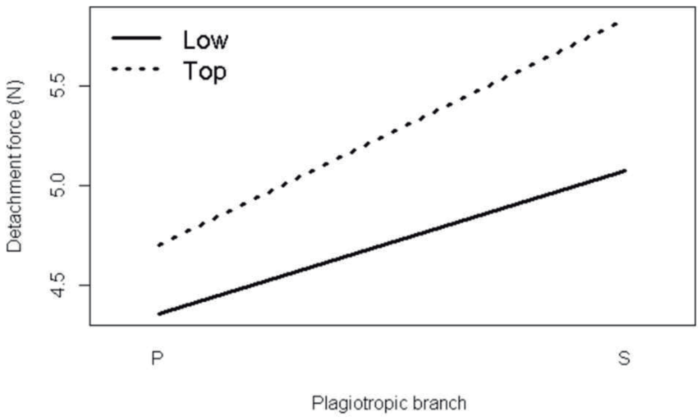

FIGURE 2 - FDF behavior in the first- (F) and second-order (S) branches for the upper and lower plant positions, regardless of fruit ripeness.

For the studied Catuaí cultivar, the results indicate the vibrational energy, i.e., the necessary tensile strength to harvest the fruits positioned in the second-order branches should be greater in relation to the first-order fruits, since its FDF was greater in relation to the fruits from the first-order branches.

However, there are still devices and resources in the coffee harvesters that provide harvesting by localized vibrational energy to the fruits in different branches of the plant. However, the study serves as basis for the development of new equipment and as guidance for a possible selective harvesting with portable harvesters, enabling "vibrating fingers" that directed to the desired position in the plant.

4 CONCLUSIONS

The average fruit detachment force for the green and cherry ripeness reduced throughout the evaluation periods, but the average value of the force difference between ripeness stages increased.

The average value of the detachment force difference between the green and cherry ripeness was considered together with the rate of green fruits present in the crop and mean crop load, being as a set of parameters that aid in the decision to perform the full harvest in the second pass, thus closing the harvest.

The fruits of the second-order plagiotropic branches were statistically different, showing the highest values for the detachment force in both ripeness stages.

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ALTERNATIVE SUBSTRATES IN DIFFERENT CONTAINERS FOR PRODUCTION OF CONILON COFFEE SEEDLINGS

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ABSTRACT: Different substrates and containers influence the production of coffee seedlings, which can reduce production costs, both with alternative substrates and with containers of smaller volumes of substrates. The aim the present study was to evaluate the viability of alternative substrates in different containers for production of Conilon coffee (Coffea canephora Pierre ex Froehner) seedlings in the nursery of the Federal Institute of Espírito Santo - Campus of Alegre, ES, Brazil. The experimental design was a randomized complete block design with three replications, in split-plot with three plots and four subplots. The plots consisted of three containers (120 cm³ tube, 280 cm³ tube and 615 cm³ bag), and the subplots of four substrates (S1 - Conventional, S2 - Legume compost, S3 - Grass compost, S4 - Vermicompost). At 165 days after sowing, the evaluated variables were shoot and root dry mass, number of leaves, shoot height, leaf area, Dickson quality index, shoot/root ratio, root length, nitrogen and total crude protein. The alternative substrates (Legume compost, Grass compost and Vermicompost) were efficient for production of Conilon coffee seedlings and can replace the conventional substrate at this development stage, providing good quality seedlings. The major developments were observed in the containers with the highest volume (280 cm³ tube and 615 cm³ bag) and reflected directly on the quality of seedlings.

Index terms: *Coffea canephora*, development, alternative compost.

SUBSTRATOS ALTERNATIVOS EM DIFERENTES RECIPIENTES NA PRODUÇÃO DE MUDAS DO CAFEEIRO CONILON

RESUMO: Diferentes substratos e recipientes influenciam a produção de mudas de cafeeiro, podendo reduzir custos de produção, tanto com substratos alternativos quanto com recipientes de menores volumes de substratos. Objetivando avaliar a viabilidade de substratos alternativos em diferentes recipientes na produção de mudas do cafeeiro conilon (Coffea canephora Pierre ex Froehner), realizou-se o presente trabalho no viveiro do Instituto Federal do Espírito Santo - Campus de Alegre. O delineamento experimental utilizado foi em blocos casualizados, com 3 repetições, em parcela subdividida, com 3 parcelas e 4 subparcelas. As parcelas foram constituídas por 3 recipientes (tubete de 120 cm³, tubete de 280 cm³ e sacola de 615 cm³), e as subparcelas por 4 substratos (S1 - Convencional; S2 - Composto de leguminosa; S3 - Composto de gramínea; S4 - Vermicomposto). Aos 165 dias após a semeadura as variáveis avaliadas foram: massa seca da parte aérea e raiz, número de folhas, altura da parte aérea, área foliar, índice de qualidade de Dickson, relação parte aérea/raiz, comprimento da raiz, nitrogênio e proteína bruta total. Os substratos alternativos (Composto de leguminosa; Composto de gramínea e Vermicomposto) foram eficientes na produção de mudas de cafeeiro conilon e podem substituir o substrato convencional nesta fase do desenvolvimento, proporcionando mudas de boa qualidade. Os maiores desenvolvimentos foram observados nos recipientes de maior volume (tubete de 280 cm³ e sacola de 615 cm³) e refletiram diretamente na qualidade das mudas.

Termo para indexação: *Coffea canephora*, desenvolvimento, composto alternativo.

1 INTRODUCTION

The quality of seedling is linked directly to the productivity and quality of the final product (TRAZZI et al., 2013). For the Brazilian coffee growing, the quality of Conilon coffee (*Coffea canephora* Pierre ex Froehner) seedling is extremely important, since it undergoes major transformations such as the increasing planted area, renewal of the coffee plantation and adaptation to the current planting systems. Thereby, the planting of vigorous coffee seedlings is fundamental for a good setting, reducing the expenses with the replanting operation and contributing to the rapid initial growth of seedlings in the field (ALVES; GUIMARÃES, 2010; CARVALHO et al., 2008).

The technology of coffee seedling production has been changed with research to determine the type of container, substrate, time and management of the fertilization and irrigation ideal for its quality production (HENRIQUE et al., 2011). The most commonly used containers are

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plastic bags filled with substrate formed by soil and cow dung (7:3 ratio) and polyethylene tubes with different dimensions, using a commercial substrate (VALLONE et al., 2010; VALLONE; GUIMARÃES; MENDES, 2010).

For container types and volumes, Silva et al. (2010) and Vallone, Guimarães and Mendes (2010) sought to define an ideal set, associating quality with reduced production cost providing a better development to the coffee plants. According to Silva et al. (2010), soil block (60 x 40 x 15 cm), polyethylene bag (18 cm height x 10 cm diameter) and large tube (120 ml) are the most suitable containers for the production of *C. canephora* seedlings.

Regarding the substrate, Vallone, Guimarães and Mendes (2010) reported that the mixture of organic wastes to the substrate improves their chemical, physical and biological characteristics, providing an adequate environment for roots and plant as a whole, notably in its initial development, reducing the soil usage and hence avoiding the contamination risks by pests and diseases. Thus, the substrates should have good characteristics such as adequate porosity, high cation exchange capacity, good water retention, and must be produced in a sustainable way with economic viability (ALMEIDA et al., 2011).

It is necessary the use plant and animal residues in the preparation of substrates for the production of agricultural seedlings, besides giving adequate destination to them. According to Caldeira et al. (2008), organic matter is one of the fundamental constituents of substrates, whose basic purpose is to increase the water retention capacity and availability of nutrients to the seedlings.

Based on the usage relevance of alternative residues for the production of agricultural seedlings and the effect of the container on the production of seedlings, the present study aimed to evaluate the effects of alternative substrates in different containers for production of Conilon coffee seedlings.

2 MATERIAL AND METHODS

The experiment was carried out at the Federal Institute of Espírito Santo (IFES) - Campus of Alegre, in the city of Alegre, ES, Brazil, in a seedling nursery built with bamboo structure and covered with 50% shade net. The nursery has as geographic coordinates 20º45'44" S, 41º27'43" W, and 134 m altitude. According to Köppen classification, the climate of the region is "Aw" type, dry winter and rainy summer with annual average temperature of 23 ºC and annual rainfall around 1,200 mm. The rainy season in the region is concentrated from November to March.

The experimental design was a randomized complete block design with three replications, in split-plot with three plots and four subplots. The plots consisted of three containers (120 cm³ tube, 280 cm³ tube and 615 cm³ polyethylene bag), and the subplots of four substrates (S1 - Conventional, S2 - Legume + dried cow dung compost, S3 – Grass + cow dung compost, S4 - Vermicompost). The used containers have the primary characteristic of non-releasing toxins in the culture substrate. The experimental plot consisted of 20 plants, being used the average of three plants, discarding the edge.

The used substrates were: S1 - Conventional - made with ravine land with cow dung at 3:1 ratio (v/v) added with N-P-K fertilization recommended for the crop (PREZOTTI et al., 2007); S2 - Organic compost of legume, constituted based on legume (pigeon pea) with cow dung at of 1:1 ratio (v/v) after the maturation process of the material reaching 90 days; S3 - Organic compost of grass derived from the compost process of cow dung and grass clippings at 1:1 ratio (v/v), as described by Souza et al. (2013); and S4 - Vermicompost, prepared after the maturation process of the organic compost (grass and dried cow dung), using redworms (*Eisenia foetida*) throughout 60 days for the vermicompost process.

The substrates were characterized through a chemical analysis in the Soil Fertility Laboratory of the Department of Soils of the Federal Rural University of Rio de Janeiro, RJ, Brazil (Table 1).

The "EMCAPER 8151 - Robusta Tropical" cultivar was evaluated. Two seeds were used per container, sowed at 1.0 cm depth. The thinning was performed soon after the first pair of true leaves emerged, removing the less vigorous plants (MATTIELO et al., 2005).

Irrigations were performed twice a day (morning and afternoon) by micro-sprinkling until the end of the experimental phase. At 165 days after sowing, the evaluated characteristics were shoot and root dry mass (g plant^{-1}), number of leaves, shoot height (cm plant^{-1}), leaf area (cm² plant^{-1}), Dickson quality index, shoot/root ratio, root length (cm plant^{-1}), total nitrogen (% plant^{-1}) and total crude protein (% plant^{-1}). Root length was measured with graduated scale, measuring the pivoting root.

TABLE 1 - Chemical characterization of substrates used for production of Conilon coffee seedlings

Substrates	N	P_2O_5	K_2O	Mg	Ca	C	pH in water
		mg dm^{-3}		cmol$_c$ dm^{-3}		g kg^{-1}	
S1	18	38	18.07	5	26	40.7	6.2
S2	33	28.1	15.36	5.7	2.9	158	8.8
S3	15	16	30.6	5.3	27.9	62	7.4
S4	15	36.3	36.72	7.9	5.3	113	6.7

S1 - Conventional; S2 - Legume + dried cow dung compost; S3 - Grass + dried cow dung compost; S4 - Vermicompost.

The shoot and root dry mass were obtained in digital scale after drying in a convection oven at 75 °C until constant weight. The height was measured with a millimeter ruler, considering the region between the collar and the apical bud.

Leaf area (LA) was measured by the mathematical model $AF = 0{,}2027\ CNC^{2{,}1336}$ $AF = 0{,}2027\ CNC^{2{,}1336}$ (PARTELLI et al., 2006), where ML is the midrib length.

The Dickson quality index was obtained by the formula: DQI = [total dry mass / (height/diameter ratio + shoot/root ratio)] recommended by Dickson, Leaf and Hosner (1960).

The total nitrogen was obtained by the Kjeldahl method based on the decomposition of organic matter by digesting the sample at 400 ^{0}C with concentrated sulfuric acid in the presence of copper sulphate as a catalyst that accelerates the oxidation of organic matter. The nitrogen present in the resulting acid solution was determined by steam distillation followed by titration with diluted acid (NOGUEIRA; SOUZA, 2005).

The protein content of a food is measured from the nitrogen content present in the analyzed sample. The analysis is performed by the Kjeldahl method and the obtained nitrogen percentage is multiplied by 6.25 and then expressed as crude protein (CP). This analysis is because all proteins have 16% nitrogen, and that all nitrogen in the food is in protein form (NOGUEIRA; SOUZA, 2005).

The expression (TCP = TN x F_N) was used to determine the total crude protein (TCP), where TN is the total nitrogen and F_N is the factor of 6.25 (NOGUEIRA; SOUZA, 2005).

The data were subjected to analysis of variance and mean test, with means grouped by the Scott-Knott test at 5% probability, using SISVAR software version 5.3 (FERREIRA, 2011).

3 RESULTS AND DISCUSSION

According to the analysis of variance (Table 2) there was a significant container x substrate interaction for the number of leaves, Conilon coffee height, root length and total nitrogen. For the other variables, there was no significant effect.

When evaluating the significant effect of the isolated factors, it was noted that only the root length and the Dickson quality index had a significant effect for the substrate factor. For the container factor, the variables had a significant effect, except for the SDM/RDM ratio.

According to Table 3, when evaluating the number of leaves, it was noted that there was no significant difference for the Cont. 1 and 2 within the substrates. However, the Cont. 3 showed significance in the substrates S1 and S2 (17.00 and 16.00 leaves, respectively), differing statistically from S3 and S4 (11.67 and 14.00 leaves, respectively). The results demonstrate the S2 potential to replace the commercial substrate for production of seedlings.

Different substrates for production of seedlings still need further studies aiming at alternative means for the producer. Dias et al. (2009) added 40% turkey litter to the conventional substrate and found favoring development of coffee seedlings, while the cow dung when added to the conventional substrate hindered the development of seedlings, regardless of its proportion.

When evaluating the effect of container on the number of leaves, it is evident that the increased volume of the same favored greater development, once the Cont. 2 and 3, tube and bag provided higher values of this variable.

Similar result was verified by Vallone et al. (2009). When evaluating different containers for production of Arabica coffee (*Coffea arabica*) seedlings, the authors concluded that seedlings produced in polyethylene bags (700 mL) and in a 120 mL tube, using standard substrate, were superior to the derived from seedlings produced in 50 mL tubes.

TABLE 2 - Summary of the analysis of variance of the interaction between container and substrate (Cont.*Sub.), indicating the coefficients of variation (CV), degrees of freedom (GL) and the mean squares of response variables

Source of variation	GL	Mean square				
		SHDM	RDM	NL	HGT	LA
Container (Cont.)	2	13.81**	0.80**	84.00**	824.77**	3673.39**
Error 1	6	0.12	0.06	3.67	12.29	90.63
Substrate (Sub.)	3	0.69^{ns}	0.10^{ns}	0.81^{ns}	41.27^{ns}	133.22^{ns}
Cont.*Sub.	6	0.98^{ns}	0.06^{ns}	12.48*	41.11*	530.51^{ns}
Block	2	0.10^{ns}	0.03^{ns}	4.08^{ns}	6.67^{ns}	142.60^{ns}
Error 2	16	0.91	0.22	4.03	13.61	403.84
Total	35					
Overall average		1.92	0.71	13.67	22.39	38.00
CV 1 (%)		18.49	34.23	14.01	15.66	25.05
CV 2 (%)		49.88	66.61	14.69	16.48	52.88
		DQI	SDM/RDM	RS	TN	TCP
Container (Cont.)	2	0.02^{ns}	6.47^{ns}	208.44**	917.65**	3689.12**
Error 1	6	0.01	2.00	18.31	47.68	90.90
Substrate (Sub.)	3	0.03*	0.86^{ns}	34.03*	22.71^{ns}	131.27^{ns}
Cont.*Sub.	6	0.01^{ns}	4.16^{ns}	22.30*	156.16**	527.46^{ns}
Block	2	0.00^{ns}	0.11^{ns}	3.69^{ns}	9.87^{ns}	143.27^{ns}
Error2	16	0.01	0.27	6.44	27.87	403.84
Total	35					
Overall average		0.19	2.93	19.19	24.96	38.19
CV 1 (%)		53.03	48.29	22.19	27.67	24.96
CV 2 (%)		45.70	51.51	13.22	21.15	52.62

** and * significant by F test at 1% and 5% probability, respectively. ^{ns} - not significant; SDM - shoot dry mass; RDM - root dry mass; NL - Number of leaves; PH - height; LA - leaf area; DQI - Dickson quality score; SDM/RDM - ratio between shoot dry mass and root dry mass; RL - root length; TN - total nitrogen; and TCP - total crude protein.

TABLE 3 - Number of leaves (NL) and plant height (PH) of Conilon coffee seedlings in different substrates and containers

Substrates	NL			PH (cm plant^{-1})		
	Cont. 1	Cont. 2	Cont. 3	Cont. 1	Cont. 2	Cont. 3
S1	9.67Ab	14.67Aa	17.00Aa	11.83Ac	19.83Bb	34.17Aa
S2	11.33Ab	14.00Aa	16.00Aa	14.50Ab	29.00Aa	31.83Aa
S3	10.67Ab	17.33Aa	11.67Bb	12.83Ab	23.50Ba	24.00Ba
S4	11.00Ab	16.67Aa	14.00Ba	15.50Ab	20.50Bb	30.67Aa

S1 - Conventional; S2 - Legume + dried cow dung compost; S3 - Grass + dried cow dung compost; S4 - Vermicompost. Cont. 1 - tube (120 cm³); Cont. 2 - tube (280 cm³); Cont. 3 - bag (615 cm³).

Averages followed by the same capital letters on the columns and lowercase on the rows belong to the same group by Scott-Knott test ($p \leq 0.05$).

For plant height, that there was no significant difference between the substrates in the Cont. 1. In the Cont. 2, the highest average was in S2 (29 cm plant^{-1}), differing statistically from the others. In the Cont. 3, the statistically superior averages were found in S1, S2 and S4 (34.17, 31.83 and 30.67 cm plant^{-1}, respectively). The grass + cow dung compost (S3) provided lower plant height (24.00 cm plant^{-1}).

It is evidenced the effect of the container in the development of Conilon coffee height, once the greater averages were found in Cont. 3, showing the highest volumetric capacity (615 cm^3) in relation to Cont. 1 and 2 (120 and 280 cm^3, respectively).

In S2 and S3, the Cont. 2 and 3 were statistically superior to Cont. 1. In S1 and S4, the highest average was obtained in Cont. 3 (34.17 and 30.67 cm plant^{-1}, respectively), differing from the others.

For Dias et al. (2009), the volumetric capacity of containers directly influence the plant development, altering their physiological development. The authors also highlight that the number of leaf pairs should be a variable to define the management of seedlings under nursery conditions and their acclimatization for field planting.

When the root length was evaluated (Table 4), it was observed that there was statistical difference only for Cont. 2 within S4, whose average was 21.17 cm plant^{-1}, differing from the others. When the effect of the container on root development was studied, it is noted that Cont. 3 presented the highest averages of this variable in the majority of treatments, following a certain tendency of root growth with increasing substrate volume.

The good root development is a key factor for the good setting of coffee seedlings in the field. According to Vallone et al. (2009), coffee seedlings produced in higher volume containers (120 and 700 cm³) will have superior development in the field in relation to the smaller ones (50 cm³).

A higher growth and distribution of the root system provides a greater absorption of water and nutrients by the plant, besides a lower susceptibility to soil water deficit, which was observed by Vallone et al. (2010) when they found that larger container volumes (700 cm³) favored the development of Arabica coffee plants.

For TN, the highest average was obtained in S3 within Cont. 2 (38.17% plant^{-1}), differing from the others. However, within Cont. 1 and 3 there was no statistical difference between the used substrates.

For the effect of the container on the nitrogen content in the plant, it is clear that Cont. 3, with higher volume, provided the highest averages in most treatments. However, within S2, such variable did not show a significant difference. It is remarkable the nutritional effect of the legume + dried cow dung compost on the development of Conilon coffee.

TABLE 4 - Root length (RL) and total nitrogen (TN) of Conilon coffee seedlings in different substrates and containers.

Substrates	RL (cm)			TN (%)		
	Cont. 1	Cont. 2	Cont. 3	Cont. 1	Cont. 2	Cont. 3
S1	16.00Aa	19.00Ba	22.00Aa	15.25Ab	19.58Bb	36.08Aa
S2	15.83Ab	27.33Ba	22.83Aa	19.25Aa	26.75Ba	26.89Aa
S3	14.83Ab	16.83Bb	21.67Aa	11.94Ab	38.17Aa	31.67Aa
S4	11.00Ab	21.17Aa	21.83Aa	16.58Ab	19.36Bb	38.00Aa

S1 - Conventional; S2 - Legume + dried cow dung compost; S3 - Grass + dried cow dung compost; S4 - Vermicompost. Cont. 1 - tube (120 cm³); Cont. 2 - tube (280 cm³); Cont. 3 - bag (615 cm³).

Averages followed by the same capital letters on the columns and lowercase on the rows belong to the same group by Scott-Knott test ($p \leq 0.05$).

A higher nitrogen content in the plant may be associated with the higher volume of substrate explored by the root system, besides the availability of this nutrient in the compost. According to Santinato et al. (2014), the addition of nitrogen to the substrate containing cow dung is important to supply the requirement for this nutrient in the seedlings. However, the data obtained in the present study demonstrate that the substrate volume (larger containers) significantly influenced the nitrogen concentration in the plant, since the higher volumes of substrates provided higher nitrogen contents for the plant.

The shoot dry mass (Figure 1) showed higher average in Cont. 3 (2.92 g plant^{-1}), differing significantly from the others. The lowest dry mass was obtained in Cont. 1 (0.78 g plant^{-1}). Therefore, the higher substrate volume favors the production of shoot dry mass and hence the production of Conilon coffee seedlings.

When evaluating different containers and substrates, Vallone et al. (2009) observed that Arabica coffee seedlings produced in a 120 mL tube and a 700 mL bag were superior to those produced in a 50 mL container at 20 months after field transplantation. Thereby, the influence of substrate volume is evident both in the development stage of seedlings in the nursery and in the field.

For the root dry mass (Figure 2), it is noted that the Cont. 2 and 3 showed the highest averages (0.76 and 0.94 g plant^{-1}), differing statistically from the Cont. 1 (0.43 g plant^{-1}). The root volume favors the absorption of water and nutrients by the plant, besides providing good stability, being its development essential for the success of seedling setting in the field.

In this way, the use of higher volume containers is a strategy for production of seedlings corroborated by Francisco et al. (2010) and Vallone et al. (2009). However, as the Cont. 2 was significantly equal the Cont. 3, the smaller volume can be used aiming at the economy of substrates, decreasing the production cost of seedlings.

The leaf area (Figure 3) was significantly influenced by the container volume. It is noted that Cont. 3 provided the highest average (53.61 cm² plant^{-1}), differing statistically from the others. The Cont. 1 presented the worst result (19.09 g plant^{-1}).

The leaf area is a response to the good root development of plant, which can be understood when comparing Figures 2 and 3. A larger leaf area will directly influence the production of photoassimilates and hence the plant development. Therefore, containers that favor the leaf area should be preferred to the detriment of those that restrict it.

According to Dias et al. (2009), the plants growing in a higher volume of substrate show higher leaf area parameters, favoring a greater amount of reserve (carbohydrate) and metabolized, thus providing quality seedlings. This result was corroborated by Dardengo et al. (2013).

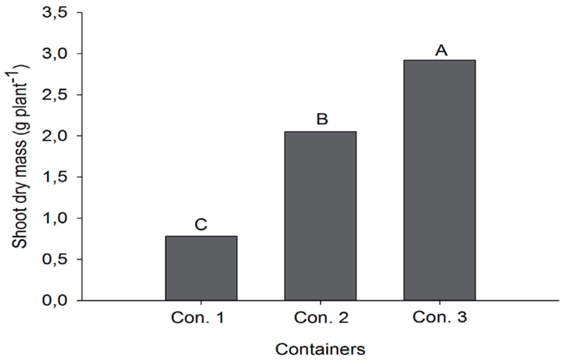

FIGURE 1 - Shoot dry mass in function of the containers. Cont. 1 - tube (120 cm³); Cont. 2 - tube (280 cm³); Cont. 3 - bag (615 cm³).

Averages followed by the same capital letters on the columns belong to the same group by Scott-Knott test (p≤0.01).

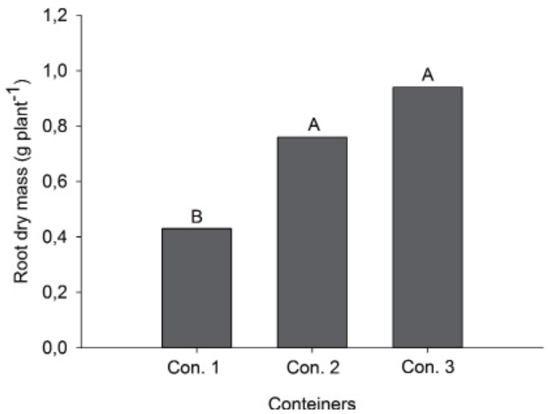

FIGURE 2 - Root dry mass in function of the containers. Con. 1 - tube (120 cm³); Con. 2 - tube (280 cm³); Con. 3 - bag (615 cm³).

Averages followed by the same capital letters on the columns belong to the same group by Scott-Knott test (p≤0.01).

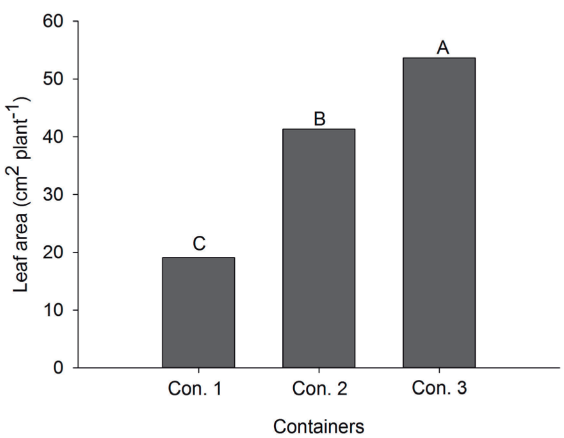

FIGURE 3 - Leaf area in function of the containers. Cont. 1 - tube (120 cm³); Cont. 2 - tube (280 cm³); Cont. 3 - bag (615 cm³).

Averages followed by the same capital letters on the columns belong to the same group by Scott-Knott test (p≤0.01).

According to Figure 4, the S2 provided the highest average for the Dickson quality index (0.26), differing statistically from the others. The lowest average was obtained in S3 (0.13). According to Marana et al. (2008), the principle of quantitative evaluation is that the bigger the seedlings, the better. However, in order to avoid distortions from excess nitrogen, e.g., or from leaf growth to the detriment of the root system, quality indexes are used as relationships among growth parameters.

When establishing the minimum value of 0.2 for the Dickson quality index (HUNT, 1990), it is observed that only S2 showed a value higher than that (0.26). For Dardengo et al. (2013), this index was efficient to indicate the quality of Conilon coffee seedlings in different containers (120 cm^3 tube and 770 cm^3 bag). The values obtained in the present study are close the mentioned by Dardengo et al. (2013).

When studying the effect of tube size on seedling quality of three forestry species, Ferraz and Engel (2011) observed that the best averages for the Dickson quality index were obtained in larger containers.

In Figure 5 is shown that Cont. 3 provided the highest average for total crude protein (53.82% $plant^{-1}$), differing statistically from the others. The second best average was obtained in Cont. 2 (41.53% $plant^{-1}$) followed by Cont. 1 (19.23% $plant^{-1}$). Thereby, it is suggested that a higher volume of substrate favors the crude protein production in Conilon coffee plants and hence their initial development.

Similarly to the total nitrogen content, the crude protein showed higher average content in Cont. 3. The nitrogen concentration in the plant is related to the protein synthesis (TAIZ; ZEIGER, 2013), as verified by Gomes Júnior and Sá (2010) in the bean crop.

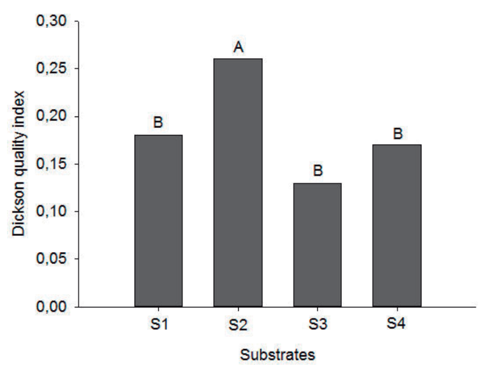

FIGURE 4 - Dickson quality index in function of the substrates. S1 - Conventional; S2 - Legume + dried cow dung compost; S3 - Grass + dried cow dung compost; S4 - Vermicompost.

Averages followed by the same capital letters on the columns belong to the same group by Scott-Knott test (p≤0.05).

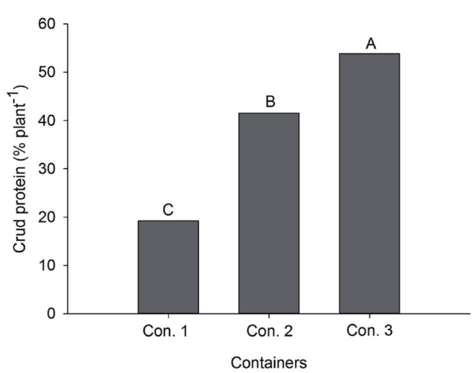

FIGURE 5 - Total crude protein in function of the containers. Cont. 1 - tube (120 cm^3); Cont. 2 - tube (280 cm^3); Cont. 3 - bag (615 cm^3).

Averages followed by the same capital letters on the columns belong to the same group by Scott-Knott test (p≤0.05).

4 CONCLUSIONS

The alternative substrates (Legume compost, Grass compost and Vermicompost) were efficient for production of Conilon coffee seedlings and can replace the conventional substrate at this development stage, providing good quality seedlings.

The major developments were observed in the containers with the highest volume (280 cm^3 tube and 615 cm^3 bag) and reflected directly on the quality of seedlings.

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DEVELOPMENT AND PRODUCTION OF FERTIGATED COFFEE TREES IN THE WEST REGION OF BAHIA, BRAZIL

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ABSTRACT: The aim in the present study was to evaluate the effects of different split fertigation and doses on the development and production of drip irrigated coffee in the western region of the state of Bahia, Brazil. The study was performed at the Café do Rio Branco Farm, in Barreiras, BA, Brazil, in adult coffee trees aged approximately 3.5 years from the variety *Catuaí IAC 144*. A 3 x 3 factorial design was adopted, with three levels of nitrogen and potassium fertilization (900/800, 600/500 and 300/250 kg ha^{-1} year^{-1} N and K_2O) in three monthly split fertigation (two, four and eight times). Stem and crown growth, productivity, yield and sieve were evaluated. The doses of 600/500 and 900/800 kg ha^{-1} year^{-1} N/K_2O and the splits in two and eight times provided the highest productivities of coffee. A higher split fertigation was observed on the effect of N and K_2O doses in coffee development variables (crown diameter and plant height). There was no effect of split fertigation and doses in the classification by sieves of coffee beans.

Index terms: *Coffea arabica* L., irrigation, nitrogen, potassium.

DESENVOLVIMENTO E PRODUÇÃO DO CAFEEIRO FERTIRRIGADO NA REGIÃO OESTE DA BAHIA

RESUMO: Este trabalho foi realizado com o objetivo de avaliar os efeitos de diferentes doses e parcelamentos da fertirrigação no desenvolvimento e na produção do cafeeiro irrigado por gotejamento na região Oeste da Bahia. O trabalho foi conduzido na fazenda Café do Rio Branco, localizada em Barreiras - BA, em cafeeiros adultos, com aproximadamente 3,5 anos de idade, da variedade Catuaí IAC 144. Foi adotado um esquema fatorial 3 x 3, sendo três níveis de adubação nitrogenada e potássica (900/800, 600/500 e 300/250 kg ha-1 ano-1 de N e K2O) em 3 parcelamentos mensais de fertirrigação (2, 4 e 8 vezes). Foram avaliados o crescimento do caule e copa, a produtividade, o rendimento e peneira. As doses de 600/500 e 900/800 kg ha-1 ano-1 de N/K2O e os parcelamentos em dois e oito vezes proporcionaram as maiores produtividades do cafeeiro. Observou-se efeito maior do parcelamento da fertirrigação, sobre o efeito das doses de N e K2O, nas variáveis de desenvolvimento do cafeeiro (diâmetro de copa e altura de planta). Não houve efeito das doses e parcelamento da fertirrigação na classificação por peneira dos grãos do café.

Termos para indexação: *Coffea arabica* L., irrigação, nitrogênio, potássio.

1 INTRODUCTION

Irrigation is characterized as part of a set of techniques used to guarantee the economic production of coffee, with adequate management of natural resources (MANTOVANI; VICENTE, 2015).

The water requirement of the coffee tree is a limiting factor in bean yield and quality, being the minimum limit required by the coffee tree during a cycle is 800 mm (VENANCIO et al., 2016). Associated with water consumption is the phenomenon of mass flow, responsible for large part of plant's absorption of nutrients. Based on this, research correlating the supply of water and fertilizer arose from the fertigation. Currently, fertigation has been intensively used in coffee growing through irrigation systems that apply water and conventional fertilizers, saving labor force and with better fertilizer distribution in the area.

The benefits of the fertigation technique are limited due to the scarcity of specific scientific information for the coffee tree, especially in relation to the doses and split number required in the year (SOBREIRA et al., 2011).

Fernandes et al. (2007) evaluated coffee fertigation in Uberaba, MG, Brazil, after four harvests and observed that the used fertilizer sources both in fertigation and in conventional soil application did not show significant differences in terms of coffee productivity and quality.

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Lima et al. (2016), in Araguari, MG, Brazil, evaluated the vegetative and productive parameters of coffee as a function of different sources, doses and forms of nitrogen application and observed that agricultural urea applied through fertigation was not better in the vegetative and productive parameters of the coffee tree in relation to the applied conventionally, and that the conventionally applied ammonium nitrate can be considered as the best source of N when all the variables are analyzed together.

Coelho et al. (2009), in an experiment performed in Lavras, MG, Brazil, did not observe an effect of the split number of N, P and K (4, 12, 24 and 36 applications) applied through fertigation in the coffee productivity.

Although there are publications on the application of fertilizers through irrigation water, it is verified that there is still a need for research on fertilizer doses for the coffee tree, since there are several variables involved in the use of this technique.

The aim in the present study was to evaluate the effects of different doses and split fertigation by dripping on production and development of coffee tree in western Bahia region, Brazil.

2 MATERIAL AND METHODS

The experiment was installed in adult coffee plantations, aged approximately 3.5 years, *Catuaí Vermelho IAC 144* variety, spaced 3.80 x 0.5 m with drip irrigation at Fazenda Café do Rio Branco (11°48'01" S; 45º35'50" W; 735 m altitude) municipality of Barreiras, BA, Brazil. The analyzed period was from November 2004 to May 2008.

Soil texture analysis is presented in Table 1. Field capacity value was determined from the 5 kPa tension as a function of the soil texture in the experiment. For the permanent wilting point, the moisture corresponding to the 1540 kPa tension was adopted. Soil moisture values corresponds to the field capacity and permanent wilting point, in the 0-60 cm profile, were 27.01 and 17.63% volume, respectively.

Urea was used as source of nitrogen and potassium chloride with potassium source.

The crop evapotranspiration (ETc) was estimated using the coefficients of adjustment ("kc" crop, "kl" landscape and "ks" soil) on reference evapotranspiration (ETo), according to the methodologies described by Mantovani et al. (2009) and Mantovani and Vicente (2015). The gross irrigation depth was calculated through a water balance using the Irriplus software (MANTOVANI et al., 2009), in which the inputs of water were the irrigation and the effective rainfall, and the outputs, crop evapotranspiration (ETc) and percolation depth, besides the depth considered for the root system.

The method for estimating the ETo used by Irriplus is the Penman-Monteith-FAO 56 model (ALLEN et al., 1998; PEREIRA et al., 2015). The meteorological data used to perform the experiment were obtained from an automatic agrometeorological station, Davis brand, Vantage Pro model, located on the property.

In the experiment, the values of the crop coefficient (Kc), percentage of shaded area (P) and effective depth of the root system were 1.0, 50% and 0.60 m, respectively, were used.

The experiment used drip irrigation, with flow emitters 2.3 L h^{-1}, spaced every 0.75 m.

Harvests were performed manually. Coffee production of the plot was determined after each harvest, and two 5 L samples were taken to determine the yield and sieve of each treatment. The productivity result was calculated in 60 kg bags of processed coffee per hectare (bg ha^{-1}).

To evaluate the vegetative development, the plant height and crown and stem diameter were considered. For measuring the crown diameter, the perpendicular length to the planting line was determined as reference. The evaluations were performed on December 10, 2005 and September 19, 2007.

The development variables (plant height, crown and stem diameter), sieve classification and yield of coffee fruits were performed by analysis of variance by F test at 5% probability. Means were compared using the Tukey test at 5% probability.

3 RESULTS AND DISCUSSION

In Figure 1 are observed the soil moisture content estimated by Irriplus, the safe soil moisture (moisture relative to the soil water availability factor), the irrigation depths and the rainfall occurred throughout the experiment during the analyzed period (November 2004 to May 2008). The total applied irrigation depth was 3,029 mm (135, 1083, 645, 919 and 247 mm for the years 2004, 2005, 2006, 2007 and 2008, respectively) and accumulated rainfall was 3,715 mm (321, 1075, 1210, 588 and 522 mm for the years 2004, 2005, 2006, 2007 and 2008, respectively).

TABLE 1- Particle size composition, texture classification and soil specific weight.

Depth (cm)	Particle size composition (%)			Soil density (g/cm^3)	Texture classification
	Sand	Silt	Clay		
0-20	65.53	2.23	32.24	1.57	Sandy clay loam
20-40	63.37	2.86	33.78	1.57	Sandy clay loam
40-60	57.20	2.83	39.97	1.47	Sandy clay

The experiment was set up in a 3 x 3 factorial design with three levels of nitrogen and potassium fertilization, in three split fertigation (Table 2), and the randomized block design with four replicates. The experimental plots consisted of 20 plants (10 m).

TABLE 2 - Description of the different treatments of N and K_2O levels and splits, Barreiras, BA, Brazil

Treatment	Doses (kg ha^{-1} $year^{-1}$)		Split	No. monthly applications
	N	K_2O		
1	900	800		2
2	600	500	every 15 days	2
3	300	250		2
4	900	800		4
5	600	500	1 per week	4
6	300	250		4
7	900	800		8
8	600	500	2 per week	8
9	300	250		8

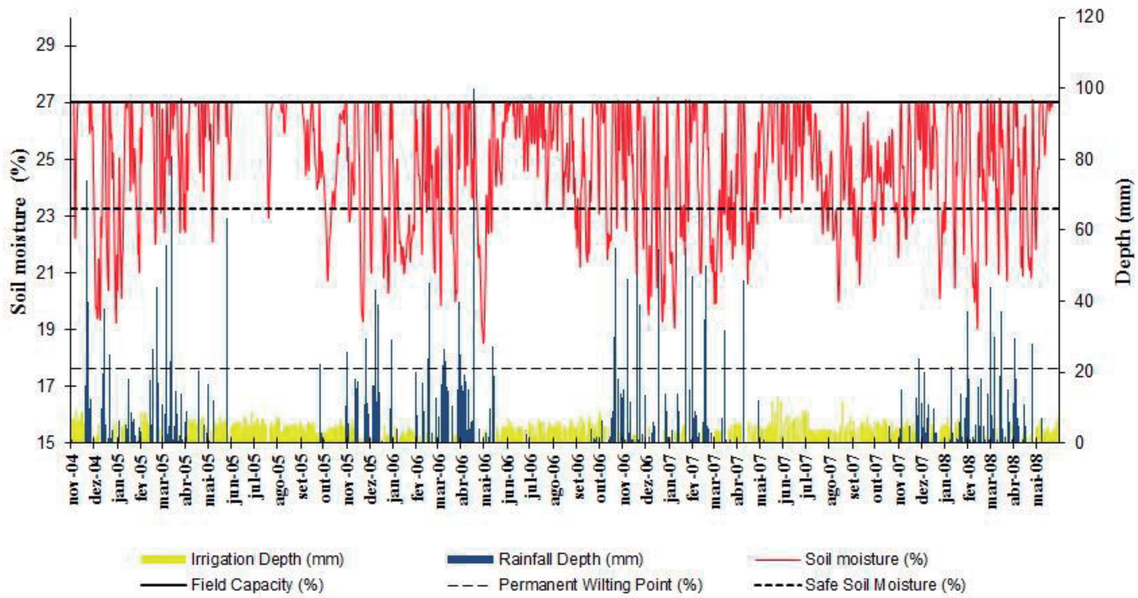

FIGURE 1 - Soil (volumetric) moisture estimated by the Irriplus software, applied irrigation depths and rainfall for the experiment.

There was an isolated effect among the different doses ($p < 0.05$) for coffee productivity, in bg ha^{-1} for the harvests 2005, 2006, 2008, and for the average of the four studied harvests (Table 3).

The doses 600/500 and 900/800 (N/K_2O) differed from the dose 300/250 in the average of four harvests, being that the dose 600/500 provided the highest average productivity, occurring the same in the 2006 and 2008 harvests. The dose of 600/500 N/K_2O, according to the obtained productivity (60.9 bg ha^{-1}) corroborates Santinato (2005) for the western region of Bahia, Brazil, which observed the requirements of 574 kg ha^{-1} N and 454 kg ha^{-1} K_2O for obtaining similar productivity. For the same region, Guerra et al. (2007) state that the doses of 500-600 kg/ha N and K_2O, generally applied in crops with productive potential from 60 to 70 bg/ha, are consistent with the research results obtained at Embrapa Cerrados and are adequate to meet the needs of coffee trees.

The four harvest average did not present higher productivity at the 900/800 dose (Table 3) because of the nutrient leaching.In a study performed on coffee plantations in the western Bahia, Brazil, Bortolotto et al. (2012) verified that the nitrogen leaching corresponding to 104.5 kg ha^{-1} at the dose of 800 kg ha^{-1} N applied as urea was associated with concentrated rainfall.

The found results contrast with the obtained by Rena, Nacif and Guimarães (2003) in Patrocínio, MG, Brazil. The authors observed that doses of 1000-1200 kg ha^{-1} $year^{-1}$ of 20-5-20 (200-240 kg ha^{-1} $year^{-1}$ N and K_2O) were sufficient to meet the demands of coffee, although it is worth mentioning that the productivity under dry conditions obtained by the authors was 31.0 bg ha^{-1}, almost half of that obtained in the present experiment.

There was also an isolated effect of the fertigation frequency ($P < 0.05$) on coffee yield, in bg ha^{-1}, for all the crops except for the 2006 harvest and the average of four harvests (Table 4).

Split in two monthly applications provided higher productivity than the other splits, not statistically differing from the split fertigation applied eight times a month for the average of four harvests.

Coelho et al. (2009), in Lavras, MG, Brazil, observed that the split application of fertilizers did not result in differences on coffee productivity. Karasawa, Faria and Guimarães (2002) and Vilella and Faria (2003) in Lavras, did not observe a significant effect of split nutrient.

Sant'ana (2015) observed in Lavras that the average productivity of the 2010, 2011, 2012 and 2013 harvests were not influenced by the split nitrogen and potassium fertilization (four applications in Nov, Dec, Jan and Feb and 12 monthly applications), although observing higher leaching with lower splits. Lima et al. (2016) also did not observe effect of urea fertigation (weekly splits from September of each year until July of the following year) in relation to conventional fertilization split in three applications (November, January and March of all evaluated years).

TABLE 3 - Productivity, in bags per hectare, of fertigated coffee trees subjected to different doses of N and K_2O

Doses (kg ha^{-1} $year^{-1}$) (N/K_2O)	Productivity (bg ha^{-1})				
	2005	2006	2007	2008	Average
600/500	52.2 AB	68.9A	58.9 A	67.3 A	60.9 A
900/800	53.7 A	64.5 A	54.9 A	66.1 AB	60.4 A
300/250	49.1 B	50.7 B	61.3 A	55.5 B	53.3 B

Averages followed by the same letter on the column do not differ among themselves by Tukey test ($p<0.05$)

TABLE 4 - Productivity, in bags per hectare, of coffee tree subjected to different monthly split fertigation, in Barreiras, BA, Brazil

Split (monthly)	Productivity (bg ha^{-1})				
	2005	2006	2007	2008	Average
2	56.1 A	62.6 A	63.0 A	62.1 AB	60.9 A
8	53.3 AB	61.6 A	51.6 B	69.3 A	58.5 AB
4	45.6 B	59.9 A	55.6 AB	57.8 B	55.2 B

Averages followed by the same letter on the column do not differ among themselves by Tukey test ($p<0.05$)

In the analyses, interaction between doses and monthly split fertilization was significant ($P < 0.05$) for coffee productivity in the 2005 and 2007 harvests and for the average of four harvests (Table 5).

Similar results were found by Leite Júnior and Faria (2016), obtaining a productivity average of 63.5 bags for the most productive year and 38 bags for the lowest productive year, thus concluding that fertigation make possible to stagger production and increase productivity.

Treatment 2 (600/500 kg ha^{-1} year^{-1} N/K_2O with two monthly splits) showed the highest productivity in the average of four studied harvests (65.6 bg ha^{-1}). Treatment 3 (300/250 kg ha^{-1} year^{-1} N/K_2O with two monthly splits) provided higher productivities in the 2005 and 2007 harvests, but lower than the treatment 2 on average. The higher productivities in the 2005 and 2007 harvests for treatment 3 can be explained by the more efficient use of nitrogen, as observed by Bruno et al. (2015), in Barreiras, MG, Brazil, where the dose of 200 kg N ha^{-1} year^{-1} urea showed the lowest losses and greater N recoveries by coffee.

In Table 4 is noted that split is more relevant in the years of low productivity (2005 and 2007) and the dose in the years of high productivity (2006 and 2008), although observing interaction between dose and split.

The results corroborate with the presented by Bruno et al. (2011), demonstrating that it is possible to reduce the nitrogen dose from 600kg ha^{-1} year^{-1} to 200 kg ha^{-1} without decreasing coffee yield. It should be highlighted that the authors evaluated only one harvest, i.e., the effect on future harvests were not evaluated.

For the analyses of coffee development (crown diameter and stem height), a statistical difference ($p < 0.05$) was observed in the first evaluation between the doses and splits for the crown diameter and between the splits and stem height.

TABLE 5 - Productivity, in bags per hectare, of coffee tree subjected to different monthly doses and split fertigation

Doses (kg ha^{-1} year^{-1}) (N/K_2O)	Monthly split		
	2	4	8
	Productivity 2005 (bg ha^{-1})		
900/800	50.0 A a	51.2 A a	59.8 A a
600/500	54.8 AB a	42.4 B a	59.4 A a
300/250	63.3 A a	43.2 B a	40.9 B b
	Productivity 2006 (bg ha^{-1})		
900/800	67.4 A a	67.1 A a	59.1 A a
600/500	77.1 A a	64.2 A a	65.5 A a
300/250	43.3 A a	53.5 A a	55.2 A a
	Productivity 2007 (bg ha^{-1})		
900/800	50.5 A b	64.8 A a	56.3 A a
600/500	61.3 A b	55.8 A ab	47.7 A a
300/250	77.1 A a	46.3 B b	50.87 a
	Productivity 2008 (bg ha^{-1})		
900/800	67.0 A a	61.0 A a	70.4 A a
600/500	69.2 A a	60.5 A a	79.0 A a
300/250	50.0 A a	52.0 A a	64.5 A a
	Average productivity (bg ha^{-1})		
900/800	58.7 A b	61.0 A a	61.4 A a
600/500	65.6 A a	55.8 B a	61.4 AB a
300/250	58.4 A b	48.8 B b	52.9 AB b

Averages followed by the same capital letter on the row and same lowercase letter on the column within each harvest do not differ among themselves by Tukey test ($P<0.05$)

In the second evaluation, a statistical difference ($p < 0.05$) was verified between the doses only for the crown diameter. In Tables 6, 7 and 8 are presented the results of the first and second biometric measurements of the experiment.

It is observed in Table 6 that the 600/500 dose of N and K_2O provided the largest crown diameter in the first evaluation, while the best result was observed at the 300/250 dose in the second evaluation. The results are similar to the found by Nazareno et al. (2003) and Rezende et al. (2010), which observed a response to N and K for crown diameter and growth in number of plagiotropic branches, demonstrating the synergistic effect of adequate water availability and better nutrient distribution in fertilizers, concluding that fertigation is a good alternative to be used in the formation of coffee plants to the detriment of conventional fertilization.

In the first evaluation, the largest crown diameter of coffee tree was provided by split fertigation eight times per month (Table 7), differing only from the splits applied four times. The small difference between the average crown diameter for the first and second crop (191.9 and 189.0 cm, respectively) may be correlated with the fact that the first evaluation was performed in the rainy season in contrast to the second one at the end of the dry period of the year.

For stem development (Table 8), it is noted that split fertigation applied eight times provided the highest average stem growth (67.2 cm) in 21 months.

The effect of the monthly split on the yield, in liters of coffee per acre ($p<0.05$), was observed in the 2008 harvest (Table 9).

TABLE 6 - Average crown diameter of coffee in centimeters as a function of the different doses of N and K_2O in the two evaluations

Doses (kg ha^{-1} $year^{-1}$) N/K_2O	Crown diameter (cm) 1st evaluation	Crown diameter (cm) 2nd evaluation
900/800	191.4 AB	185.7 B
600/500	197.2 A	188.6 AB
300/250	187.2 B	192.5 A

Averages followed by the same letter on the column do not differ among themselves by Tukey test ($p<0.05$)

TABLE 7 - Crown diameter of coffee in centimeters as a function of the different monthly splits of N and K_2O in the two evaluations

Split (monthly)	Crown diameter (cm)	
	12/10/2005	9/19/2007
2	191.5 AB	186.9 A
4	186.8 B	188.6 A
8	197.4 A	191.3 A

Averages followed by the same letter on the column do not differ among themselves by Tukey test ($p<0.05$)

TABLE 8 - Stem height of coffee in centimeters as a function of the different monthly splits of N and K_2O in the two evaluations

Split (monthly)	Stem height (cm)	
	12/10/2005	9/19/2007
2	213.0 A	266.0 A
4	209.4 AB	267.1 A
8	203.3 B	270.5 A

Averages followed by the same letter on the column do not differ among themselves by Tukey test ($p<0.05$)

TABLE 9 - Yield (L bg^{-1}) of coffee necessary to produce one processed bag

Split (monthly)	Yield (liters of coffee per processed bag)
4	531 A
2	518 AB
8	512 B

Averages followed by the same letter do not differ among themselves by Tukey test ($p<0.05$)

The split four times a month provided the best yield. It can be observed in Table 4, for the 2008 harvest, that the split four times per month also provided the lowest productivity in relation to the other splits. The yield is affected considerably by water deficit occurring in the expansion of the coffee bean (October-December), which did not occur throughout the experiment. Such difference in the yield can be explained by the greater easiness in filling the coffee bean by the treatments subjected to the split four times a month, since were produced in smaller amount.

There were no significant effects of treatments on the percentage of beans classified in the 16-mesh sieve or above. The percentage found was 46.3%, translating into a good coffee percentage for export, since exporters prefer larger beans, thus automatically eliminating defects. This value is consistent with that presented by Custódio, Gomes and Lima (2007).

4 CONCLUSIONS

The doses of 600/500 and 900/800 kg ha^{-1} $year^{-1}$ N/K_2O provided the highest productivities of coffee;

Split fertigation applied two and eight times a month was superior in productivity;

A higher split fertigation was observed on the effect of N and K_2O doses in coffee development variables (crown diameter and plant height).

There was no effect of split fertigation and doses in the classification by sieves of coffee beans;

Split fertigation applied four times a month resulted in a better yield, in liters of coffee per acre, for the 2008 harvest, although this same split provided lower productivity than the others.

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KASUGAMYCIN INFLUENCE ON BACTERIAL BLIGHT OF COFFEE AND ON GREEN COFFEE BEANS PHYSICOCHEMICAL QUALITY

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ABSTRACT: Brazil stands out as the world's largest coffee exporter. However, in the cold and windy regions, such as the southern of Minas Gerais, have been undergoing attack of diseases, including the bacterial blight of coffee caused by the bacterium *Pseudomonas syringae* pv. *garcae*, which despite not having the same importance as the coffee leaf rust, is causing damages and losses to the coffee plantation. The control is mainly done through preventive measures such as installation of windbreaks. When bacterial blight of coffee is already installed, the chemical control is used with syrups of copper-based products and antibiotics. The aim of the present study was to verify the efficiency of the antibiotic kasugamycin associated with copper hydroxide in the control of bacterial blight of coffee and raw coffee beans quality. The experimental design was a randomized block with five treatments, four replicates and plots of 10 plants in the field where the treatments consisted of different concentrations of the kasugamycin: 0.0, 250, 500, 750 and 1000 mL ha^{-1} added with 1.0 L copper hydroxide. The percent analysis was performed on the raw beans in order to verify their physical and chemical quality. The obtained results demonstrate that the solution is efficient in the control of bacterial blight of coffee as well as in the improvement of vegetative vigor and production, but does not influence the quality of raw coffee bean.

Index terms: Bactericidal, *Coffea arabica* L., *Pseudomonas syringae* pv. *garcae.*

INFLUÊNCIA DE KASUGAMICINA NA MANCHA AUREOLADA DO CAFEEIRO E NA QUALIDADE FÍSICO-QUÍMICA DO GRÃO CRU

RESUMO: O Brasil se destaca por ser o maior exportador mundial de café, no entanto nas regiões frias e expostas ao vento, como no Sul de Minas Gerais, vêm sofrendo com o ataque de doenças, como bacteriose chamada Mancha Areolada causada pela bactéria Pseudomonas syringae pv. garcae Amaral que embora não tenha a mesma importância da ferrugem alaranjada vem causando danos e perdas a cafeicultura. O controle se dá principalmente por medidas preventivas, como a instalação de quebra-ventos, quando já instalada a bacteriose o controle químico é utilizado com caldas de produtos à base de cobre e antibióticos. O objetivo do trabalho foi verificar a eficiência do antibiótico kasugamicina associado com hidróxido de cobre no controle da mancha aureolada e na qualidade dos grãos cru de café. O delineamento experimental utilizado foi em blocos casualizados com 5 tratamentos, 4 repetições e parcelas de 10 plantas no campo onde os tratamentos constaram de diferentes concentrações do bactericida kasugamicina: 0,0; 250, 500, 750 e 1000 mL ha-1 adicionados de 1,0 litro de hidróxido de cobre. A análise centesimal foi realizada nos grãos crus para verificar a qualidade físico-química dos mesmos. Os resultados obtidos demonstram que a solução é eficiente no controle da bacteriose assim como na melhoria do vigor vegetativo e produção, porém não interfere na qualidade do grão cru do café.

Termos para indexação: Bactericida, *Coffea arabica, Pseudomonas syringae pv. garcae*.

1 INTRODUCTION

Brazil stands out as the world's largest coffee producer and exporter, generating wealth and foreign exchange for the country, besides having a great social function. Exports historically represent more than half of foreign exchange earnings for 30% of the most important exporting countries and contributes with more than 25% to the value of total exports for the remaining 70% (JACOMINI; BACHA; FERRACIOLI, 2015). In Brazil, coffee represents 7% total exports of agricultural products, being the revenues of coffee crop quite significant in the southern region of Minas Gerais in relation to industry and commerce (ARAUJO et al., 2008). The state of Minas Gerais accounts for the largest coffee growing and production park in Brazil, the South and Center-West regions of the state are highlighted in relation to the production of processed Arabica coffee (*Coffea arabica*) (VALE; CALDERARO; FAGUNDES, 2014).

The bacterial blight of coffee caused by the bacterium *Pseudomonas syringae* pv. *garcae* causes severe damage to Brazilian coffee cultivation, especially in coffee plants exposed to wind and cold and high-altitude coffee regions (ITO et al., 2008). It can be stated that bacterial blight of coffee does not have the same economic importance of coffee leaf rust, but it has become

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limiting in colder regions exposed to wind, such as in the Brazilian states of Paraná, São Paulo and South of Minas Gerais, especially in young and pruned coffee plantations and in nurseries (GOMES et al., 2015).

Bacterial blight of coffee causes damage to leaves, rosettes, new fruits and branches. In the leaves, this bacterium causes necrotic lesions surrounded by yellowish halos. Such lesions are distributed throughout the leaf surface, being more frequent in the edges of leaves whereby the bacterium shows ease of penetration through lesions caused by mechanical damages (ITO et al., 2008). Moreover, it causes the drought of young branches and necrosis in rosettes and in new fruits. The new crops, from three to four years of age, are more affected, occurring defoliation, dieback, witch's broom and delay in the development of plants. However, in nurseries, the affected seedlings undergo defoliation and apical death, even leading to the plant death. The incidence of bacterial blight of coffee has been higher in crops at high altitudes, unprotected from winds and moderate cold (ANDREAZI et al., 2015).

The temperature and humidity that favor the disease are still being discussed. Bacterial blight of coffee generally begins in November and December, with the entry of cold periods. With wind and humidity, the disease can also be observed between May and July. (ITO et al., 2008). The bacterium is spread inside the plant and from plant to plant, by the action of rain splashes, light rain and wind (ZOCCOLI; TAKATSU; UESUGI, 2011).

The management of bacterial blight of coffee should be mainly preventive, through the installation of windbreaks, since it is an efficient, economic and ecologically correct method aimed to combat the entry of the disease in the crops and/or hamper its progress in affected areas (OLIVEIRA; OLIVEIRA; MOURA, 2012).

In chemical control, the use of copper compounds to control bacterial blight of coffee has been used due to its low cost to the producer, low environmental toxicity and relative efficacy (ITAKO et al., 2012). Currently, the chemical control used for seedlings consists of the application of kasugamycin hydrochloride intercalated with copper oxychloride, while products with copper salts as active principle have also been used in field conditions (CARVALHO; CUNHA; SILVA, 2012), which may not have good efficacy in the control.

The aim of the present study was to evaluate the efficiency of the bactericidal kasugamycin associated with copper hydroxide in the control of bacterial blight of coffee in young coffee plantations and to evaluate the influence on the physicochemical green coffee beans quality.

2 MATERIAL AND METHODS

The installation and the realization of the present experiment were performed in two distinct stages.

The first phase of the experiment was performed in a coffee plantation on São Domingos farm, Palméia neighborhood in Muzambinho, MG, Brazil, from August 2012 to July 2013. Muzambinho is in the South of Minas Gerais, at 21°22'00" S, 46°31'00" W and 1048 m altitude.

The used cultivar was *Catucaí 2SL* with four years old and spacing 3.0 m between lines and 0.8 m between plants; the used experimental design was in randomized blocks with five treatments, four replicates and plots composed by 10 plants in the field, where the treatments used different concentrations of the bactericidal kasugamycin: 0.0, 250, 500, 750 and 1000 mL ha^{-1} added with 1.0 L copper hydroxide. Spraying was performed in August and November 2009, with application interval of 90 days.

The experiment was evaluated during the realization period through the following variables: productivity (bags ha^{-1}), vegetative vigor and occurrence of bacterial blight of coffee. To evaluate the occurrence of bacterial blight of coffee, a scale proposed by Mohan, Cardoso and Paiva (1978) was modified, assigning grades from 1 to 5, being: 1 = plants without lesions; 2 = few lesions in leaves with yellow halo, indicating bacterial blight of coffee development; 3 = many lesions on the leaves with yellowish halo, without dieback in the branches; 4 = lesions in the leaves with yellow halo, with dieback of plagiotropic branches and/or orthotropic branches (from the tip up to five nodes towards the root); and 5 = almost total dieback of the upper third of the plant. The vegetative vigor was evaluated based on the color of leaves, assigning grades from 1 to 5, being: 1 = yellowish leaf; 2 = light green; 3 = medium green; 4 = dark green; and 5 = very dark green.

The second stage of the experiment was performed in the Laboratory of Bromatology of the Federal Institute of Education, Science and Technology of the South of Minas Gerais - Campus Muzambinho, from August to December 2013.

During this stage, samples of green coffee beans were collected from the treatments cited above. The experimental design was in randomized blocks with five treatments (0, 250, 500, 750 and 1000 mL ha^{-1} kasugamycin).

The laboratory analysis followed the methodology of percent analyses: humidity (H) (ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS - AOAC, 1990); crude fiber (CF) (KAMER; GINKEL, 1952); crude protein (CP) (AOAC, 1990); ether extract (lipids) (EE) (AOAC, 1990); mineral residue or ash fraction (A) (AOAC, 1990); carbohydrate fraction (CF) determined by equation: % CF = 100 - (H + EE + P + F + A); energy value used the Atwater conversion factors: 4 Kcal/g for proteins and carbohydrates, and 9 kcal/g for lipids (OSBORNE; VOOGT, 1978).

The control data of bacterial blight of coffee and quality of collected green beans were subjected to analysis of variance in order to verify significant differences among themselves and later analyzed by polynomial regression. Statistical analyses were performed using the SISVAR statistical software version 4.6 (FERREIRA, 2011).

3 RESULTS AND DISCUSSION

In Figures 1 and 2 can be verified that both the vegetative vigor and the productivity of the coffee plantation were influenced inasmuch as the kasugamycin concentrations were increased. These factors are related closely to plant health, adequate nutrient balance and availability of water resources, among other factors that influence the vegetative vigor of the plant (OLIVEIRA; OLIVEIRA; MOURA, 2012).

It is noteworthy that the isolated effect of kasugamycin and copper oxychloride on the control of the bacterial blight of passion fruit caused by the bacterium *Xanthomonas campestris* pv. *passiflorae* observed “early death”, whereby copper oxychloride showed better results in the production (JUNQUEIRA et al., 2011). Oliveira et al. (2012) also proved greater efficiency in coffee plantations using cuprous oxide fungicide, resulting in higher productivity.

In the present study, a solution containing two products (kasugamycin and copper hydroxide) was tested. Therefore, it was not possible to evaluate the isolated effect of these products on the analyzed parameters, although the result allows suggesting that the association of both products influenced the increase of productivity and vegetative vigor.

It can be observed in Figure 03 that the intensity of bacterial blight of coffee decreased inasmuch as the kasugamycin concentrations decreased.

For the control of *Xanthomonas campestris* pv. *passiflorae* in passion fruit culture, copper oxychloride was more efficient than kasugamycin while tested separately (JUNQUEIRA et al., 2011). For the control of bacterial fruit blotch caused by *Acidovorax avenae* subsp. *Citrulli* which affects melon (*Cucumis melo*), the best control of the disease occurred with kasugamycin, especially when alternated with copper oxychloride applications (OLIVEIRA et al., 2012).

It is noteworthy that kasugamycin at a dosage of 500 $mg.L^{-1}$ was very efficient to reduce populations of *Pseudomonas syringae* van Hall in kiwi (*Actinidia chinensis* Planch.), grape (*Vitis* spp.) and peach (*Prunus persicae* (L.) Batsch) according to Luisetti, Gaignard and Ride (1989).

The results obtained in the present study, based on the implemented conditions, are in agreement with the literature, in which kasugamycin is efficient in the control of bacterial blight in several cultures. Regarding the control of bacterial blight of coffee caused by *Pseudomonas syringae* pv. *garcae* Amaral, this active principle was significantly efficient (Figure 03), controlling the intensity of the disease in the crop and positively influencing the properties of vegetative vigor and productivity.

In Table 1, it is presented that there was no significant effect of the solution on the physical and chemical quality of the treated green coffee bean.

The values found in the percent analysis of the average of green bean treatments (Table 02) corroborate the averages found in the literature, demonstrating the quality of beans, as well as the beverage quality, which is extremely important for market acceptance, since the average values found in ether extract (lipids) are below the found average, which is 9% - 16% (TSUKUI; OIGMAN; REZENDE, 2013). Therefore, the values of carbohydrate (g) and energy (Kcal) are out of the average due to the conversion factor applied for the calculation, which considers the average values of the ether extract (lipids), according to the used methodology.

Thereby, it is understood that nothing can be stated on the influence of kasugamycin and copper hydroxide in the percent analysis, considering the time elapsed of harvesting, storage and laboratory analysis of approximately 12 months.

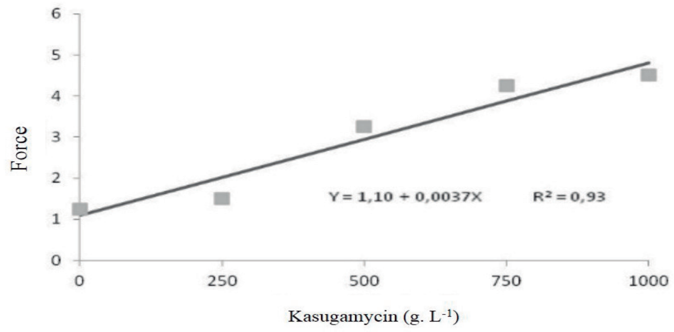

FIGURE 1 - Influence of kasugamycin on vegetative vigor of coffee plantation. Federal Institute of the South of Minas Gerais - Campus Muzambinho. Muzambinho, MG, Brazil. 2013.

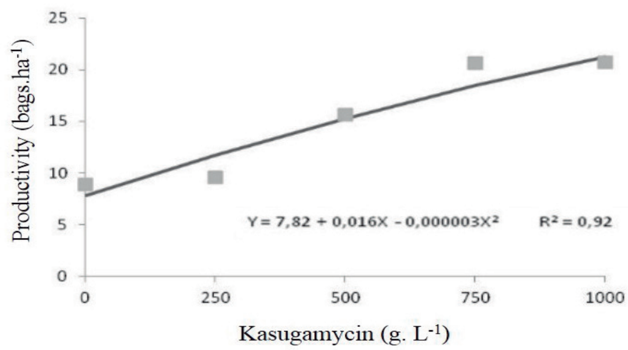

FIGURE 2 - Influence of kasugamycin on productivity of coffee plantation. Federal Institute of the South of Minas Gerais - Campus Muzambinho. Muzambinho, MG, Brazil. 2013.

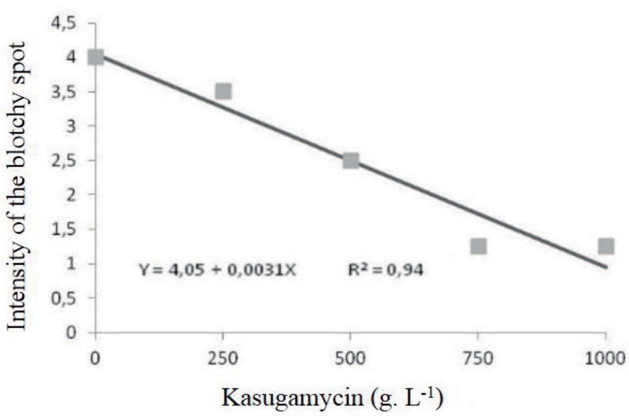

FIGURE 3 - Influence of kasugamycin on productivity of coffee plantation. Federal Institute of the South of Minas Gerais - Campus Muzambinho. Muzambinho, MG, Brazil. 2013.

TABLE 1 - Physical and chemical analysis of green coffee bean treated with kasugamycin and copper hydroxide. Federal Institute of the South of Minas Gerais - Campus Muzambinho. Muzambinho, MG, Brazil. 2013.

		Mean square (MS)				
Source of variation	GL	Moisture	Ash	Crude protein	Ether extract	Crude fiber
Kasugamycin	4	2.10ns	0.29ns	1.20ns	0.01ns	2.33ns
Block	3	2.67ns	15.82ns	0.60ns	2.47ns	0.82ns
CV(%)		11.17	10.88	5.35	8.79	9.83

*ns Not significant by F test

TABLE 2 - Averages of treatments of the green coffee bean *Catucaí 2SL* in 100 g of sample. Federal Institute of the South of Minas Gerais - Campus Muzambinho. Muzambinho, MG, Brazil. 2013.

Moisture	Mineral Matter	Crude Protein	Stereo Extract	Crude Fiber	Carbohydrates	Calorie Kcal
9,75	4,58	13,83	4,75	21,72	48,37	291,55

In this respect, it should be noted that stored seeds undergo a deterioration process caused by irreversible degenerative changes, which can be mitigated through proper management of environmental conditions during the storage period (CARVALHO; ALMEIDA; GUIMARÃES, 2014). Otherwise, peroxidation reactions are initiated, which consists on the spontaneous generation of free radicals through auto-oxidation or catalysis by oxidative enzymes, which contribute to the seed deterioration in the storage period (COELHO et al., 2015).

It is relevant to consider that coffee quality is related directly to several physical and chemical constituents and the chemical composition of the green coffee bean, and it is influenced by pre- and post-harvest management conditions as well as related to genetic and environmental factors (ABRAHÃO et al., 2010).

4 CONCLUSIONS

It is concluded that the kasugamycin mixture associated with copper hydroxide raises the vegetative vigor and productivity of the coffee tree; is efficient in the control of the bacterial blight of coffee and does not affect the physical and chemical quality of the green coffee bean.

5 ACKNOWLEDGEMENTS

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PERFORMANCE OF A SPECIAL TRACTOR AS A FUNCTION OF BALLASTING AND FRONT-WHEEL DRIVE IN COFFEE HARVESTING

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ABSTRACT: One of the main concerns before agricultural mechanization is the fuel cost from an economic and environmental point of view. In some literature, it has been demonstrated that the adequacy of tractors is directly related to consumption, which may become a strategy to reduce it. However, the studies were performed with conventional tractors, without information on how the special coffee tractors behave to the adequacy. In this respect, the aim of the present study was to evaluate the hourly fuel consumption in six possible adjustments of a special tractor in the operation of mechanized coffee harvesting. A 4x2 FWD tractor was used, with 52.2 kW power and 2400 kg mass, with 40% to the front axle and 60% to the rear to pull a Master Café 2 coffee harvester with 2900 kg mass without load. The treatments consisted of three ballast configurations in the tractor whether or not using auxiliary front-wheel drive (FWD). The adopted mass-power ratios were: 48, 52 and 56 kg kW^{-1}; obtained through the quantitative alteration of liquid and solid ballasts of the tractor, respecting the mass distribution between the axles recommended by the tractor manufacturer. The evaluations consisted of monitoring fuel consumption at regular hourly intervals, following the premises of statistical process control. It is concluded that the mass-power ratio of 56 kg kW^{-1} with driven FWD should be used in order to obtain lower slipping, lower average hourly fuel consumption and higher quality.

Index terms: Statistical process control, operating balance, fuel consumption.

DESEMPENHO DE UM TRATOR ESPECIAL EM FUNÇÃO DA LASTRAGEM E DO ACIONAMENTO TRAÇÃO DIANTEIRA AUXILIAR NO RECOLHIMENTO DE CAFÉ

RESUMO: Uma das principais preocupações perante a mecanização agrícola é o gasto de combustível, do ponto de vista econômico e ambiental. Em algumas literaturas é demostrado que a adequação de tratores está diretamente ligada ao consumo, podendo ser uma estratégia de redução do mesmo. Entretanto, os estudos foram realizados com tratores convencionais, não tendo informações sobre como os tratores especiais cafeeiros se comportam a adequação, neste sentido, objetivou-se neste trabalho avaliar o consumo horário de combustível em seis possíveis adequações de um trator de categoria especial na operação de recolhimento mecanizado de café. Utilizou-se um trator 4x2 TDA com 52,2 kW de potência e massa de 2400 kg, distribuída 40% na dianteira e 60% na traseira tracionando uma recolhedora Master Café 2 com massa 2900 kg sem carga. Os tratamentos constituíram de três configurações de lastros no trator utilizando ou não a tração dianteira auxiliar. As relações de massa-potência adotadas foram: 36 cv-1, 39 cv-1 e 42 kg cv-1; obtidas por meio da alteração quantitativa de lastros líquidos e sólidos do trator, respeitando-se a distribuição de massa entre os eixos recomendada pelo fabricante do trator. As avaliações consistiram em monitorar o consumo de combustível em intervalos regulares de uma hora, seguindo as premissas do controle estatístico de processo. Conclui-se que deve-se trabalhar na relação massa-potência de 42 kg ha-1 com a TDA acionada, para obter menor patinagem, menor consumo horário médio de combustível e maior qualidade.

Termos para indexação: Controle estatístico de processo, equilíbrio operacional, consumo de combustível.

1 INTRODUCTION

There are few studies with mechanized coffee harvesting, however, this phase is essential in mechanized harvesting areas, since the coffee naturally dropped before harvest plus the dropped coffee from the harvester can represent up to 20% of the total load (SANTINATO et al., 2015b; TAVARES et al., 2015). The hand-picked coffee is almost unviable due to the low operating capacity and the labor costs (LANNA; REIS, 2012; SANTINATO et al., 2015a).

In modern coffee growing, the resource management is increasingly viewed in a business way, analyzing costs and using strategies to increase profitability in the short, medium and long terms (CUNHA et al., 2016; FERNANDES et al., 2012, 2016). In recent years, mechanization is evident in all productive stages; however, the concern of managers is to use machines in a rational and economic way (SANTOS; SILVA; GADANHA JUNIOR, 2014).

Among the mechanization costs, fuel is one of the main components, although this consumption is connected to the type of operation, machine and environment (MONTANHA et al., 2011). According to Miranda, Oliveira and Nunes (2000), the fuel consumption of tractors can be reduced, increasing their use efficiency or reducing the need for useful energy within agricultural operations.

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Fuel consumption and traction performance are influenced by soil conditions, tire size, load/pressure ratio, mass distribution on axles and type of carcass (radial/diagonal), angle and height of claws (SPAGNOLO et al., 2013). Moreover, the presence and use of the auxiliary front-wheel drive (FWD) can increase the traction level of the mechanized set (RALALDI et al., 2016).

Another important factor is the advancement or kinetic relationship that represents the number of turns that the front axle gives while the rear axle gives one turn with driven FWD. According to Prade et al. (2016), this advance should be between 1% and 5% for an adequate displacement of the tractor. The advance rate can be altered by changing the tire type or internal tire pressure (FEITOSA et al., 2015).

However, most of the studies with adequacy are performed with conventional-sized tractors, while in the coffee-growing field are used special (compact) tractors, and there are no studies that guide the adequacy of this class in coffee operations.

In this respect, knowing that the tractor should pull a machine that demands a lot of energy for the harvesting operation, it is assumed that the tractor's adequacy can reduce the slipping and the fuel consumption. Thus, the aim of the present study was to evaluate the hourly fuel consumption and slipping on mechanized coffee harvesting in three working configurations, whether or not using auxiliary front-wheel drive (FWD).

2 MATERIAL AND METHODS

The study was performed in a coffee plantation in the municipality of Presidente Olegário, Minas Gerais, Brazil, close to the geodesic coordinates 18°02' S and 47°27' W, with average altitude and slopes of 917 m and 3%, respectively. The farming is characterized by a traditional savanna with commercial crop of *Catuaí Vermelho IAC 144* variety and spacing of 4.00 m between rows and 0.50 m between plants, totaling 5000 plants ha^{-1}, with 10 years of age. There was no turnover in the interlines, showing firm ground.

The used mechanized set consisted of a tractor John Deere 5425N 4x2 FWD with 52.2 kW (75 hp) in the engine (nominal rotation) operated in the speed of 1.26 km h^{-1} at 1700 rpm and a MIAC Master Café 2 harvester with 2900 kg mass and 1.40 m working width equipped with an axial cleaning system and bulk tank with 3000 L capacity. The tractor was equipped in the front and rear wheels with 9.5x16 and 14.9x24 diagonal tires, respectively.

The treatments consisted of three ballast configurations in the tractor, resulting in mass-power ratios of 48, 52 and 56 kg kW^{-1}. The tractor shows 2400 kg mass without ballast, with 40% to the front axle and 60% to the rear. For the 48 kg kW^{-1} ratio, only 50% liquid ballast (water) was used in the front and rear tires, increasing 160 kg and 238 kg in the front and rear axles, respectively. In the 52 kg kW^{-1} ratio, four metallic ballasts of 47 kg without liquid ballast were used in the front axle, while in the rear axle were used two metallic ballasts of 48 kg and 75% liquid ballast in the tires (totaling 356 kg of liquid ballast in both tires). For the 56 kg kW^{-1} ratio, three metallic ballasts of 47 kg and 75% liquid ballast (228 kg) were used in the front axle, while in the rear axle were used two metallic ballasts of 48 kg and 75% liquid ballast in the tires (356 kg liquid ballast). For each configuration, the mechanized set was operated with or without driven the auxiliary FWD. In all the treatments, the advance and the slipping were measured using an electronic measurement system developed by the "Finger do Brasil", also adjusting the tire pressure according to the load and speed (LATIN AMERICAN TIRE AND RIM ASSOCIATION - ALAPA, 2008). The advance measurement system has two sensors that are positioned on the outer left-wheel of the tractor, which send the reading to a digital receiver that calculates and provides the advance and slipping information. The advance is evaluated at a distance of approximately 200 m, verifying the percentage of difference in the number of turns of the wheels with or without driven the FWD. The slipping is obtained by the ratio of the number of tire turns in a linear distance of 50 m without operating (in transport) and the same distance under operation, computed automatically by the sensors.

Hourly fuel consumption was obtained by monitoring the operation over time at hourly regular intervals. Ten supplies were performed for each mass-power configuration with the tractor operating with or without driven the FWD. At each working hour, the tractor's hour meter was collected, the fuel was replaced and the consumption obtained according to the methodology described by Barbosa et al. (2008).

As performed by Tavares et al. (2015), the data were first analyzed through descriptive statistics using measures of central tendency and dispersion. For measures of central tendency, an arithmetic mean was used, allowing finding a mean value of data for each treatment; the median refers to a found value that separates the data, having the same amount of data below and above the same. The used dispersion measures were: data amplitude, standard deviation and coefficient of variation. These measures show how the data behaves around the mean. Measurements of skewness and kurtosis were also used.

The coefficient of skewness (Cs) quantifies how far the variable is in relation to a central value, characterizing how and how much the frequency distribution of the data is longer from the symmetry, being that when the Cs is greater than zero, there is an asymmetric distribution with a tendency of these values to be to the right of the central value; when Cs is below zero (of a negative nature), the distribution is asymmetric, tending to the left; and if Cs is equal to zero, the distribution is symmetric, i.e., there is a balance among data distribution (ORMOND et al., 2016).

The coefficient of kurtosis, identified as Ck, which can be classified as a weight measure of the distribution causes, indicating the dispersion (flattening and stretching) of the data distribution in relation to a pattern, being usually the normal curve. The kurtosis receives the following classification: the index equal to zero (Ck=0) indicates a normal mesokurtic distribution; whether Ck is lower than zero (Ck<0), i.e., a negative value, the distribution is platykurtic (thinner tails) and whether Ck is greater than zero (Ck>0), the distribution is leptokurtic (fatter tails) (ORMOND et al. al., 2016).

The coefficient of variation followed the classification of Pimentel-Gomes and Garcia (2002), which classifies as low (lower than 10%); medium (from 11 to 20%); high (from 21 to 30%) and very high (greater than 30%). To verify the data normality, the used test was the Anderson-Darling, whose objective is to measure the proximity between the points and the fitted line of the probability plot, as used by Cassia et al. (2013).

Afterwards, the consumption behavior was analyzed through statistical process control using the control charts for individual values in order to allow verifying the stability of the process. According to Voltarelli et al. (2013), control charts present all the observations obtained in the evaluations as well as their variability and behavior over time.

These charts show three rows, the center line representing the mean value while the other two represent the upper and lower control limits (UCL and LCL, respectively), being calculated based on the standard deviation of variables (for UCL, mean plus three times the standard deviation, and for LCL, mean minus three times the standard deviation, when greater than zero), indicating that if the process is under control, the points will be between the two threshold lines. Whether the points are outside the upper and lower control limits or are within limits, but presenting a non-random pattern, the process is given as potentially out of control, requiring an investigation to find corrective measures seeking to eliminate the causes responsible for such variation (VOLTARELLI et al., 2015).

3 RESULTS AND DISCUSSION

For the treatment 48 kg kW^{-1}, the advance rate was 2.53% and 5.37% slipping, for the 52 kg kW^{-1}, the advance rate was 1.8% and 2.88% slipping, while the treatment 56 kg kW^{-1} showed the advance rate of 2.28% and 0.01% slipping. Several studies indicate that ideal slipping varies from 5 to 15%, in loose ground values close to 15% are accepted while values close to 5% for firm ground (SERRANO et al., 2008); however, these studies were not performed with tractors, thus precluding the decision-making. It is believed that slipping results may be lower when working on firm terrain with low slope and at speeds around 1.3 km h^{-1}. Regarding the advance rate, it can be observed that the values were acceptable (0 to 5%) in all configurations, according to the recommendation established by Prade et al. (2016).

Based on the descriptive statistics of the fuel hourly consumption results (Table 1), it was noted that the data presented a normal distribution in all treatments, except for the treatment 52 kg kW^{-1} with the driven FWD, showing a non-normal distribution. Moreover, the means and medians have close values, being that the greatest difference occurs in the configuration where the data do not show normal distribution. The values found for the data amplitude of each configuration were low. On the other hand, the values of the standard deviation and coefficient of variation were high for the treatments 48 kg kW^{-1} with FWD and 52 kg kW^{-1} without FWD. For the other treatments, the values were medium, according to the classification of Pimentel-Gomes and Garcia (2002).

TABLE 1 - Descriptive statistics for fuel consumption as a function of the mass-power ratio and the use of auxiliary front-wheel drive.

Treatment		Average	Median	σ	Amplitude	CV	Cs	Ck	AD
48 kg kW^{-1}	with FWD	7.25	7.11	1.52	3.99	20.93	0.14	-1.81	0.43^N
	without FWD	7.35	7.10	0.75	2.54	10.18	1.83	3.66	0.78^N
52 kg kW^{-1}	with FWD	7.05	6.52	1.34	4.00	18.96	1.76	2.02	1.37^A
	without FWD	7.66	7.27	1.73	4.92	22.63	0.09	-1.08	0.30^N
56 kg kW^{-1}	with FWD	6.39	6.57	0.71	2.22	11.11	1.16	0.50	0.62^N
	without FWD	7.28	7.50	0.81	2.62	11.17	-0.8	0.21	0.75^N

σ - Standard deviation; CV (%) - Coefficient of variation; Cs - Coefficient of skewness; Ck - Coefficient of kurtosis; AD - Anderson-Darling normality test (N: normal distribution; A: non-normal distribution).

It is also observed that the values of the coefficient of skewness in the treatments 48 kg kW^{-1} with FWD and 52 kg kW^{-1} without FWD had small skewness degrees to the right, while the treatments 48 kg kW^{-1} without FWD, 52 kg kW^{-1} with FWD and 56 kg kW^{-1} with FWD had a high skewness degree to the right. On the other hand, the treatment 56 kg kW^{-1} without FWD had moderate skewness degree to the left. By the coefficient of kurtosis, it was observed that the treatments 48 kg kW^{-1} with FWD and 52 kg kW^{-1} without FWD had a platykurtic distribution of the curve, while the other treatments showed leptokurtic (fatter tails) distribution.

In the control charts of the hourly fuel consumption (Figure 1) for configuration of 48 kg kW^{-1}, it can be observed that the averages were considerably close by whether or not using the FWD, resulting in average consumption of 7.25 and 7.35 L h^{-1}, respectively. On the other hand, there is a considerable difference in the variability of values, in which a greater consumption variability is observed when the harvesting operation is performed with FWD, which was also found in the moving range charts. However, despite the variability, whether or not using the FWD in the 48 kg kW^{-1} configuration demonstrates stability in the process.

A study performed in field operation by Fontana et al. (1986) showed that the use of auxiliary FWD increased hourly fuel consumption by 5.82%, although provided an average increase of 5.76% in operating capacity. Lopes et al. (2003) emphasized that fuel consumption is not only dependent on whether or not using the auxiliary FWD, but rather on a number of factors, including tire type, inflation pressure, soil type and ballasting.

Fiorese et al. (2015) found that the tractor load (mass-power ratio) together with the energy demand of the operation causes that the fuel consumption (energy demand) is changed as a function of the FWD usage. Thus, it is believed that the 48 kg ha^{-1} ratio is not indicated for the harvesting operation due to the greater harvester mass in relation to the tractor mass, which leads to the combination that generates the highest average hourly consumption when compared to the other configurations. The performance of this operation with the lightweight (low ballast) tractor is against the safety principles, having a high susceptibility to slipping and lateral slippage mainly in places with more sloping terrain.

For treatments in which the mass-power ratio is 52 kg kW^{-1} (Figure 2), it is verified that the use of FWD had an average hourly fuel consumption of 7.05 L h^{-1}, 7.96% (0.61 L h^{-1}) hourly consumption saving in relation to the performance of the service without driven the FWD. It can also be verified that the use with driven FWD generates less variability in the hourly fuel consumption when compared to the FWD off. However, when FWD was used, there was an out-of-control point, evidencing some special cause that makes the process unstable, which can be attributed to the machine and to the environment in which the collector was jammed due to the excess of mineral impurities in the collected material.

Miranda, Oliveira and Nunes (2000) mentioned that fuel consumption is not significantly altered considerably, but reduced slipping increases the operating capacity, resulting in lower operating consumption. In this respect, Schlosser and Dallmeyer (1988) mentioned that the use of FWD in soil preparation operations reduced slipping and increased by 17% the operating capacity.

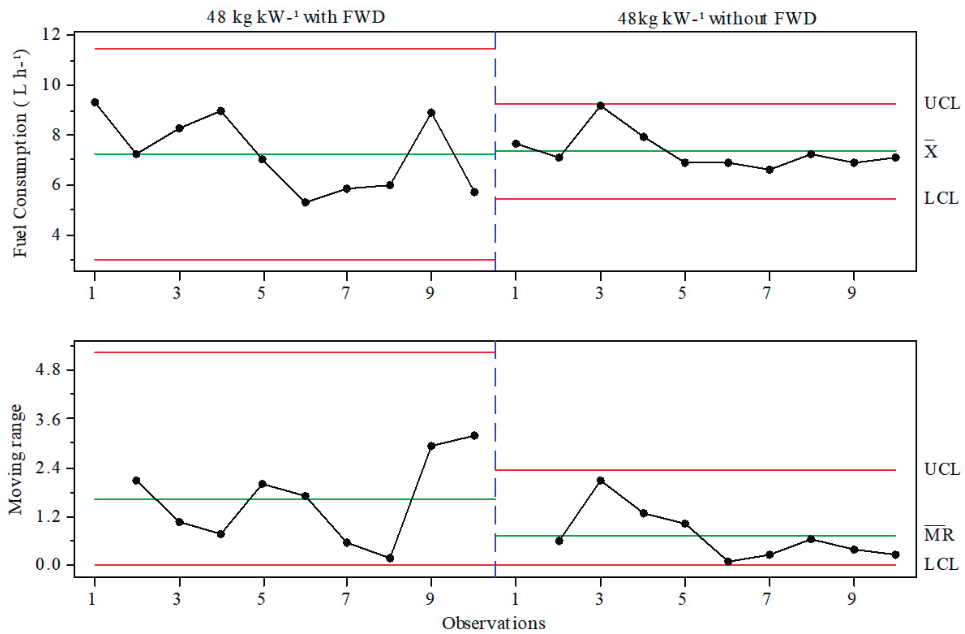

FIGURE 1 - Control charts of individual values and moving range for hourly fuel consumption in the configuration 48 kg kW[-1] with and without auxiliary front-wheel drive (FWD).

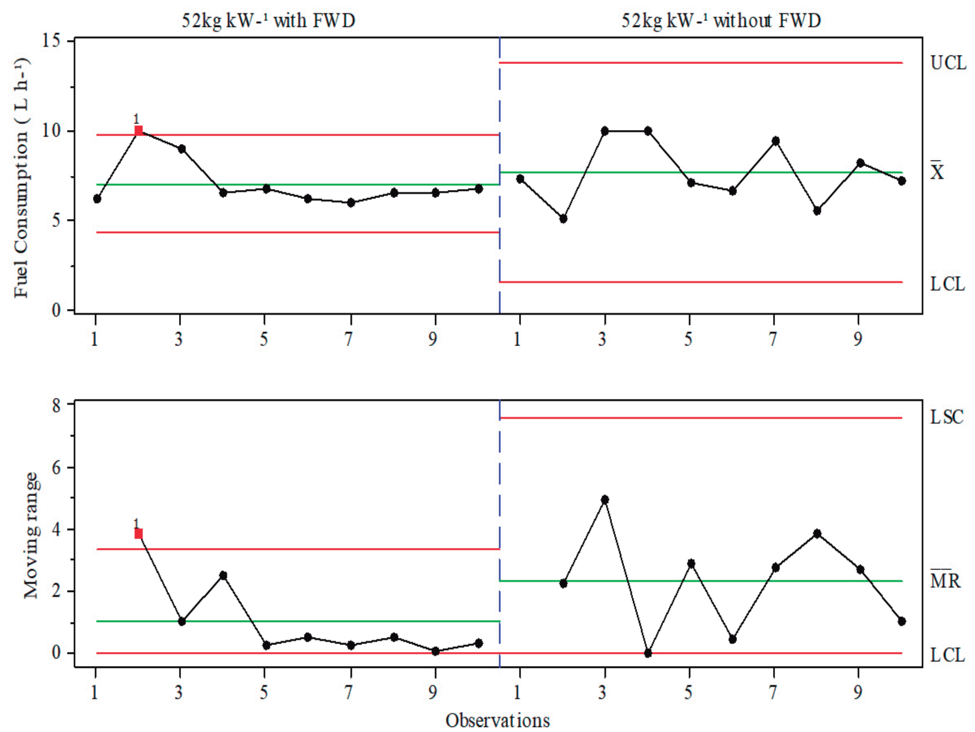

FIGURE 2 - Control charts of individual values and moving range for hourly fuel consumption in the configuration 52 kg kW[-1] with and without auxiliary front-wheel drive (FWD).

Thus, it is believed that the results obtained in this ratio 52 kg ha^{-1} (standard ratio of coffee tractors) be explained since it deals with a special tractor category (coffee), resulting in lower hourly fuel consumption for harvesting.

In the configuration 56 kg kW^{-1} (Figure 3), a similar behavior to the 52 kg kW^{-1} was observed (Figure 2), in which the use of the driven FWD promotes a lower fuel consumption as well as lower variability in the mean values obtained over time. Thus, it is observed that the average hourly consumption in the treatment 56 kg kW^{-1} with FWD was 12.22% (0.89 L h^{-1}) lower than 56 kg kW^{-1} without FWD, which throughout a harvest can represent a high saving in the operating costs of the operation under study.

On the other hand, the first observation of the individual chart values of the treatment with FWD is outside the control limits, causing instability. However, once it is a value below the lower control limit, this observation refers to a lower average consumption value, thus being economically desirable. The possible explanation for this low fuel consumption value would be the characteristic of piles that, when there is a lower level of material to be collected, demand less energy from the tractor to the harvester.

Given all the presented results, it is possible to note an influence of the activation of the auxiliary traction in relation to the hourly fuel consumption for special tractors (coffee trees). For the harvesting operation, the use of 56 kg kW^{-1} with driven FWD generates the lowest fuel consumption when compared to the other tested configurations. This configuration makes the tractor more suitable to pull a machine with a mass bigger than its own mass, improving the traction power and reducing the fuel consumption. This hypothesis is confirmed by the lower average value, among all treatments, of hourly fuel consumption and lower range, therefore with greater reliability in the obtained results. The adoption of the 56 kg kW^{-1} ratio with driven FWD leads to lower fuel consumption, reducing up to 1.27 L h^{-1}, showing best cost-effectiveness and economic viability. Once the total working hours in this operation is high, even small differences in hourly consumption averages would result in a large amount at the end of harvest.

Montanha et al. (2011) state that in operations, such as harvesting, where the harvester has a larger mass than the tractor, it is extremely important to use the FWD in order to provide greater stability in the operation, thus becoming safer to the operator.

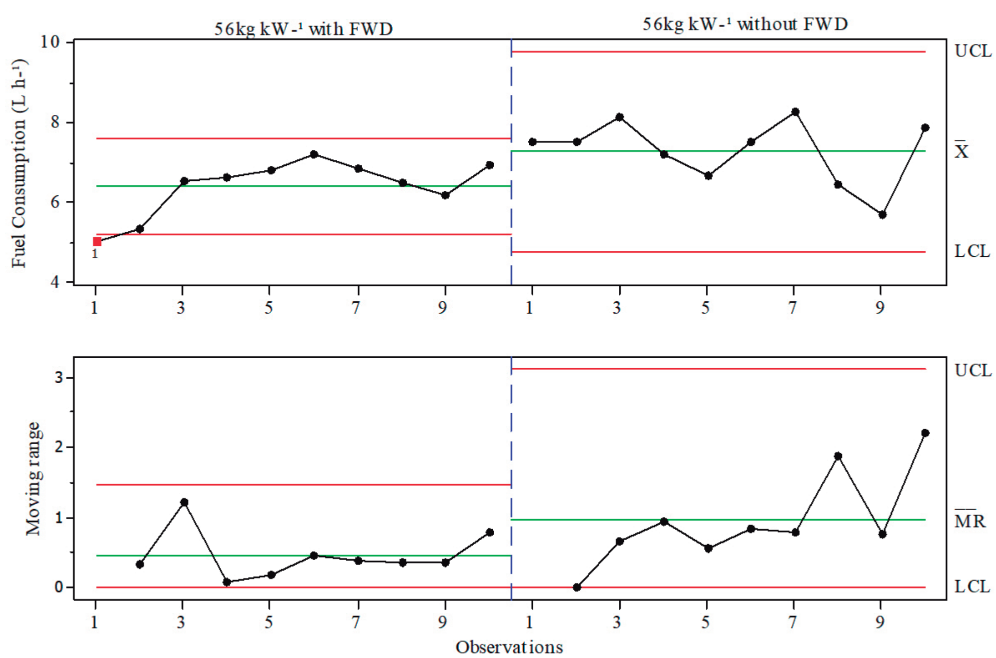

FIGURE 3 - Control charts of individual values and moving range for hourly fuel consumption in the configuration 56 kg kW^{-1} with and without auxiliary front-wheel drive (FWD).

4 CONCLUSIONS

The best performance of the special coffee tractor in the coffee harvesting was observed in the mass-power ratio 56 kg kW^{-1} operating with the driven FWD, resulting in lower fuel consumption.

The adequacy of ballasts to the operation reduced fuel consumption by up to 1.27L h^{-1} in the harvesting, besides reducing slipping.

Statistical process control proved to be effective in monitoring the fuel consumption variability throughout the operation

5 ACKNOWLEDGEMENTS

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PLANT SAMPLING GRID DETERMINATION IN PRECISION AGRICULTURE IN COFFEE FIELD

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ABSTRACT: The aim of the present study was to evaluate different grid samples applied to plant properties of a coffee plantation by using precision coffee growing and geostatistical techniques. The study was performed at the Brejão Farm in the municipality of Três Pontas, MG, Brazil, using productivity, the maturation index and the detachment force difference, sampled at georeferenced points. With the intention of choosing an optimum grid, 20 grid samples were tested through semivariogram fitting and validation tests seeking to combine the accuracy and precision that the grid sample can present through an optimal grid indicator, allowing choosing a more suitable grid. It was possible to characterize the magnitude of the spatial variability of plant properties under study in all the proposed grids. The grid that best represented the three variables under study was the grid with 64 sample points in squared grid and nine zoom grid points. The proposed methodology for the present study allowed observing the difference among different grid samples and among the variables of plant productivity, maturity index and detachment force.

Index terms: Precision agriculture, geostatistics, coffee tree, spatial variability.

DETERMINAÇÃO DE MALHAS AMOSTRAIS DA PLANTA EM CAFEICULTURA DE PRECISÃO

RESUMO: O objetivo do presente trabalho foi estudar diferentes grades amostrais aplicadas aos atributos da planta de uma lavoura cafeeira por meio do uso da cafeicultura de precisão e das técnicas geoestatísticas. O trabalho foi realizado na fazenda Brejão no município de Três Pontas - MG, utilizando-se a produtividade, o Índice de Maturação e a Diferença da Força de Desprendimento, amostrados em pontos georreferenciados. Para que pudesse ser escolhida uma grade ótima, foram testadas 20 grades amostrais, por meio do ajuste de semivariogramas e testes por validação, buscando aliar a exatidão e a precisão que a grade amostral pode apresentar por meio de um indicador de grade ótima, o que permite a escolha de uma grade mais adequada. Foi possível caracterizar a magnitude da variabilidade espacial dos atributos da planta em estudo em todas as grades propostas. A grade que melhor representou as três variáveis em estudo foi a grade com 64 pontos amostrais em malha quadrada e 9 pontos de grade zoom. A metodologia proposta por este trabalho permitiu observar a diferença existente entre as diferentes grades amostrais e também entre as variáveis da planta produtividade, índice de maturação e força de desprendimento

Termos para indexação: Agricultura de Precisão, geostatistica, cafeeiro, variabilidade espacial.

1 INTRODUCTION

According to Ferraz et al. (2012c), the precision agriculture of the coffee growing has been termed as precision coffee growing, being define by the authors as a set of techniques and technologies capable of assisting the coffee farmer to manage the crop, based on the spatial variability of soil and plant properties, in order to maximize profitability, increase efficiency of fertilization, spraying and harvesting, thus increasing productivity and the product's final quality. Additionally, according to Ferraz et al. (2011), precision coffee growing may be an economically viable technique for producers.

It is known that the coffee cultivation in Brazil occurs within a diversity of factors that can strongly influence the coffee productivity and the crop management homogeneously and lead to a reduced profitability to the rural producer. In this respect, spatial analyses of productivity tend to provide a more efficient management of the production process (ALVES et al., 2009). Based on spatial variability maps of productivity, the producers can identify crop areas where productivity can be improved or require adjustments in the fertilizer recommendation in order to optimize the income of the property (PIERCE et al., 1997).

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The fruit harvesting is characterized by being more difficult to study than other crops such as cereals due to the characteristics as plant shape, non-uniform ripeness of fruits and high moisture of fruits. Silva et al. (2006) indicated that the maturation index (MI) allows defining the harvest period of each plot, being that 20 to 25% green fruits characterize the beginning of the harvest (MI from 75 to 80%), 10 to 15% green fruits represent the middle of the harvest (MI from 85 to 90%) and less than 5% for the end of the harvest (MI of 95%). Silva (2008) observed that the detachment force of green fruits was 73% higher than the cherry fruits, and that this difference could be a relevant factor for the selective mechanized harvest of coffee fruits. Thereby, the study on the spatial variability of the MI and the detachment force of coffee fruits allied to the productivity study may be extremely important for a better mechanized harvesting operation.

Spatial variability is one of the premises for the application of precision coffee growing and its identification is very difficult for farmers. The use of grid samples allows the coffee grower observing this variability, but the use of grids with unsatisfactory size can generate maps that do not reflect the field and therefore generating erroneous recommendations, which may cause losses to the producers. Thus, the study of grid samples becomes highly relevant for the more precise management of the spatial variability of plant properties in a coffee plantation, particularly aiming the mechanized harvest.

The aim of the present study was to evaluate different grid samples applied to the plant properties (productivity, MI and detachment force) of a coffee plantation using precision coffee growing and geostatistical techniques in order to find a grid sample best fitted to the variables under study.

2 MATERIAL AND METHODS

The experiment was developed at the Brejão Farm, in the municipality of Três Pontas, southern of the state of Minas Gerais, Brazil, in an area of 22 ha of coffee (*Coffea arabica* L.) cv. Topázio transplanted in December 2005 at a spacing of 3.8 m between the lines and 0.8 m between plants, totaling 3289 plants.ha^{-1}. The geographic coordinates of the center point of the area are 21°25'58" S and 45°24'51" WGr. The limit points of the area were obtained using topographic GPS (mean error of 10 cm).

The climate of the region is Cwa according to Köppen classification, characterized as mild, high altitude tropical climate, hot and rainy summer (SÁ JUNIOR et al., 2012). The soil of the area was classified as clayey dystrophic red latosol (FERRAZ et al., 2017; JACINTHO et al., 2017).

A regular square grid sampling of 57 x 57 m was demarcated in the study area, totaling 64 georeferenced sample points (2.9 points per hectare) using topographic GPS. Within this regular grid sampling, another four regular grid samples of 3.8 x 3.8 m were created, called zoom, which were positioned at four points of the main grid. Each zoom will correspond to 10 georeferenced sample points (one point of the main grid and nine of the new grid). Thus, the initial grid sampling consisted of 100 georeferenced points (Figure 1a).

Each sampling point corresponds to four plants: two located in the coffee line where the point was georeferenced and the other two in each lateral line to the reference point.

The use of zoom grids aims to detect variations in small distances, collaborating to reduce the nugget effect and hence contributing to improve the used grid. This type of sampling using smaller grids (zoom) within a larger grid was also used in the studies of Gontijo et al. (2007) and Sampaio et al. (2010).

Based on the initial grid, another 19 grids were created (Table 1 and Figure 1). The grids were grouped into four groups that were based on base grids. In Group 1, the base grid had 64 georeferenced sample points (2.9 points per hectare) (grid 5); in Group 2, the base grid had 46 points (2.09 pt/ha) (grid 10); in Group 3, the base grid had 23 points (1.04 pt/ha) (grid 15); and the Group 4, the base grid had 12 georeferenced sample points (0.54 pt/ha) (grid 20).

The initial grid of each group consists of the base grid plus four zoom grids. The second grid of each group consists of the initial grid of the group removing the grid that is in the southeast portion of the area. The third grid is characterized by the second grid of the group removing the zoom grid of the northwest portion of the area. To form the fourth grid, the third grid was used removing the zoom grid in the northeast portion of the area. The fifth grid is characterized only by the base grid (Figure 1). Three properties related to the plant were collected: productivity, MI and fruit detachment force. The collection of coffee plant properties such as productivity, MI and detachment force was performed in 2011.

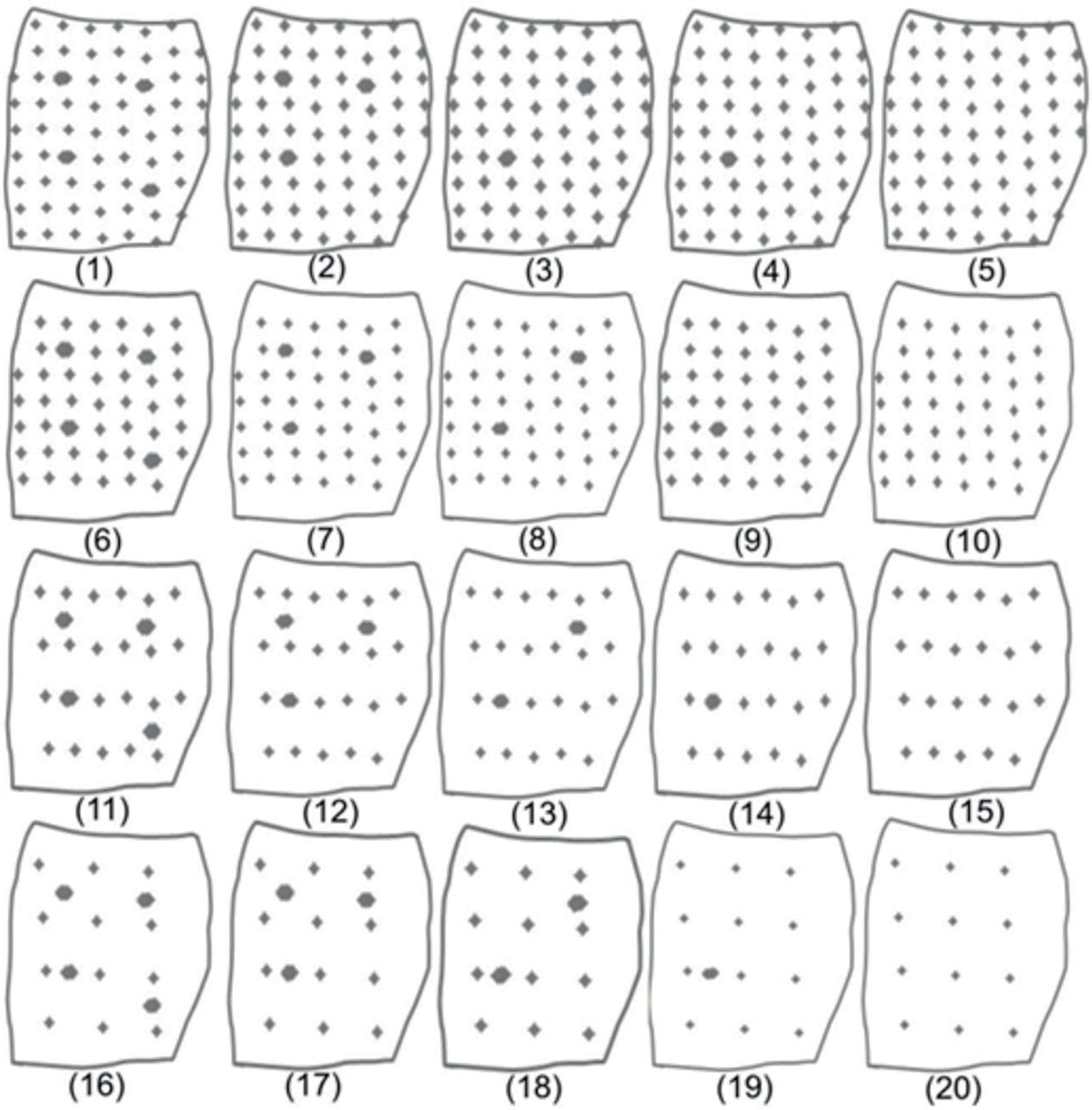

FIGURE 1 - Grid sampling tested in the study area.

The coffee productivity ($L.plant^{-1}$) was obtained by manual harvesting on cloths of the four plants around the sampling point, and the volume harvested from each plant, after cleaning, was measured in a graduated container in liters. After this measurement, the average yield of these four plants was obtained, resulting in the productivity value for the sampling point.

At each sampling point, after the productivity measurements, the harvested fruits from the four plants were placed in the same container, being homogenized to take a 0.5 L sample of fruits (CARVALHO et al., 2003; SILVA, 2008). Based on this volume, the fruit counting was performed for each ripeness stage (dry, raisin, cherry and green) and transformed them as percentage so that the equation (Maturation Index) described by Alves et al. (2009) could be used:

$$MI = \sum \%cherry, \%raisin, \%dry$$

TABLE 1 - Evaluated grid samples divided into groups showing the sample points of the base grid, the amount of zoom grid, the zoom grid points and the total points of each grid sample.

Group	Grid	Sample points of the base grid	Amount of zoom grids	Sample points of the zoom grid	Total points
1	1	64	4	36	**100**
	2	64	3	27	**91**
	3	64	2	18	**82**
	4	64	1	9	**73**
	5	64	0	0	**64**
2	6	46	4	36	**82**
	7	46	3	27	**73**
	8	46	2	18	**64**
	9	46	1	9	**55**
	10	46	0	0	**46**
3	11	23	4	39	**62**
	12	23	3	30	**53**
	13	23	2	20	**43**
	14	23	1	10	**33**
	15	23	0	0	**23**
4	16	12	4	40	**52**
	17	12	3	30	**42**
	18	12	2	20	**32**
	19	12	1	10	**22**
	20	12	0	0	**12**

In order to obtain the fruit detachment force (DF) data, five fruits were collected (two from the upper third, one from the middle third and two from the lower third), according to the methodology proposed by Ferraz et al. (2017), for each ripeness stage (green and cherry) at every plant from the sampling point. After collecting these fruits, the average of the detachment force of the four plants was obtained for each ripeness stage.

The determination of this detachment force was performed through a portable digital dynamometer model DD-500 manufactured by Instrutherm Instrumentos de Medição Ltda. that offers measurements in Newton.

After obtaining the green fruit detachment force (GDF) and the cherry fruit detachment force (CDF), the detachment force difference (DFD) was obtained as follows:

$$\text{DFD} = \text{GDF} - \text{CDF}$$

The spatial dependence of plant properties of the coffee plantation were analyzed by semivariogram fitting, estimated as follows:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h)\right]^2$$

where N (h) is the number of experimental pairs of observations $Z(x_i)$ and $Z(x_i + h)$ separated by a distance h. The semivariogram is represented by the graph $\hat{\gamma}(h)$ versus h. From the fit of a mathematical model to the calculated values of $\hat{\gamma}(h)$, the coefficients of the theoretical model were estimated for the semivariogram called nugget effect (C_0); sill (C_0+C_1); and range (a), as described by Bachmaier and Backers (2008).

The ordinary least squares (OLS) method and the spherical model were used for all the studied variables and for all the tested grids. According to Webster and Oliver (2007), the spherical mathematical model is most often used in geostatistics. This model is widely used on spatial variability studies in coffee crops of soil properties, productivity, defoliation, fruit detachment force and pest infestation (ALVES et al., 2009; FERRAZ et al., 2012b; MOLIN et al., 2010; SILVA et al., 2007, 2008; SILVA, A. et al., 2010; SILVA, F. C. et al., 2010).

The spatial dependence degree of properties under study were analyzed through the classification of Cambardella et al. (1994), in which semivariograms with strong spatial dependence show a nugget effect < 25% sill, moderate between 25 and 75% and weak > 75%.

According to Isaaks and Srivastava (1989), validation is the error estimation technique that allows comparing predicted values with the sampled ones. The sample value, at a certain location $Z(s_i)$, is temporarily discarded from the data set, and then a (ordinary) kriging prediction is performed on the location $\hat{Z}(s_{(i)})$, using the remaining samples. Thereby, it is possible to extract some values that will be very useful for observing the errors presented by each grid, such as absolute error (AE), standard deviation of absolute error (SD_{AE}).

The selection criteria based on cross-validation should find the AE value closer to zero and the value of SD_{AE} as lower as possible. These criteria can be obtained by using the following expressions:

$$AE = \frac{1}{n}\sum_{i=1}^{1}\left(Z(s_i) - \hat{Z}(s_{(i)})\right)$$

$$SD_{AE} = \sqrt{\frac{1}{n}\sum_{i=1}^{1}\left(Z(s_i) - \hat{Z}(s_{(i)})\right)^2}$$

where: n is the data number; $Z(s_i)$ is the value observed at point s_i; and $\hat{Z}(s_{(i)})$ is the value predicted by ordinary kriging at point s_i, excluding the observation $Z(s_i)$.

The AE value reflects the accuracy of the grid sample, since the accuracy gives conceptually an idea of the conformity degree of a measured or calculated value in relation to a standard reference. The AE compares the values obtained by validation with the actual values obtained by the field samplings. In order to be able to find an accuracy component that would allow comparing among the grids, the accuracy index (AI) was developed.

The AI is given by the AE value of the grid, in module, divided by the largest value, in module, of the absolute error (mAE) presented by the analyzed grids.

$$AI = \frac{AE}{mAE}$$

On the other hand, the value of the SD_{AE} reflects the grid accuracy, where by definition the accuracy is used to express the dispersion of results. Moreover, the precision index (PI) was developed to compare the accuracy component of the grid among the different studied grids.

The PI is given by the value of SD_{AE} of the grid divided by the highest value of the standard deviation of absolute error (mSD_{AE}) presented by the group of analyzed grids.

$$PI = \frac{SD_{AE}}{mSD_{AE}}$$

In order to select the best grid sampling (optimum grid) among the 20 studied grids, the optimum grid indicator (OGI) was created, which considers both AI and PI. The OGI is given by:

$$OGI = (0{,}5xAI) + (0{,}5xPI)$$

The OGI ranges from zero to one, being that the closer the zero, the better the grid (more accurate and more precise), while the closer to one, the worse (the more inaccurate and imprecise) is the grid.

The data was tabulated in electronic spreadsheets. For the geostatistical analysis, the R statistical software was used, through the geoR package (RIBEIRO JUNIOR; DIGGLE, 2001).

3 RESULTS AND DISCUSSION

Based on the geostatistical analysis methodology, it was possible to quantify the magnitude and structure of spatial dependence of productivity (Prod), Maturation Index (MI) and the detachment force difference (DFD) and in all the grids under study (Table 2). The absolute value of the difference between two observed samples increased when the samples distanced away until a value in which the locality no longer influenced, resulting in the stability of the experimental semivariogram from the distance separating the structured variability from the random one.

The nugget effect is an important parameter of the semivariogram and indicates unexplained variability, considering the sampling distance used. For the Prod variable, the nugget effect ranged from 0 (grid 10 and 15) to 1.84 (grid 3) (Table 2). The MI ranged from 43.38 (grid 20) to 353.13 (grid 4) (Table 2). For the DFD, the nugget effect ranged from 0 (grid 19 and 20) to 0.64 (grid 12) (Table 2).

TABLE 2 - Parameters estimated by the semivariogram fitted by the ordinary least squares method and by the spherical model, validation parameters and grid choice indices for productivity (Prod), maturation index (MI), and detachment force difference (DFD).

Grid	NPG	Max dist	C_0	$C_0 + C_1$	C_1	a	DD		SP	$SD_{(AE)}$	AI	PI	OGI
						Productivity (Prod)							
1	100	285	1.40	0.44	1.84	125.74	76.19	Weak	0.0011	1.33	0.0655	0.8165	0.4410
2	91	290	1.14	0.90	2.04	241.28	56.10	Mod	0.0042	1.34	0.2482	0.8212	0.5347
3	82	390	1.84	0.31	2.14	354.63	85.58	Weak	0.0032	1.39	0.1867	0.8532	0.5199
4	73	300	1.05	1.08	2.13	287.61	49.35	Mod	0.0042	1.29	0.2453	0.7919	0.5186
5	64	290	1.20	1.00	2.19	261.53	54.54	Mod	0.0036	1.31	0.2091	0.7993	0.5042
6	82	243	1.50	0.40	1.90	113.24	79.03	Weak	0.0017	1.36	0.0995	0.8296	0.4645
7	73	243	1.60	0.50	2.10	272.18	76.19	Weak	0.0050	1.39	0.2929	0.8521	0.5725
8	64	300	1.58	0.65	2.23	274.94	70.72	Mod	0.0066	1.46	0.3883	0.8903	0.6393
9	55	243	0.83	1.20	2.03	214.99	40.98	Mod	0.0121	1.39	0.7078	0.8513	0.7796
10	46	243	0.00	2.14	2.14	165.34	0.00	Str	0.0121	1.39	0.7078	0.8513	0.7796
11	62	223	1.00	0.93	1.93	130.08	51.82	Mod	-0.0001	1.40	0.0041	0.8570	0.4306
12	52	223	1.13	0.93	2.06	178.36	54.74	Mod	0.0027	1.49	0.1608	0.9114	0.5361
13	42	223	1.28	1.30	2.58	216.09	49.71	Mod	0.0028	1.63	0.1612	1.0000	0.5806
14	32	223	0.75	1.45	2.20	175.96	34.03	Mod	0.0095	1.47	0.5585	0.9021	0.7303
15	23	223	0.00	2.64	2.64	117.98	0.00	Str	0.0107	1.50	0.6259	0.9148	0.7703
16	52	223	1.13	0.56	1.69	129.02	66.73	Mod	0.0125	1.34	0.7307	0.8221	0.7764
17	42	223	1.24	0.63	1.86	134.95	66.34	Mod	0.0114	1.45	0.6680	0.8896	0.7788
18	32	220	1.39	0.66	2.05	148.24	67.84	Mod	0.0158	1.60	0.9233	0.9775	0.9504
19	22	223	0.75	1.07	1.82	137.61	41.34	Mod	0.0171	1.45	1.0000	0.8850	0.9425
20	12	223	0.53	1.53	2.05	100.00	25.65	Mod	0.0000	1.61	0.0000	0.9864	0.4932
						Maturation index (MI)							
1	100	370	191.96	234.37	426.33	295.26	45.03	Mod	-0.1127	15.66	0.2185	0.8206	0.5196
2	91	283	211.49	176.96	388.45	271.66	54.44	Mod	-0.0733	15.98	0.1420	0.8373	0.4897
3	82	283	262.73	142.68	405.40	299.73	64.81	Mod	-0.0263	16.78	0.0510	0.8792	0.4651
4	73	390	353.13	237.11	590.23	353.13	59.83	Mod	-0.0013	16.09	0.0026	0.8427	0.4226
5	64	390	107.21	301.17	408.38	322.85	26.25	Mod	-0.0928	14.79	0.1800	0.7750	0.4775
6	82	280	198.75	149.90	348.65	242.12	57.00	Mod	-0.0968	15.18	0.1877	0.7955	0.4916
7	73	280	225.07	100.66	325.73	268.52	69.10	Mod	-0.0109	15.34	0.0212	0.8035	0.4124
8	64	310	288.28	17.60	305.88	257.11	94.24	Weak	0.0177	16.79	0.0343	0.8795	0.4569
9	55	290	273.53	22.61	296.13	264.77	92.37	Weak	0.0370	15.80	0.0717	0.8279	0.4498
10	46	248	99.50	146.96	246.45	234.36	40.37	Mod	-0.0175	14.16	0.0339	0.7418	0.3879
11	62	260	178.15	200.91	379.05	245.93	47.00	Mod	-0.1451	16.22	0.2814	0.8496	0.5655
12	52	280	186.45	187.32	373.77	248.62	49.88	Mod	-0.0170	16.76	0.0330	0.8782	0.4556
13	42	280	295.46	99.73	395.19	252.25	74.76	Mod	0.0905	18.35	0.1755	0.9615	0.5685
14	32	260	273.56	120.49	394.06	213.02	69.42	Mod	0.1565	17.42	0.3035	0.9127	0.6081
15	23	260	126.51	159.82	286.34	225.94	44.18	Mod	-0.2860	16.30	0.5546	0.8537	0.7041

16	52	270	123.62	268.52	392.14	246.69	31.52	Mod	0.0670	16.51	0.1300	0.8651	0.4975
17	42	270	163.91	204.19	368.10	258.15	44.53	Mod	0.2214	17.25	0.4293	0.9035	0.6664
18	32	270	257.82	149.69	407.51	230.62	63.27	Mod	0.3997	19.09	0.7751	1.0000	0.8875
19	22	280	255.15	98.34	353.49	240.07	72.18	Mod	0.5157	17.82	1.0000	0.9337	0.9669
20	12	280	44.38	132.71	177.09	115.53	25.06	Mod	0.0001	14.82	0.0001	0.7764	0.3883
Detachment force difference (DFD)													
1	100	340	0.55	0.16	0.71	250.92	77.50	Weak	0.0017	0.7166	0.0235	0.7729	0.3982
2	91	340	0.63	0.11	0.74	261.73	85.10	Weak	0.0010	0.7376	0.0144	0.7955	0.4050
3	82	350	0.62	0.10	0.72	279.04	85.53	Weak	0.0001	0.7257	0.0008	0.7827	0.3918
4	73	380	0.44	0.22	0.66	135.82	66.31	Mod	0.0058	0.6916	0.0799	0.7459	0.4129
5	64	300	0.22	0.44	0.65	193.70	33.15	Mod	-0.0036	0.6603	0.0497	0.7121	0.3809
6	82	320	0.63	0.12	0.75	242.28	83.64	Weak	0.0034	0.7477	0.0472	0.8064	0.4268
7	73	320	0.70	0.09	0.79	260.00	88.29	Weak	0.0028	0.7738	0.0387	0.8345	0.4366
8	64	350	0.63	0.13	0.76	216.17	83.52	Weak	0.0025	0.7481	0.0339	0.8068	0.4204
9	55	390	0.34	0.34	0.69	75.27	50.02	Mod	0.0133	0.7573	0.1832	0.8168	0.5000
10	46	250	0.07	0.59	0.66	128.01	10.30	Str	0.0012	0.7099	0.0164	0.7656	0.3910
11	62	360	0.55	0.22	0.77	188.38	71.77	Mod	0.0108	0.7638	0.1490	0.8237	0.4864
12	52	360	0.64	0.22	0.85	227.93	74.47	Mod	0.0098	0.7986	0.1349	0.8613	0.4981
13	42	290	0.52	0.45	0.97	254.62	53.85	Mod	0.0100	0.7865	0.1372	0.8483	0.4928
14	32	240	0.00	1.19	1.19	39.93	0.07	Str	0.0521	0.8469	0.7173	0.9134	0.8154
15	23	240	0.11	0.70	0.81	168.76	13.49	Str	0.0099	0.8558	0.1362	0.9230	0.5296
16	52	260	0.38	0.51	0.89	71.61	42.61	Mod	0.0203	0.7966	0.2799	0.8591	0.5695
17	42	260	0.37	0.63	1.00	49.65	37.30	Mod	0.0265	0.8374	0.3658	0.9032	0.6345
18	32	260	0.31	0.84	1.16	70.07	27.07	Mod	0.0219	0.8283	0.3024	0.8933	0.5979
19	22	260	0.00	1.43	1.43	47.03	0.00	Str	0.0726	0.9272	1.0000	1.0000	1.0000
20	12	280	0.00	0.91	0.91	120.07	0.00	Str	0.0726	0.9272	1.0000	1.0000	1.0000

NPG - Number of points of the grid sampling; Max dist - Maximum distance used for semivariogram fitting; C_0 - Nugget effect; C_1 - Contribution; C_0+C_1 - Sill; a - range; DD - Spatial dependence degree; AE - Absolute error; SD_{AE} - Standard error of absolute error; AI - Accuracy index; PI - Precision index; OGI - Optimum grid indicator; Str - Strong; Mod - Moderate.

Once it is impossible to quantify the individual contribution of these errors, the nugget effect can be expressed as sill ratio, thus facilitating the comparison of the of spatial dependence degree (DD) of the study variables (TRANGMAR; YOST, UEHARA, 1985). Through the classification of Cambardella et al. (1994), the Prod variable can be classified as a strong spatial dependence degree for two grids (grids 10 and 15), moderate for 14 grids and weak for four grids (grids 1, 3, 6 and 7). The MI variable showed moderate DD for 18 grids and only two grids showed weak DD (grids 8 and 9). For the DFD, five grids showed strong DD (grids 10, 14, 15, 19 and 20), nine with moderate DD and six with weak DD (grids 1, 2, 3, 6, 7 and 8).

The range values for semivariograms are highly relevant in determining the spatial dependence threshold, which can also be indicative of the interval among soil mapping units (TRANGMAR; YOST; UEHARA, 1985) or properties related to plants (FERRAZ et al., 2012c).

The studied variables showed different spatial dependence ranges, where the Prod had a range varying from 100 m (grid 20) to 354.63 m (grid 3) and the MI had its range varying from 115.53 m (grid 20) to 353.13 m (grid 4). For the DFD, the range varied from 39.93 m (grid 14) to 279.04 m (grid 3).

Ferraz et al. (2012a) studied productivity for three years and found range values equal to 217.24 m (2008), 280.51 m (2009) and 203.41 m (2010). Silva et al. (2008) studied two harvests and found range values equal to 65.04 m and 60.43 m, respectively, for the first and second harvests. Silva, F. M. et al. (2010) studied the productivity of coffee trees in three harvests and found range values equal to 21.3 m, 27.6 m and 36.0 m.

In the present study, it was noted that the nugget effect and particularly the range varied according to the studied properties and among the tested grids. Thus, in order to evaluate the 20 grids under study, the validation criteria were used considering the AE and SDAE. For comparison purposes, the AI, PI, and an index that correlates the two OGI were created to choose the best grid.

For a good evaluation of the grid sampling, three plant properties were evaluated: Prod, MI and DFD.

Although a coffee harvester manufacturer has developed and launched a productivity sensor, used by Molin et al. (2010), this is not yet widespread and a good option to map the coffee crop productivity is performing the georeferencing of sampling points and manual harvesting of fruits, as proposed in the studies of Ferraz et al. (2012a, 2012b, 2012c), Silva et al. (2007, 2008) and Silva, F. M. et al. (2010), performed by the present study. Thus, it becomes important to analyze a grid sample that allows mapping the productivity in a coffee plantation harvested manually.

When performing the semivariogram fitting for every grid samples for the Prod variable and find the OGI, it can be noted that the grid that best fitted this variable (lower OGI) was the grid 11, whose value was 0.4305, with 62 sample points, followed by the grid 1 (OGI equal to 0.4409, with 100 sample points) and the grids 6, 20 and 5.

The MI is strongly widespread among coffee growers and this is one of the factors that indicate the harvesting time to the producer, especially the mechanized harvest, influencing even the number of passes that the harvester will perform in a certain area. Taking into consideration the importance of such index, the study on the spatial variability can reflect in the indication of more favorable locations to begin the harvest, besides indicating more precisely when to start the operation.

When observing the OGI for the MI variable, it can be observed that the grid 10, with 46 sample points, showed the lowest MI (0.3878). This was followed by the grids 20, 7, 4 and 9, respectively.

In the selective manual harvesting, coffee growers can choose which fruits should be collected, choosing those that are under optimal ripeness for harvesting. However, when the mechanized harvest is performed, this process may be difficult to be carried out. In this way, a parameter that can aid for the mechanized and selective harvesting of coffee fruits is the study of the detachment force. Silva, F. C. et al. (2010) mention that the greater the difference between the detachment force of green and cherry fruits the better the selective mechanized harvest of coffee fruits.

When testing the 20 grid samples for the DFD, the grid 5, with 64 sample points, showed the lowest OGI (0.3809), followed by the grids 10, 3, 1 and 2.

However, as can be noted, the management of mechanized and selective harvesting of coffee fruits involves both the productivity analysis and the MI and DFD, so that the harvesting process can be optimized. Therefore, these data should not be analyzed separately but rather as a whole in order to optimize and reduce the sampling and harvest operating costs. In order to proceed to the choice of the best grid sampling, it should start from the one that best fit the three variables under study. Thus, the average OGI was calculated, which is nothing more than the average OGI value showed by the three variables for each grid. In Table 3, the grids were classified according to the calculated average OGI values.

The grids 4, 1, 5, 3 and 6 showed the lowest average OGI values. In this list, the grid 5 is highlighted, with 64 sample points, 2.9 pt/ha, without zoom grids, facilitating the sampling process. It was also noted a great influence of zoom grids, in which the grid samples that had this type of grid were superior the base grids of their groups.

According to Nanni et al. (2011) the grid samples used for soil sampling in the most diverse Brazilian cultures are around one point every 2 to 3 ha, being that, in some cultures, up to one point is used every 4 ha. The most commonly used grid sampling in coffee growing is one point per hectare (FERRAZ et al., 2012c).

Whether only the base grids (grids 5, 10, 15 and 20) were tested, the grid 5 (2.9 pts/ha) would be highlighted, followed by grids 10 (2.09 pts/ha), grid 20 (approximately 0.5 pt/ha) and grid 15 (1.0 pt/ha).

Therefore, it can be observed that major errors would occur by using the wrong grid, being the correct choice of the grid sample of plant properties extremely important for the good management of the mechanized harvest.

TABLE 3 - Ranking of grids based on average OGI

Rank	Grid	NPG	Average OGI
1	4	73	0.4514
2	1	100	0.4529
3	5	64	0.4542
4	3	82	0.4589
5	6	82	0.4610
6	7	73	0.4738
7	2	91	0.4765
8	11	62	0.4941
9	12	52	0.4966
10	8	64	0.5055
11	10	46	0.5195
12	13	42	0.5473
13	9	55	0.5765
14	16	52	0.6145
15	20	12	0.6272
16	15	23	0.6680
17	17	42	0.6932
18	14	32	0.7179
19	18	32	0.8119
20	19	22	0.9698

4 CONCLUSIONS

It was possible to characterize the magnitude of the spatial variability of plant properties under study in all the proposed grids.

It was observed that the variables presented a spatial dependence structure, allowing obtaining the validation parameters.

Based on the methodology proposed in the present study, the grid that best suited the plant variables in order to optimize the harvesting operation was the grid 4, with 64 sampling points in the base grid plus nine zoom grid points, totaling 73 points.

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SENSORY ANALYSIS AND CHEMICAL COMPOSITION OF 'BOURBON' COFFEES CULTIVATED IN DIFFERENT ENVIRONMENTS

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ABSTRACT: Given the growing participation and appreciation of specialty coffees in the international market, coupled to the intrinsic quality of cultivar Bourbon for the production of differentiated coffees and the environmental diversity of Brazil, this study was conducted, with the objective to evaluate how the interaction between 'Bourbon' genotypes and different environments affect the sensory quality of coffees, besides relating the chemical composition (trigoneline, 5-CQA and caffeine) of beans with their sensory profile. Four Arabica coffee genotypes were evaluated: one of them is widely grown in Brazil *(Mundo Novo*) and three belong to the group of cultivar Bourbon. The genotypes were evaluated in a field experiment, in Lavras, MG; Santo Antônio do Amparo, MG and São Sebastião da Grama, SP. Thelatter was the most promising environment for the production of specialty coffees. Genotypes Yellow Bourbon IAC J9 and Yellow Bourbon/SSP were the most suitable for the production of specialty coffees. Regardless of culture environment, the genotype Yellow Bourbon/CM is not suitable for the production of specialty coffees. Caffeine content enabled coffee differentiation regarding beverage quality. Coffees with superior quality have lower caffeine contents. The content of 5-CQAallowed to differentiate environments.

Index terms: Specialty Coffees,genotypes, yellow bourbon, multidimensional scaling.

ANÁLISE SENSORIAL E COMPOSIÇÃO QUÍMICA DE CAFÉS 'BOURBON' CULTIVADOS EM DIFERENTES AMBIENTES

RESUMO: Diante da crescente participação e valorização dos cafés especiais no mercado internacional, associadas à qualidade intrínseca da cultivar Bourbon para a produção de cafés diferenciados e à diversidade ambiental do Brasil, realizou-se o presente trabalho, com o objetivo de avaliar como a interação entre genótipos de 'Bourbon' e diferentes ambientes afetam a qualidade sensorial dos cafés, bem como relacionar a composição química (trigonelina, 5-ACQ e cafeína) dos grãos com a sua expressão sensorial. Foram avaliados quatro genótipos de café arábica, sendo um amplamente cultivado no Brasil (*Mundo Novo*) e três pertencentes ao grupo da cultivar Bourbon. Os genótipos foram avaliados na forma de experimento em campo, nos municípios de Lavras, MG; Santo Antônio do Amparo, MG e São Sebastião da Grama, SP. Este último foi o ambiente mais promissor para a produção de cafés especiais. Os genótipos Bourbon Amarelo IAC J9 e Bourbon Amarelo/ Origem SSP foram os mais indicados para a produção de cafés de especiais. Independente do ambiente de cultivo, o genótipo Bourbon Amarelo origem CM não é indicado para a produção de cafés especiais. O conteúdo de cafeína possibilitou a discriminação de cafés quanto à qualidade de bebida. Cafés com qualidade superior têm menores teores de cafeína. O conteúdo de 5-ACQ permitiu discriminar ambientes.

Termos para indexação: Cafés especiais, genótipos, Bourbon amarelo, escalonamento muldimensional.

1 INTRODUCTION

Although the commodity coffee segment represents the largest share of all coffee exported worldwide, the specialty coffee segment has achieved great prominence in the international market. The increasing participation of this segment justifies various incentives to improve quality, both in farming practices and in research and technological innovation. Coffee producing countries increasingly show interest in understanding environmental, genetic and technological factors affecting quality (AVELINO et al., 2005). Brazil is traditionally known as a supplier of large quantities of common and low-cost coffees, and has favorable conditions to increase its share in the specialty coffee market, given the diversity of its coffee plantations and the high technological level of coffee production(GIOMO; BORÉM, 2011).

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In general, any *Coffea Arabica* L. cultivar has the potential to produce high-quality coffees. However, it has been found that different tastes and smells occur more frequently in some cultivars. Cultivar Bourbon has world-renowned intrinsic qualities due to its sensory characteristics. It is used for the production of specialty coffees in different regions of the world. However, different genotypes are described as Bourbon, resulting in the occurrence of crops with totally different characteristics and named Bourbon. In addition to the phenotypic and agronomic variability, Ferreira et al. (2012), Figueiredo et al. (2013) and Figueiredo et al. (2015) evaluated the interaction between Bourbon genotypes and different environments and observed that there are Bourbon genotypes more adapted to the production of quality coffee for each environment.

Coffee is a product whose quality is differently expressed as a function of the planting site. It is directly influenced by environmental aspects, both natural and human (AVELINO et al., 2005; BERTRAND et al., 2006; VILLARREAL et al., 2009; CAMARGO, 2010; ALVES et al., 2011). In Brazil, there are numerous coffee-producing regions with different edaphoclimatic characteristics, which are essential for beverage flavor.

Several studies were conducted in order to correlate the levels of some chemical compounds, such as caffeine, trigoneline and chlorogenic acids, with species differentiation, the assessment of degree of roasting, quality and functional properties of coffee (DESSALEGN et al., 2008; PERRONE et al., 2008; DUARTE et al., 2010; RIBEIRO et al., 2011; KY et al., 2013).In other studies, it was sought to relate these chemical compounds as potential descriptors for quality expression of coffee genotypes in different environments. Avelino et al. (2005) differentiated the environments Santa Maria de Dota e Orosi, in Costa Rica, through the quantification of chemical compounds caffeine, trigoneline, chlorogenic acids and sucrose, justifying the sensory differences among these coffees. The composition of chlorogenic acids and especially fatty acids allowed the differentiation of environments Naranjal, Paraguaicito and Rosario, located in Colombia (BERTRAND et al., 2008).

It is observed that, despite the great potential of cultivar Bourbon for the production of specialty coffees, it is not well understood if there is a genotype capable of producing high-quality coffees, regardless of the environment. On the other hand, it is believed that it is possible to find one or more Bourbon genotypes suitable for the production of specialty coffees in different environments and that its chemical composition can be used as an indicator of that capacity.In this context, this study was conducted in order to assess how the interaction between Bourbon genotypes and different environments affects the sensory quality of coffees, as well as relate the chemical composition of the beans with their sensory quality.

2 MATERIALS AND METHODS

Four genotypes of Coffea Arabica L. (Table 1) were grown in experimental field plots since 2005 in the southern region of the state of Minas Gerais and in the region of Mogiana in the state of São Paulo. Both regions are highlighted for their production of Arabica coffee on a large scale. The distinct edaphoclimatic conditions of these important Brazilian coffee producing regions were represented in this study, and their main characteristics are shown in Table 2.The genotypes were chosen for this research from a group of 14 Bourbon genotypes, which were 11 Bourbon genotypes and 3 commercial cultivars. Then, 01 commercial cultivar widely grown in various regions (G1) and 03 Bourbon genotypes (G2, G3 and G4) were picked. In addition, this selection was based on a previous research Figueiredo (2010) and preliminary dataset of the present study. The agronomic characteristics of the studied genotypes can be observed in Ferreira et al. (2013).

Coffee harvest and processing

Coffee fruits were handpicked (collected in 2010 and 2011) and selectively harvested when the fruits were completely mature to guarantee the complete uniformity of the material from the different parcels. Then, the coffee fruits were peeled to obtain the pulped coffee. Drying was carried out in patio drying immediately after processing according to the method of Borém, Andrade and Isquieredo (2014), until coffee beans were at the level of 11% (w.b) moisture content.

Sample preparation

After drying, the samples were packed in paper bags and covered with plastics bags, identified and stored in chambers at a controlled temperature of 18°C for 60 days.

TABLE 1 - Studied genotypes and environments and their codes[a].

Environments	Genotypes
A1 = Lavras	G1 = Mundo Novo IAC 502/9
A2 = São Sebastião da Grama	G2 = Yellow Bourbon IAC J9
A3 = Santo Antônio do Amparo	G3 = Yellow Bourbon /Origin SSP[b]
	G4 = Yellow Bourbon /Origin CM[b]

[a] A1, A2, A3, G1, G2, G3 e G4 = codification of the genotypes and environments used in the discussion of the results.

[b] SSP = São Sebastião do Paraíso, MG; CM = Carmo de Minas, MG.

TABLE 2 - Geographic region, climatic variables and characterization of the three studied environments.

Municipality	Lavras	São Sebastião da Grama	Santo Antônio do Amparo
Region	Southern Minas Gerais	Mogiana Paulista	Southern Minas Gerais
Altitude	919 m	1300 m	1050 m
Mean temperature	20.4 °C	20 °C	19.9 °C
Mean annual precipitation	1460 mm	1560 mm	1700 mm
Latitude	21°14’43”S	21°44’50”S	20°56’47”S
Longitude	44°59’59”W	46°55’33”W	44°55’08”W
Soil type	Clayey Oxisol	Clayey Oxisol	Clayey Oxisol

Then, the samples were hulled and the defects were removed in order to standardize the samples and minimize interferences unrelated to the genetic material or the environment. Chemical analysis and roasting were performed in beans retained on screen 16 and higher (16, 17 and 18/64 inches).

Roasting and sensory evaluation

All procedures were performed according to the protocol described by the Specialty Coffee Association - SCA. Ten sensory attributes were evaluated by a panel of six trained judges and scored on a scale of 10 points according to SCA (LINGLE, 2011). The sensory attributes included the aroma, uniformity, absence of injuries, sweetness, flavor, acidity, body, balance, completion and overall impression. The final sensory grade was generated from the sum of all of the evaluated attributes. For each evaluation, five cups of coffee representing each genotype were evaluated, with one session of sensory analysis for each repetition and a total of three repetitions. Each environment was evaluated separately. In addition to the final grade obtained from the sensory evaluation, the attributes of aroma, acidity, body and flavor were also analyzed statistically in order to complement the analysis, considering that these are the main attributes responsible for distinguishing the different sensory profiles of the coffee.

Caffeine, trigonelline and 5-caffeoylquinic acid (5-CQA)

Extractions of compounds were performed in duplicate for each of the three replicates according to (FIGUEIREDO et al., 2013). The concentrations of caffeine, trigonelline and 5-CQA were determined simultaneously using high-performance liquid chromatography (HPLC). Therefore, the system operated with a Rheodyne injection valve (model 77251), with a loop fixed at 20 µL and a data processor (Shimadzu). Areverse-phase C18 column (5 µm, 250 mm x 4.6 mm,Shim-pack CLC-ODS (M), Shimadzu) wasused, with a 4-µm pre-column. Elution was isocratic with a mobile phase consisting of methanol:aceticacid:water (30: 0.5:69.5; v:v:v), flow of 1 mL/min at 22 °C.The concentration of the compounds was determined by the ratio among peak areas of caffeine, trigonelline and 5-CQA of the sample and the respective standards of known concentrations. The final contents of caffeine, trigoneline and 5- CQA were given in percentage of dry matter (% DM).

Statistical analysis

Four Arabica coffee genotypes were evaluated in three production environments. The three experiments were conducted in a randomized block design (RBD), with three replications in the field and plots consisting of ten plants. Multidimensional geometric representation of the data was performed using multidimensional scaling (MDS) (COX; COX, 2001) with the statistical software R (R CORE TEAM, 2012). Qualitative or quantitative relationships between the data correspond to geometric relationships in this representation.

3 RESULTS AND DISCUSSION

Sensory quality and chemical composition: effect of genotypes and environments

The mean values of sensory attributes, final sensory score and chemical compounds in relation to genotypes, environments, and interactions between genotypes and environments are presented in Table 3.

Table 4 shows the dissimilarity matrix among the twelve points of the interaction between genotypes and environments ($A_xG_{y)}$ for sensory variables of the transformed data matrix. It is possible to observe that lower values indicate more similar points (AxGy), while higher values indicate dissimilarity between points (AxGy).

Figure 1 shows the biplot with multidimensional scaling of 4 genotypes and 3 environments for sensory attributes (acidity, fragrance, flavor and body) and final sensory score, besides the stress function generated for the purpose of checking the quality of the adjustment MDS provided by the reduction in variables. In the representation, the distances between the points are directly related to dissimilarities between them (Figure 1A). The stress function was equal to 0.02, indicating a high-quality setting (Figure 1B). This fact allows to state that the relationship between sensory attributes and environments can be synthesized by these variables, represented in predictive axes.

The points A3G2 and A2G3; A2G1 and A1G3, for example, are the most similar to each other, as shown in Table 4, of dissimilarity measures. Given this proximity between the points, it is possible to visualize the formation of groups genotypes χ environments: group I, formed by the points A3G1, A1G1, A2G4, A1G4 and A3G4; group II, by points A3G3 and A1G2 and group III, by points A2G2, A1G3, A3G2, A2G3 and A2G1. It is important to emphasize that group III is that with the greatest proximity, that is, the greatest similarity between their points.

It is observed that coffees grouped to the left of the biplot (group I) showed lower intensity of the attributes fragrance, flavor and acidity, when compared to coffees grouped on the right (group III) (Figure 1A). This grouping also has lower sensory scores (below 80 points), when compared to group III (Table 3). All genotypes that showed scores above 80 have the potential for the production of specialty coffees, especially those with a score higher than 81 points.

The attributes flavor, acidity and fragrance were the most decisive for coffee differentiation. On the other hand, in this study, the attribute body little contributed to group differentiation (Figure 1A). However, it was responsible for approaching or distancing points within the groups formed in relation to the vertical axis. The points allocated to group I were those which suffered the greatest interference of the variable body. This can be observed by analyzing the points A3G1 and A1G4. Both points have values of acidity, flavor and final sensory score very similar and differed for the attributes fragrance, and especially body.

From the groups formed, it is possible to observe that the genotype Yellow Bourbon (G4) did not express well, from a sensory point of view. In addition, regardless the environment studied, it was always allocated in group I and presented high similarity to the genotypes allocated in this group. Therefore, although the intrinsic quality of Bourbon is globally known and widely used for the production of specialty coffees in various regions of the world (FIGUEIREDO et al., 2013), it is observed that there is variability in beverage quality among the Bourbon genotypes studied. Variations found in flavor, acidity and fragrance indicate that not all Bourbon genotypes have the same potential for the production of specialty coffees. These results corroborate those of Ferreira et al. (2012) and Figueiredo et al. (2013), who detected differences in the potential to produce quality coffees among different Bourbon genotypes.

The environment São Sebastião da Grama (A2) stood out, compared to the others. In this environment, all genotypes, except G4, showed higher intensity of the sensory attributes acidity, flavor and fragrance and comparatively higher

TABLE 3 - Sensory evaluation and average levels of 5-CQA, trigoneline and caffeine of beans from different Arabica coffee genotypes and environments.

genotype/environment	fragrance	flavor	acidity	body	final	5-CQA (%)	trigoneline (%)	caffeine (%)
G1	7.25	7.11	7.25	7.37	80.38	4.30	0.88	1.14b
G2	7.60	7.39	7.38	7.37	81.61	4.51	0.82	1.06a
G3	7.58	7.44	7.43	7.33	81.76	4.63	0.86	1.11b
G4	7.26	7.07	7.15	7.17	79.87	4.76	0.90	1.14b
A1	7.36	7.20	7.22	7.24	80.59	4.36	0.85	1.13
A2	7.52	7.35	7.37	7.36	81.42	4.52	0.86	1.08
A3	7.38	7.22	7.32	7.33	80.70	4.75	0.88	1.12

TABLE 4 - Dissimilarity matrix among the twelve points (interactions genotypes χ environments, $A_xG_{y)}$ for sensory variables.

	A1G1	A1G2	A1G3	A1G4	A2G1	A2G2	A2G3	A2G4	A3G1	A3G2	A3G3	A3G4
A1G1	0.000	1.403	2.460	0.355	2.398	2.257	2.780	0.191	0.236	2.659	1.531	0.498
A1G2	1.403	0.000	1.080	1.187	1.019	0.867	1.393	1.234	1.435	1.277	0.181	0.990
A1G3	2.460	1.080	0.000	2.244	0.155	0.234	0.332	2.295	2.477	0.221	0.939	2.050
A1G4	0.355	1.187	2.244	0.000	2.192	2.037	2.559	0.302	0.528	2.449	1.315	0.338
A2G1	2.398	1.019	0.155	2.192	0.000	0.237	0.413	2.232	2.414	0.273	0.878	1.986
A2G2	2.257	0.867	0.234	2.037	0.237	0.000	0.531	2.090	2.274	0.428	0.740	1.849
A2G3	2.780	1.393	0.332	2.559	0.413	0.531	0.000	2.615	2.797	0.157	1.258	2.371
A2G4	0.191	1.234	2.295	0.302	2.232	2.090	2.615	0.000	0.275	2.494	1.365	0.346
A3G1	0.236	1.435	2.477	0.528	2.414	2.274	2.797	0.275	0.000	2.672	1.565	0.614
A3G2	2.659	1.277	0.221	2.449	0.273	0.428	0.157	2.494	2.672	0.000	1.139	2.251
A3G3	1.531	0.181	0.939	1.315	0.878	0.740	1.258	1.365	1.565	1.139	0.000	1.114
A3G4	0.498	0.990	2.050	0.338	1.986	1.849	2.371	0.346	0.614	2.251	1.114	0.000

G1= Mundo Novo IAC 502/9, G2= YellowBourbonIAC J9, G3= Yellow Bourbon/SSP, G4= Yellow Bourbon/CM, A1= Lavras, A2= São Sebastião da Grama, A3= Santo Antônio do Amparo.

final sensory scores, always placed in group III. Thus, when the environment is favorable to the production of specialty coffees, it is suggested that the selection or indication of genotypes for cultivation could prioritize the identification and restriction of genotypes improper for quality. The three studied environments stand out for the production of Arabica coffee in large scale. However, according to Alves et al. (2011), even in areas suitable for the production of good-quality coffees, climate diversity can cause variations in beverage characteristics. According to Dal Molin et al. (2008), changes in climate conditions interfere in the formation and maturation of fruits, changing their intrinsic characteristics, which can allow different beverage qualities.

Environment A2 is that with the highest altitude (1,300 m). In many studies, there are reports that the rise in altitude is related to the increase in beverage quality (GUYOT et al., 1996; DECAZY et al., 2003; AVELINO et al., 2005; BERTRAND et al., 2006). Decazy et al. (2003) evaluated the quality of coffees grown in six regions of Honduras and concluded that higher altitudes and rainfall lower than 1,500 mm were favorable for sensory quality. Avelino et al.(2005) related high altitudes with higher-quality coffees, located in two terroirs of Costa Rica, Orosi and Santa Maria de Dota. Guyot et al.(1996) also reported an improvement in beverage quality from higher altitudes in Guatemala.

The points A1G1 (*Lavras/Mundo Novo*) and A3G1 (*Santo Antônio do Amparo/Mundo Novo*) presented the greatest dissimilarity in relation to the group of coffees with higher sensory

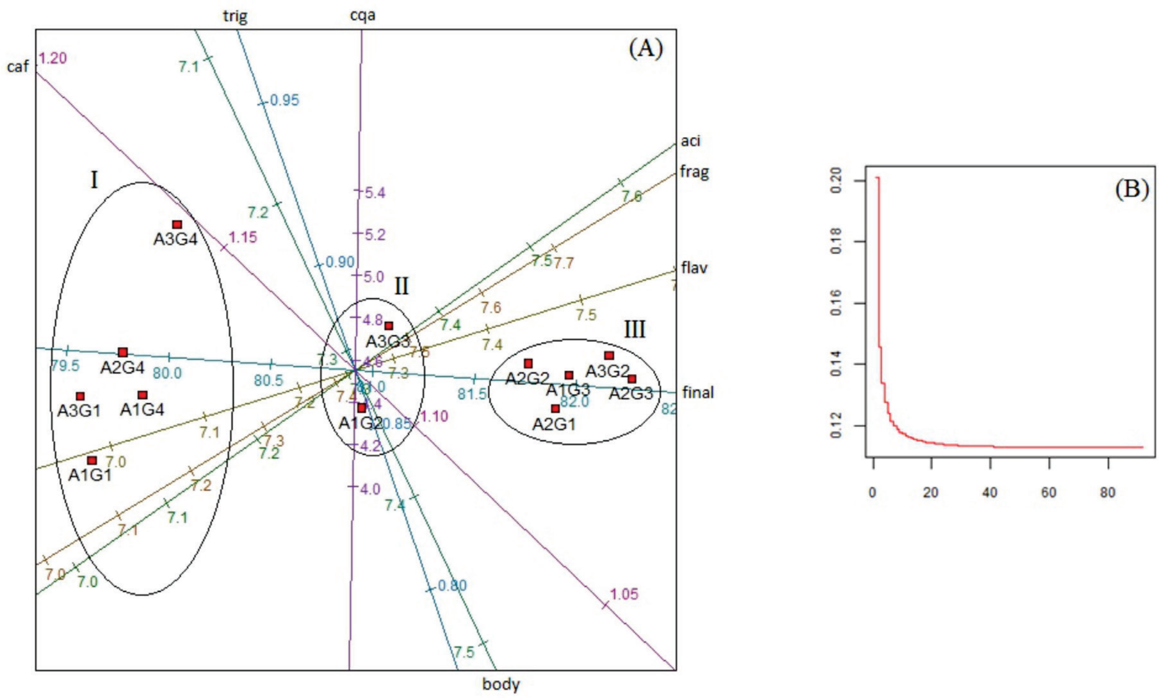

FIGURE 1 - (A) Biplot with multidimensional scaling of four genotypes (G) and three environments (A), for the sensory attributes and final sensory score evaluated. (B) S*tress*functiongenerated as a function of the interaction among factors. frag = fragrance, flav = flavor, aci = acidity, final = final sensory score, G1= Mundo Novo IAC 502/9, G2= Yellow Bourbon IAC J9, G3= YellowBourbon/SSP, G4= YellowBourbon/CM, A1= Lavras, A2= São Sebastião da Grama, A3= Santo Antônio do Amparo.

scores (group III) (Figure 1A).

Cultivar Mundo Novo (G1) is widely cultivated in Brazil, mainly due to its high yield (CARVALHO, MENDES, BARTHOLO, and CEREDA, 2006). However, it presented limitations in the production of specialty coffees, indicating that the quality of its beverage is dependent on environmental conditions where it is grown. The genotype *Mundo Novo* (G1) was sensorially highlighted only when grown in the most promising environment for the production of specialty coffees (A2).

When combined with genotypes Yellow Bourbon and Yellow Bourbon IAC J9, respectively A1G3 and A3G2, the environments Lavras and Santo Antônio do Amparo stood out in the sensory evaluation and allowed the production of flavored coffees, with intense acidity and fragrance, besides a high sensory quality. In this case, the interaction genotype and environment was crucial for the manifestation of flavors in coffees, emphasizing the contribution of Bourbon genotypes. These results confirm the high potential of genotypes G2 and G3 for the obtention of specialty coffees in different manufacturing environments. It is observed that genetic diversity is one of the factors that most contribute to the definition of Arabica coffee beverage quality (DESSALEGN et al., 2008; PEREIRA et al., 2010).Thus, it is believed that technological research and innovation programs that seek to increase the supply of specialty coffees should invest more in understanding gene expression in quality and supply of new genotypes able to produce coffee with diversity in flavor, even when grown under different conditions.

In study, the effects of processing, genotypes and production environment were evaluated on coffee quality (SALLA, 2009). A strong interference of genetic makeup was identified in flavor determination. Beverage quality of most genotypes and cultivars ranged as a function of environment and processing. However, some cultivars showed a better-quality beverage in any environment and processing, indicating high genetic stability for beverage quality (SALLA, 2009).

Table 5 shows the dissimilarity measure matrix among the twelve points of the interaction between genotypes and environments (A_xG_y) for sensory and chemical variables of the transformed

TABLE 5 - Dissimilarity matrix among the twelve points (interactions genotypes χ environments, $A_xG_{y)}$ for sensory and chemical variables.

	A1G1	A1G2	A1G3	A1G4	A2G1	A2G2	A2G3	A2G4	A3G1	A3G2	A3G3	A3G4
A1G1	0.000	1.429	2.501	0.508	2.419	2.305	2.821	0.521	0.377	2.714	1.670	1.248
A1G2	1.429	0.000	1.097	1.194	1.022	0.891	1.410	1.254	1.437	1.307	0.450	1.335
A1G3	2.501	1.097	0.000	2.246	0.204	0.248	0.334	2.296	2.482	0.254	0.965	2.169
A1G4	0.508	1.194	2.246	0.000	2.194	2.042	2.563	0.348	0.535	2.459	1.351	0.854
A2G1	2.419	1.022	0.204	2.194	0.000	0.291	0.443	2.238	2.414	0.358	0.947	2.154
A2G2	2.305	0.891	0.248	2.042	0.291	0.000	0.539	2.095	2.283	0.443	0.778	1.986
A2G3	2.821	1.410	0.334	2.563	0.443	0.539	0.000	2.616	2.803	0.188	1.274	2.467
A2G4	0.521	1.254	2.296	0.348	2.238	2.095	2.616	0.000	0.340	2.495	1.383	0.774
A3G1	0.377	1.437	2.482	0.535	2.414	2.283	2.803	0.340	0.000	2.686	1.610	1.051
A3G2	2.714	1.307	0.254	2.459	0.358	0.443	0.188	2.495	2.686	0.000	1.156	2.346
A3G3	1.670	0.450	0.965	1.351	0.947	0.778	1.274	1.383	1.610	1.156	0.000	1.215
A3G4	1.248	1.335	2.169	0.854	2.154	1.986	2.467	0.774	1.051	2.346	1.215	0.000

G1= Mundo Novo IAC 502/9, G2= YellowBourbon IAC J9, G3= Yellow Bourbon/SSP, G4= Yellow Bourbon/CM, A1= Lavras, A2= São Sebastião da Grama, A3= Santo Antônio do Amparo

data matrix.

In the literature, there is extensive material aiming at the obtention of the correlation between chemical compounds (caffeine, trigonelline and 5-CQA) with the sensory coffee profile (BERTRAND ET AL., 2008; CAMPA ET AL., 2004; DUARTE, PEREIRA, AND FARAH, 2010; FARAH, MONTEIRO, CALADO, FRANCA, AND TRUGO, 2006; FRANCA, OLIVEIRA, MENDONÇA, AND SILVA, 2005).

The results obtained for caffeine, trigonelline and 5-CQA with multidimensional scaling of four genotypes and three environments for sensory attributes, final sensory score and chemical compounds evaluated, are shown in Figure 2. The results show a relationship between sensory characteristics and contents of chemical compounds in the differentiation of genotypes and environments.

In Figure 2, it is observed that the grouping of points obtained as a function of sensory attributes (Figure 1) was kept; the stress function (0.11) also indicates good model fit (Figure 2B).

The inclusion of chemical compounds allowed a greater distance from most points (A_xG_y), represented by the increasing dissimilarity between them, according to Table 5 of dissimilarity. Comparatively, the highest dissimilarity occurred in the group with the lowest sensory scores.

The chemical compound 5-CQA showed the highest correlation with the yaxis and thus provided greater distance of points belonging to the same genotype. Considering these points regarding the interaction of genotype G4with three environments (A1G4, A2G4 and A3G4), it is found that the content of 5-CQA enabled an increase in point divergence, that is, it allowed a greater differentiation of environments A1, A2 and A3, when combined with this genotype. The highest 5-CQA contents were found in environment A3. For other genotypes, the same behavior was observed, with higher 5-CQA contents in environment A3, compared to environments A2 and A1.

Avelino et al. (2005) differentiated the environments Santa Maria de Dota and Orosi (Costa Rica) from the quantification of chemical compounds caffeine, trigoneline, chlorogenic acids and sucrose. The composition of chlorogenic acids and especially fatty acids, allowed the differentiation of environments Naranjal, Paraguaicito and Rosario, located in Colombia (BERTRAND et al., 2008).

However, among the chemical compounds, 5-CQA was the one that best distinguished the studied environments.

The content of trigoneline was not a good discriminator of the groups formed. However, in general, the content of trigoneline was lower in coffees that had higher final scores in the sensory evaluation (group III) (Figure 2A).

It is observed that the sensory characteristics were clearly represented along the x axis, while the chemical compounds 5-CQA and

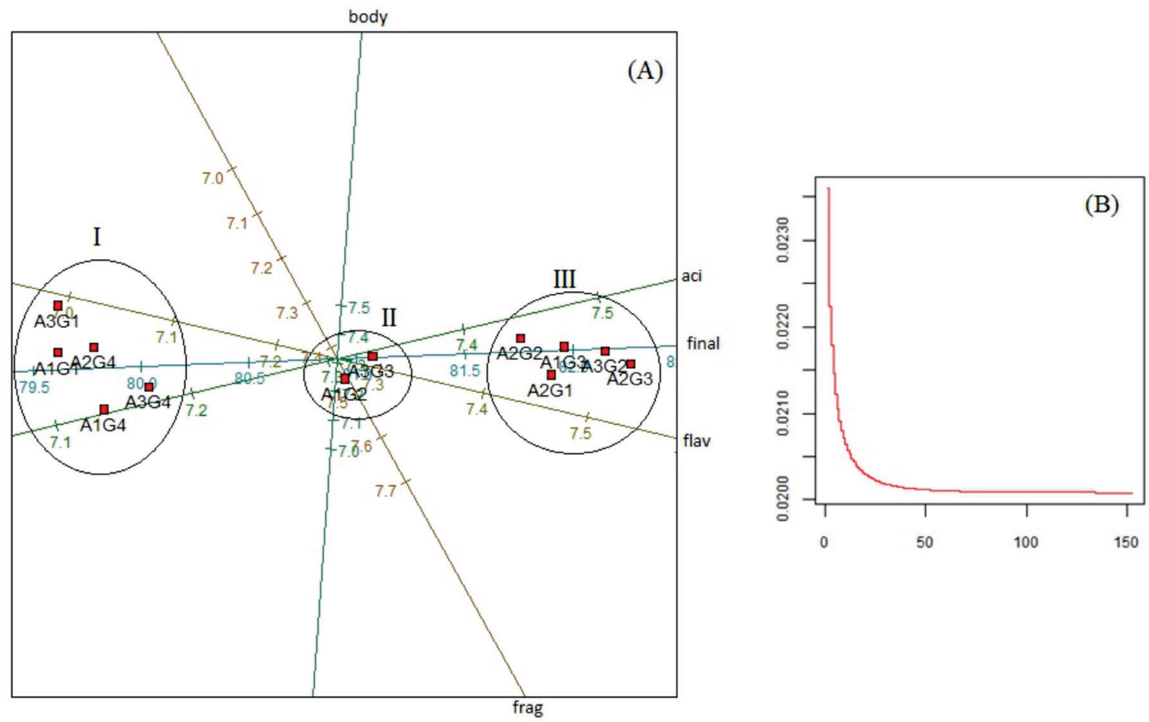

FIGURE 2 - (A) Biplot with multifunctional scaling of four genotypes (G) and three environments (A), for the sensory attributes, final sensory score and the chemical compounds evaluated. (B) S*tress* function generated as a function of the interaction among factors. frag = fragrance, flav = flavor, aci = acidity, final = final sensory score,caf = caffeine, trig = trigoneline, CQA = 5CQA, G1= Mundo Novo IAC 502/9, G2= Yellow Bourbon IAC J9, G3= Yellow Bourbon/SSP, G4= Yellow Bourbon/CM, A1= Lavras, A2= São Sebastião da Grama, A3= Santo Antônio do Amparo.

trigonelline were along the y axis (Figure 2A).

Avelino et al. (2005) also found that some chemical characteristics were largely independent of the sensory characteristics of the evaluated coffees, among them, the content of chlorogenic acids and trigoneline.

On the other hand, caffeine content correlated with the separation of groups I and III, that is, it allowed the differentiation of coffees (A_xG_y) with lower and higher final sensory scores. Coffees belonging to group III showed the lowest caffeine contents and the highest sensory scores, while those belonging to group I had higher caffeine contents and lower sensory scores.

Dessalegn et al. (2008) also observed negative and significant associations between caffeine content and sensory attributes of coffee, such as acidity, body and flavor. The same authors also related low caffeine contents with physical characteristics desirable in green coffee beans, such as size, shape and uniformity. It is believed that caffeine biosynthesis and accumulation in green beans can be more pronounced during stress than in favorable conditions. Ribeiro et al.(2011) related the content of caffeine and chlorogenic acids to the attribute bitterness.

Unlike what happened to group I, points A3G2, A2G3, A1G3 and A2G2 (group III) increased their similarity with the inclusion of chemical variables. Thus, it is observed that coffees with lower final sensory scores (group I) have higher chemical variability than coffees that have higher final sensory scores (group III) (Figure 2A).

The relationship between the content of caffeine, trigoneline and 5-CQA and sensory coffee quality is still quite controversial. In this study and under the analyzed conditions, only caffeine content was a coffee discriminator for beverage quality, while 5-CQA, an environment discriminator.

4 CONCLUSIONS

São Sebastião da Grama (A2) is the most promising environment for the production of specialty coffees. Regardless of culture environment, the genotype Yellow Bourbon (G4) is not indicated for the production of specialty coffees.In a favorable environment, cultivar *Mundo Novo IAC 502/9* produces quality coffees. Lavras and Santo Antônio do Amparo produce quality coffees, depending on the cultivated genotype. Genotypes Yellow Bourbon IAC J9 and Yellow Bourbon (G3) are the most suitable for the production of specialty coffees. Caffeine content allowed to differentiate coffees regarding beverage quality. Coffees with superior quality have lower caffeine contents. The content of 5-CQA allowed to differentiate environments.

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NOTA PRÉVIA

ARTIFICIAL DIET ADJUSTMENTS FOR BRAZILIAN STRAIN OF *Hypothenemus hampei* (FERRARI, 1867) (COLEOPTERA: CURCULIONIDAE)

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ABSTRACT: A modified artificial diet based on the "Cenibroca diet" used in Colombia for mass rearing of *Hypothenemus hampei,* was compared with the natural diet presently used to rear this insect. The modified diet was cheaper than Portilla's diet and did not affect insect fitness, developmental time, viability or sex ratio.

Index terms: Artificial diet, *Hypothenemus hampei*, rearing.

AJUSTES DE DIETA ARTIFICIAL PARA "STRAIN" BRASILEIRO DE *Hypothenemus hampei* (FERRARI, 1867) (COLEOPTERA: CURCULIONIDAE)

RESUMO: Uma dieta artificial para *Hypothenemus hampei*, com modificações a partir de uma dieta utilizada para a espécie na Colômbia e denominada Cenibroca, foi avaliada. Ela mostrou-se adequada e comparável à dieta natural utilizada para o inseto, considerando-se o tempo de desenvolvimento, a viabilidade total e a razão sexual da broca do café, sendo mais económica quando comparada com a dieta desenvolvida por Portilla em 1999.

Termos de indexação: Dieta artificial, *Hypothenemus hampei*, técnicas de criação.

The coffee berry borer (CBB) *Hypothenemus hampei* (Ferrari, 1867) (Coleoptera: Curculionidae) is considered the most damaging insect pest of coffee crops worldwide, attacking the berries and causing weight loss, berry depreciation and quality problems (BENAVIDES et al., 2013; BUSTILLO, 2002; JARAMILLO et al., 2006; ROMERO; CORTINA, 2007). Damage from this insect pest is estimated at US$500 million annually (JARAMILLO et al., 2006), affecting the income of more than 25 million small farmers worldwide (FAIRTRADE FOUNDATION, 2012).

Artificial diets are an efficient option for insect mass rearing and studies, because insect colonies can be continuously maintained in the laboratory under controlled conditions (PARRA et al., 2002). According to Portilla & Streett (2006), the artificial diets presently used in Colombia, USA and elsewhere to rear the coffee borer are adequate to maintain their development, fecundity and sex ratio.

The present study evaluated the performance of a modified of the "Cenibroca" artificial diet (PORTILLA, 1999), originally used in Colombia, as an artificial diet for mass rearing of Brazilian populations of the coffee berry borer. The diet tested included modifications in the type of agar, yeast, vitamin composition and antifungal (Table 1) and calculated the cost (in dollars) of producing one liter of diet using the components of Portilla´s recipe (1999) as well as the modified diet .

Females of the coffee berry borer (CBB) were obtained from a stock colony established in July 2010 with beetle-infested coffee berries collected from a coffee plantation in Piracicaba, São Paulo, Brazil (22°42'51.0366" S, 047°37'41.556" W). The stock colony is maintained at the Laboratory of Insect Biology of the Department of Entomology and Acarology, Luiz de Queiroz College of Agriculture, University of São Paulo (ESALQ-USP), Piracicaba, where the insects are reared on ca. 150-day-old coffee berries (*Coffea arabica* var. Obatã) kept at room temperature (25±2 °C), 65±10% relative humidity [RH], and 0:24 h (L:D) photoperiod. In this study, the insects were obtained from infested berries that are kept in square plastic containers 50x50x20 cm (height x width x depth) with perforated lids (55 mm diameter) covered with voile.

Some components of the Cenibroca artificial diet were modified (Table 1). The study evaluated whether these changes in diet affected

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TABLE 1 - Composition of artificial diets for *Hypothenemus hampei* rearing.

Component	D1[a]	D2[b]
Agar	10 g	–
Carregeenan	–	10 g
Water	993 ml	993 ml
Coffee	150 g	150 g
Sucrose	10 g	10 g
Casein	15 g	15 g
Torula yeast	15 g	–
Brewer´s yeast	–	15 g
Ethanol	10 ml	–
Benzoic acid	1 g	1 g
Vanderzant´s Vitamin solution	7.4 ml	–
Vitamin solution[c]	–	7.4 ml
Wesson salts	0.8 g	0.8 g
Formaldehyde 37%	2650 µL	2650 µL
Benomyl®	1.33 g	–
Methyl parahydroxybenzoate (Nipagin®)	–	1.33 g
Cost/L	US$ 16.06	US$ 8.73

[a] Portilla (1999)

[b] Portilla (1999), modified

[c] Niacinamide: 1.00 g; calcium pantothenate: 1.00 g; Riboflavin: 0.50 g; Thiamin: 0.25 g; Pyridoxine: 0.25 g; folic acid: 0.02 mg; Biotin: 0.02 mg; Vitamin B_{12} (1,000 mg/ml): 2.00 ml.

the development of *H. hampei*.

To prepare the diet, agar (carrageenan) was dissolved in distilled water at a temperature of 65 °C and mixed with the other ingredients (Table 1) with the aid of a blender. The diet was dried in a Marconi® MA 033 oven at 45 ± 5 °C for 12–15 h to a final water content of 55 ± 10%. The diet was offered to the insects in a 24-well culture plate (Techno Plastic Products® 920024) with 3–4 ml of diet/well. Two 24-h-old eggs from the stock colony were transferred.

This new modified diet was compared with the "natural" diet of *C. arabica* parchment coffee to 50% ± 10% water content, at a temperature of 25 ± 2 °C, RH of 65 ± 10% and 0:24 (L:D) photoperiod. The method of Romero & Cortina (2007) was used to prepare the coffee berries: a hole 1 mm in diameter and 7 mm deep was bored into each dried berry, and two 24-h-old eggs were placed in the hole. The parchment coffee were placed individually in the same type of culture plates used for the artificial diet.

The development of *H. hampei* on the artificial and natural diets was evaluated with 400 replications. The numbers of CBB life stages (eggs, larvae, prepupae, pupae and adults) were assessed daily for 30 days. Each day, 10 samples of both parchment coffee berries and diet were removed from the plates and dissected under a Zeiss® Stemi SV¨6 stereomicroscope and the immature stages and emerged females and males were counted.

Data Analysis: Data were analyzed by generalized linear models (GLMs) (NELDER; WEDDERBURN, 1972), using a binomial model for viability and sex-ratio data, and a Poisson model for duration. The data were evaluated using a standard half-probability graph with simulated envelope (DEMETRIO; HINDE, 1997;, HINDE; DEMETRIO, 1998). In case of significant differences, the Tukey multiple comparisons test was applied at 5% significance, using the glht function of the multicomp package with adjusted P.

We calculated the cost (in dollars) of producing one liter of diet using the components of Portilla´s recipe (1999) as well as the modified diet in this work

Compared with the natural diet, the modified Cenibroca artificial diet did not affect the egg-adult development period of *H. hampei*, which averaged 24.1 days on both. Nor were the total viability or the sex ratio significantly different (Table 2).

The artificial diet proved to be adequate with the proposed modifications. This diet provided the necessary nutrients for egg-adult development, with viability and sex ratio comparable to the original Cenibroca diet, which according to Portilla (1999), supports the development of these insects for 15 generations and with development similar to that obtained with the natural diet.

The cost of producing one liter of diet using Portilla´s recipe was US $ 16.06 while the cost of the modified diet was US $ 8.73.

The results obtained here allow us to conclude that this modified artificial diet can be used to maintain the breeding stock of *H. hampei* from Brazil, to obtain eggs and females for experimental use. This diet is comparable to the natural diet, in addition to being low-cost and easy to prepare.

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TABLE 2 - Effects of two different diets on *Hypothenemus hampei*: duration of developmental stages (mean days ± SE), egg to adult viability (mean % ± SE) and sex ratio. Temp.: 25 ± 2 °C, RH: 65 ± 10% and photophase: 0h.

Diet	Duration (days)[1]					Viability (%)[1]	Sex ratio[2]
	Egg	Larva	Pre-pupae	Pupae	Egg-adult		
Parchment coffee berries	4.3±0.05 a	8.6 ±0.17 a	5.1±0.12 a	5.2 ±0.12 a	24.5±0.9 a	83±2.9 a	0.85±0.01 a
Portilla modified	4.1± 0.04 a	8.4 ± 0.20 a	4.8± 0.13 a	5.9±0.09 a	24.1±0.7 a	85±3.5 a	0.82±0.07 a
F. X^2	4.19	1.71	5.17	1.87	3.69	1.19	2.50
P	0.04	0.19	0.02	0.17	0.05	0.317	0.02

[1] Means followed by the same letter in the column do not differ significantly (GLM with quasi-binomial distribution, followed by post-hoc Tukey test). df=1 for all comparisons.

[2] No difference in sex ratio (X^2, $P<0.05$)

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