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Coffee pruning: Importance of diversity among genotypes of *Coffea arabica*

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The renovation of Arabica coffee crops located in mountain regions should be based on the use of new improved genotypes and increased plant density, which require the establishment of an adequate pruning system. Little is known about the response of improved genotypes to pruning, therefore this study was done to evaluate the vegetative and reproductive recovery after pruning of genotypes of Arabica coffee cultivated in environment with high plant density, in order to identify how the different patterns of recovery may influence the crop after pruning. The experiment was developed in Espírito Santo state (Brazil), where 16 genotypes of Arabica coffee were cultivated in a randomized block design, with four repetitions (six plants per plot) and pruned after their fourth harvest. The 2-years period after pruning was evaluated to quantify the potential recovery and variability of behavior were found, making it possible to identify groups of genotypes of different behavior regarding the green coffee yield, grain size, growth rate and formation of new vegetative structures. The results show that not all genotypes recovered in the same speed after pruning, being possible to highlight some genotypes with better performance post-pruning. This fact shows the importance of genetic factors; more specifically the recovery, growth and coffee yield after the intervention; should not be ignored when deciding on the best method to renew the plantation. The decision on which cultivar and which pruning method to use should be a rational choice, based on the possible synergy between those technologies.

Key words: *Coffea arabica*, crop yield, growth, recovery.

INTRODUCTION

A considerable part of the coffee plantations in Brazil was or is still undergoing a process of renovation. This process is being supported by government programs based on the strategic plan for agriculture development, which stimulate the evaluation and planting of new coffee cultivars for renewal of the older crops (Seag, 2010).

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The promotion of new genotypes is from the scenario of cultivation in Brazil, which for decades was based on the cultivation of a very few number of cultivars (Matiello et al., 2005). Currently, several new improved cultivars are available for cultivation in Brazil, and the new genotypes used in these cultivars associate high crop yield with new agronomic traits, such as resistance to pests, diseases, drought and higher beverage quality, creating an advantageous option for the formation of more profitable and sustainable coffee plantations (Oliveira and Pereira, 2008).

Since some of the main regions where Arabica coffee (*Coffea arabica* Lineu) is cultivated in Brazil mountain regions, the use of improved genotypes should be associated with their adaptation for farming systems where the mechanization of the processes is not fully possible. The mountain plantations also require additional concern with soil conservation to make the agricultural activity sustainable in these conditions. For these conditions, the cultivation with high plant density is recommended, allowing a higher efficiency of land use, protecting the soil and bringing benefits in crop yield and efficiency of manpower to the process (Paulo et al., 2005; Oliveira et al., 2007).

However, the narrow spacing used in plantation with high plant density make the canopies to start overlapping each other with the plant aging, therefore, it is necessary to establish an adequate pruning management to mitigate the effects of an early excessive narrowing in the plantation. Pruning is a technology that has been associated with higher yield due to its promotion of reproductive output in different plant species (Bilir et al., 2006; Dutkuner et al., 2008). For coffee plants, there are several pruning managements that are recommended to be used when the canopies start overlapping and causing detrimental effects (normally after 4-6 years of cultivation, depending on the spacing, environment and growth), between the recommended pruning for *C. arabica* in Brazil, there are: “recepa” (high or low cut of orthotropic stems), “decote” (high cut above to control the plant height), “desponte” (cut of plagiotropic branches at a determined length), “esqueletamento” (association of orthotropic and plagiotropic cutting to control the shape of the canopy), and selective pruning (cutting varies per plant), as described by Cunha et al. (2011).

The differences of growth rates and patterns that exist among genotypes of *C. arabica* indicate that not all genotypes respond equally to pruning, as genotypes with vigorous growth may recover more promptly, while genotypes of slower or restrict growth may not recover satisfactory after cutting. Thus, due to the existence of diversity in canopy architecture and growth patterns, studies to characterize the adaptation and recovery capacity of cultivars become necessary to support a better recommendation cultivars and techniques for these conditions.

Little is known about the response of improved genotypes to pruning, with no conclusive scientific information about the quantification of the recovery potential of different genetic materials after pruning. Thus, it is necessary to study the existence of diversity of response among genotypes to improve the recommendation or even define groups which respond positively to the technique.

The objective of this study was to evaluate the vegetative and reproductive recovery after pruning of genotypes of Arabica coffee cultivated in environment with high plant density, in order to identify how the different patterns of recovery may influence the crop after pruning.

MATERIALS AND METHODS

Experimental design

The experiment was developed in Alegre municipality, Espírito Santo state, Brazil (20°45′S, 41°33′W), the local presents altitude of 690 m above sea level, in the mountains of the Caparaó Region, the soil is classified as oxisol. Sixteen genotypes of Arabica coffee (*C. arabica* Lineu), chosen from previews studies that affirmed their potential to be cultivated in this region (Rodrigues et al., 2016), were cultivated in a randomized block design, with four repetitions (six plants per plot). Plant spacing was 2.00 x 0.60 m, representing a high-density cultivation (Androcioli Filho and Androcioli, 2011), which was grown following the agricultural practices currently recommended for the region (Prezotti et al., 2007; Reis and Cunha, 2010, Reis et al., 2011). After the fourth harvest (5 years of cultivation), the canopies were subjected to pruning, cutting orthotropic stems at 1.60 m above soil level (horizontal cut) and plagiotropic branches at near 20 cm of canopy radius (vertical cut).

Growth, production and classification

The vegetative and reproductive recovery of the plants was evaluated, from pruning to the first reproductive cycle after recovery (2 years after pruning). The canopy growth rates were calculated based on the temporal variation of length of orthotropic and plagiotropic stems (from insertion to the apex), expressed in number of days required to grow 1 cm, resulting in the orthotropic growth rate (OGR, days cm^{-1}) and plagiotropic growth rate (PGR, days cm^{-1}). The emission of new branches from the orthotropic stem above the pruning cut was monitored and the temporal variation of number of new branches was used to calculate the branch emission rate (BER, days $branch^{-1}$). Similarly, the emission of new nodes on plagiotropic branches was monitored to determine the node emission rate (NER, days $nodes^{-1}$). After ripening, all fruits from each plant were harvested and weighted; consecutively dried, processed and reweighed to determine the mass of green coffee yielded by each plant (GCP, kg $plant^{-1}$). The ratio between mass of processed grains and original mass of coffee beans was then calculated to evaluate the mass return ratio (MRR, %). Triplicate samples of green coffee were used to classify the grain size in commercial sieves, establishing the proportion of fruits classified in larger classes of each grain shape. For large flat-shaped grains (standard), the mass graded over a 17 screen (over 6.74 mm of diameter) were determined (LFG, %); and for large egg-shaped grains (mocha), the mass graded over a 11 screen (over 4.36 mm of diameter) were determined (LMG, %).

Data analyses

The collected data was investigated using univariate variance analyses ($p<0.01$ and $p<0.05$), using the model $Y_{ijk} = \mu + B_j + G_i + \varepsilon_{ij}$, where Y_{ijk} represents the phenotypic value of the ijkth observation, B_j represents the effect of the jth block, G_i is the fixed effect of the ith genotype, and ε_{ij} is the random error related to the ijth observation. The genetic parameters were estimated following the methodology described by Cruz and Carneiro (2003): mean phenotypic variance as $\hat{\sigma}^2_p$; quadratic component as $\hat{\phi}_g$; mean environmental variance as $\hat{\sigma}^2_e$; coefficient of genotypic determination as H^2; coefficient of genetic variation as CV_g; variation index as θ (Vencovsky, 1978; Cruz and Carneiro, 2003). The means of each variable were compared ($p<0.05$) using the Scott-Knott criteria (Scott & Knott, 1974). Sequentially, the data was explored by multivariate analyses, the generalized distance of Mahalanobis was estimated for all pairing of genotypes and the relative importance of each trait was estimated from the standardized means (Singh, 1981). From the distance matrix, the genotypes were clustered using the simple link criteria through the Tocher optimization method. The statistical analyses were performed using the statistical software “GENES” (Cruz, 2013).

RESULTS AND DISCUSSION

The results show existence of considerable variability among genotypes for most traits of recovery after pruning, only not significant differences for the orthotropic growth rate occurred (Table 1). As the cutting of the upper part of orthotropic branches promotes the break of apical dominance, it is possible that the metabolic investment in plagiotropic branches made the growth of orthotropic stems to be slower (Cline, 1996; Dun et al., 2006) and hid possible differences between growth patterns of genotypes. For all others traits, significant differences (as observed for Ms_g in Table 1) can be identified among genotypes, and this heterogeneity of behavior regarding vegetative and reproductive recovery can be linked to genetic variability existing among this group of genotypes, as indicated by the genetic parameters (Table 1).

Since the estimative of quadratic components were higher than environmental variances (Table 1) in the determination of phenotypic variances for all characteristics (except OGR), it is possible to relate major influence of genetic than environmental variances in the determination of these traits. For the species, *C. arabica*, the expression of several agronomic traits have been reported to be highly related to the expression of genetic diversity among cultivars (Carvalho et al., 2012; DaMatta, 2004; Del Grossi et al., 2013; Martinez et al., 2011; Martins et al., 2015; Rodrigues et al., 2014, 2015; Shigueoka et al., 2014). Additionally, the estimative of coefficient of genotypic determinations were higher than 90% for MRR, LFG and BER (Table 1), showing that these traits are especially valuable in the genetic study of the recovery, since genetic factors seems to have major contribution in the determination of the phenotypic values of these traits. The variation indexes for GCP, MRR, LFG, PGR and BER (Table 1) also indicate favorability for a possible genotype selection, since it seems that genetic variation surpassed environmental.

Regarding the difference of means among genotypes, Table 1 shows that it is possible to distinguish up to four different homogeneous groups for LFG and BER, three groups for MRR, and two homogeneous groups for GCP, LMG, PGR and NER. No differentiation was observed for OGR.

Paraíso MG H419-1, H419-3-3-7-16-4-1-1, Araponga MG1, Catucaí 24/137, Catiguá MG2, Sacramento MG1, Pau-Brasil MG1, and Catiguá MG3 yielded over 510 kg of green coffee per plant, which shows the potential of these genotypes for narrow cultivations and how their reproductive recovery was vigorous enough to allow a production that represents values 168% over the average crop yield for Arabica coffee in Brazil (Conab, 2016). This behavior for some genotypes, such as Araponga MG1 and Pau-Brasil MG1, may be related to a higher degree of adaptation for systems with high plant density, as also observed by Rodrigues et al. (2016).

The pruning seems to stimulate the production of plants of the genotype Sacramento MG1, since this genotype tend to develop vigorous vegetative growth when cultivated with high plant density, but overall yield with less fruits in several others genotypes Rodrigues et al. (2016). After pruning however, the intervention in canopy seems to promote the production to the point of the genotype to achieve similar yield than other highly productive cultivars, this fact may be a response to the enhanced light penetration in the canopies favoring the blossoming and development of reproductive structures (DaMatta et al., 2007).

The genotype Catuaí IAC 81 presented 36.94% of mass return, showing that is possible to achieve larger mass of green coffee from the same mass of coffee beans than the other genotypes. This results are evidences of a complete recovery of grain filling from this genotype, since its higher processing ratio was also observed in plants without intervention by pruning (Rodrigues et al., 2016).

Regarding the grain size, larger proportion of flat-shaped grains screened in sieves above 17 were observed from the genotypes Katipó, Araponga MG1 and Catucaí 24/137, which presented over 32% of grains classified as large. Considering mocha grains, the genotypes Iapar 59, Acauã, Araponga MG1, Catucaí 24/137, Catiguá MG3, Oeiras MG 6851 and Catuaí IAC 44 presented over 91% of their grains screened over sieve 11 (large grains).

H419-3-3-7-16-4-1-1, Araponga MG1, Sacramento MG1 and Pau-Brasil MG1 presented slower horizontal growth, requiring over 38 days to gain an average of 1 cm

Table 1. Descriptive analyses, genetic parameters and means of eight variables obtained by evaluating the vegetative and reproductive recovery of 16 genotypes of Arabica coffee after pruning (Alegre, Espírito Santo, Brazil, 2014-2016).

Parameter	GCP[9] (g)	MRR[10] (%)	LFG[11] (%)	LMG[12] (%)	OGR[13] (days)	PGR[14] (days)	BER[15] (days)	NER[16] (days)
				Descriptive analysis				
Minimum	253.87	17.01	8.38	80.30	5.08	24.80	15.26	17.70
Maximum	775.56	39.41	45.97	97.50	19.10	55.18	65.32	33.19
Mean	476.36	23.87	24.30	90.79	7.76	35.35	26.47	24.28
CV (%)[1]	17.40	9.18	18.77	3.66	27.94	13.83	14.74	12.34
Genetic parameters								
MS_G[2]	41.481.35**	71.33**	305.87**	23.79*	7.17^{ns}	91.21**	294.10**	19.65*
$\hat{\sigma}^2_p$[3]	10.370.34	17.83	76.47	5.95	1.79	22.80	73.52	4.91
$\hat{\sigma}^2_e$[4]	1.717.82	1.20	5.20	2.76	1.17	5.98	3.81	2.24
$\hat{\Phi}_g$[5]	8.652.52	16.63	71.27	3.18	0.62	16.82	69.72	2.67
H^2[6]	83.44	93.27	93.20	53.52	34.49	73.78	94.82	54.34
CV_g (%)[7]	19.53	17.08	34.74	1.97	10.14	11.60	31.54	6.73
θ[8]	1.12	1.86	1.85	0.53	0.36	0.83	2.14	0.54
Genotype means[17]								
Iapar 59	314.94^{b}	27.21^{b}	16.28^{c}	93.50^{a}	7.61^{a}	37.12^{b}	19.12^{d}	23.36^{b}
Katipó	433.83^{b}	22.31^{c}	33.88^{a}	86.40^{b}	7.69^{a}	34.04^{b}	27.63^{c}	23.37^{b}
Acauã	430.02^{b}	21.55^{c}	31.38^{b}	92.60^{a}	6.90^{a}	34.44^{b}	22.35^{d}	25.11^{b}
Paraíso MG H419-1	546.45^{a}	23.53^{b}	19.20^{c}	90.68^{b}	8.63^{a}	32.76^{b}	35.90^{b}	27.38^{a}
H419-3-3-7-16-4-1-1	629.45^{a}	19.42^{c}	28.35^{b}	90.60^{b}	7.27^{a}	39.42^{a}	25.89^{c}	28.30^{a}
Araponga MG1	510.51^{a}	24.10^{b}	32.80^{a}	95.53^{a}	8.43^{a}	38.97^{a}	24.18^{c}	23.95^{b}
Catucaí 24/137	614.25^{a}	22.06^{c}	38.28^{a}	92.75^{a}	9.14^{a}	31.66^{b}	25.97^{c}	24.30^{b}
Catiguá MG2	535.67^{a}	21.20^{c}	10.50^{d}	89.33^{b}	6.07^{a}	36.22^{b}	18.65^{d}	24.45^{b}
Sacramento MG1	564.15^{a}	21.74^{c}	10.65^{d}	89.60^{b}	6.94^{a}	42.82^{a}	21.28^{d}	21.51^{b}
Pau-Brasil MG1	569.65^{a}	20.24^{c}	17.30^{c}	87.28^{b}	10.76^{a}	46.26^{a}	50.52^{a}	24.33^{b}
Catiguá MG3	568.98^{a}	23.50^{b}	27.15^{b}	92.40^{a}	7.07^{a}	34.64^{b}	22.55^{d}	23.29^{b}
Oeiras MG 6851	398.36^{b}	20.03^{c}	29.38^{b}	91.43^{a}	9.31^{a}	31.16^{b}	37.51^{b}	27.38^{a}
Tupi	372.97^{b}	25.98^{b}	13.65^{d}	89.38^{b}	9.07^{a}	27.29^{b}	30.51^{c}	26.28^{a}
Catuaí IAC 44	417.58^{b}	26.62^{b}	29.78^{b}	92.78^{a}	6.10^{a}	30.67^{b}	20.71^{d}	23.53^{b}
Catuaí IAC 81	354.91^{b}	36.94^{a}	21.50c	90.48^{b}	6.66^{a}	35.17^{b}	22.53^{d}	21.26^{b}
Catuaí IAC 144	360.04^{b}	25.51^{b}	28.75^{b}	87.95^{b}	6.45^{a}	32.96^{b}	18.28^{d}	20.61^{b}

**Significant at 1% probability; *Significant at 5% probability; ^{ns}Non-significant at 5% probability; [1]Coefficient of variation; [2]Mean square of genotypes; [3]Mean phenotypic variance; [4]Mean environmental variance; [5]Quadratic component; [6]Coefficient of genotypic determination; [7]Coefficient of genetic variation; [8]Variation index; [9]Green coffee yielded per plant; [10]Mass return ratio; [11]Proportion of large flat-shaped grains; [12]Proportion of large egg-shaped grains; [13]Orthotropic growth rate; [14]Plagiotropic growth rate; [15]Branch emission rate; [16]Node emission rate; [17]Means followed by the same letter do not differ by the Scott-Knott test, at 5% probability.

in their plagiotropic branches. Additionally, the slow recovery of plagiotropic branches from the genotype Pau-Brasil MG1 is also highlighted for requiring 50 days to grow a new branch. Paraíso MG H419-1, H419-3-3-7-16-4-1-1, Oeiras MG 6851 and Tupi presented slower emission of new nodes, requiring over 26 days to develop an average of one new node in their plagiotropic branches.

Based on the Mahalanobis distances, the relative contribution of the variables was estimated. OGR was discarded due to its low contribution and the order of traits that contributed the most were: BER (31.54%) > LFG (23.42%) > MRR (23.39%) > GCP (10.50%) > PGR (6.43%) > NER (2.43%) > LMG (2.29%). By the Tocher method, the genotypes were clustered in seven groups. The group I clustered genotypes which presented high fruit production, exclusively genotypes among the ones with higher green coffee yield, being composed by H419-3-3-7-16-4-1-1, Catiguá MG2, and Araponga MG1.

Group II formed Catucaí 24/137, Catuaí IAC 81, and Catiguá MG3; and was characterized by genotypes with fast recovery of plagiotropic branches, presenting fast emission of nodes in the branches and a higher growth rate of branches, which made it possible to develop a larger number of nodes that could sustain a larger number of new structures, such as secondary branches, leaves and reproductive buds.

The group III clustered Oeiras MG 6851, Catuaí IAC 44 and Paraíso MG H419-1; which are genotypes of different behaviors, but all with high growth rate of plagiotropic branches, and overall longer internodes in their plagiotropic branches. Group IV clustered genotypes of lower mass return ratio, being formed by Katipó and Pau-Brasil MG1, which require a larger mass of coffee beans to produce the same mass of green coffee due to their fruit intrinsic characteristics. These genotypes also presented a smaller proportion of mocha grains screened as large. Moreover, this group of genotypes presented fast emission of new nodes on their plagiotropic branches. Similarly, the group V, composed of Acauã and Sacramento MG1, also presented low mass return ratio and fast node recovery rate. However, this group of genotypes associated these traits to a fast emission of new plagiotropic branches. Group VI clustered genotypes of lower yield and fast plagiotropic growth, being formed by Iapar 59 and Tupi.

The group VII was formed by a single genotype, Catuaí IAC 144, which associate low fruit yield, low proportion of grains classified as large mocha, fast growth and emission of plagiotropic branches and fast emission of nodes.

Conclusion

Since the genotypes with lower means of green coffee per plant still achieved high enough yield to surpass the average yield of the region, the pruning used in this experiment is a valuable technique for renovation and for handling the density of canopies in the system. But the various growth patterns and the different characteristic of the grains found in the results, associated with the high estimate genetic parameters is a proof that some genotypes are more suitable for plantations with high plant density, but not all genotypes recover after pruning in the same speed, which is possible to highlight some genotypes with better performance post-pruning. This fact shows the importance of developing more studies in this subject, since the genetic factors; more specifically the recovery, growth and coffee yield after the intervention; should not be ignored when deciding on the best method to renew the plantation. The decision on which cultivar and pruning method to use should be a rational choice, based on the possible synergy between these technologies.

CONFLICTS OF INTERESTS

The authors have not declared any conflict of interest.

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