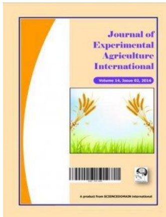

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Path Analysis of Vegetative Characteristics in Conilon Coffee Production Consortiated with Green Fertilizers in Tropical Climate

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MEPCJ, FCC, IMP and AJZ designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors GAG, WLL and LLP managed the analyses of the study. Authors TRM, SFS and MCP managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The objective of this study was to evaluate the relationship between morphoagronomic characters and coffee productivity and their direct and indirect effects under the influence of different types of green fertilizers. The experiment was carried out in the field followed by the sampling method in a pre-established coffee plantation, installed in soil with a slope of 11% in the Southern Region of the State of Espírito Santo. The intercropping of coffee with green fertilizers studied were pigeon pea,

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jack bean, velvet bean, and wild Mexican sunflower, as well as a control treatment without green fertilizers. The experimental unit consisted of a coffee plant, clonal variety "Incaper 8142" Conilon Vitoria, with a spacing of 2.30 x 2.60 meters, with a crop age of seven years, using the border of at least one coffee plant between experimental units. Eight morphoagronomic characteristics were measured, having as main dependent variable the productivity (in kg per plant) obtained in the harvest of 2015, and as primary explanatory characteristics: plant height, orthotropic branch diameter, plagiotropic branch diameter, number of leaves, number of nodes, number of orthotropic branches, number of plagiotropic branches and number of productive nodes. To increase productivity, coffee plants with the highest number of orthotropic branches and number of plagiotropic branches should be selected. The characteristics of greater direct contribution were a number of nodes and the number of productive nodes.

Keywords: Tropical environment; agricultural production; vegetative development; Coffea canephora L., green fertilizers.

1. INTRODUCTION

Brazil's coffee crop in 2017 is expected to reach 43.38 million bags of coffee, of which 84.40% are arabica, and 15.60% are conilon. The two species of coffee are grown in 18 states of the Union, involving 2000 municipalities, 370 thousand properties, occupying 8 million workers, in the cultivation of 6.73 billion plants, in 2.35 million hectares, which characterizes the size economic and social development of coffee [1].

In the case of conilon, the technologies developed by researchers, and adopted by the producers, have changed the technological bases of the production system, turning the coffee plantations of capixabas into one of the most competitive in the world [2]. However, to meet the demands of the productive chain, coffee cultivation must always be evolving.

Productivity is the main characteristic used in the selection of new varieties and/or lineages of coffee trees [3]. It is important to highlight that in research involving perennial plants such as coffee, the time required for the unambiguous confirmation of the results is great, demanding improvement programs, large volumes of physical, financial and human resources, and it is advantageous to practice the selection of superior genotypes indirectly and/or anticipated [4].

Knowing the association between characters is also of great importance in the works, especially when it comes to characters with low phenotypic potential [5].

In this type of work is important to identify, among the characteristics of high correlation with the basic variable, those with greater direct effect in a favourable sense to the selection, such that the correlated response through indirect selection is efficient [6]. Despite the usefulness of the correlations in the understanding of a complex character as the production, it only informs on the association between characters [7], not determining the importance of the direct and indirect effects of the characters that compose it. However, the primary characters may have low heritability, resulting in the need to know the influence of the secondary components on the primary components and on grain yield [8].

It is also known that the correlations are measures of linear associations between characters, being between the values -1 and +1. However, genetic correlation coefficients greater than the absolute value 1 can occur as a consequence of problems related to the distribution of variables, or even to the model used in the estimation of variances and covariates, which determine the correlation [5]. To improve the understanding of the association between characters, [9] proposed a methodology that allows, through the standardization of variables and regression equations, to deploy genotype correlations in direct and indirect effects of the explanatory variables on the main characteristic, providing a measure of the influence of each cause and its effect. This methodology is called path analysis or track analysis.

In a given experimental condition, the decomposition of the correlations depends on the set of characters studied, which are usually evaluated based on previous knowledge of their importance and possible interrelations expressed in path diagrams. However, for the evaluation to have a reliable estimate and generate a biologically appropriate interpretation, it is fundamental to evaluate the degree of colinearity in the correlation matrix of all the characteristics to be selected [5].

When a large number of characteristics are considered in the selection process, there is the possibility that some of the analyzed independent variables present a certain degree of interrelationship, characterizing the existence of multicollinearity, its harmful effects being caused not simply by its presence, but by the degree with that it manifests itself [8]. Among the effects of high multicollinearity, we can mention the unstable estimates of the regression coefficient and an overestimation of the direct effects of the explanatory variables on the main one, which can lead to the wrong results [10].

Considering the information above, the present work was proposed to evaluate the relationship between morphoagronomic characters and coffee productivity and the direct and indirect effects of different types of green fertilizers.

2. MATERIALS AND METHODS

The experiment was carried out in Alegre, Espírito Santo State, at 20º45'44" South, longitude 41º27'43" West and altitude of approximately 134 MSL (Fig. 1). According to Köppen classification, the climate of the region is "Aw" type, with dry winter and rainy summer with an average annual temperature of 23°C and annual precipitation around 1,200 mm. The rainy season in the region is concentrated from November to March [11].

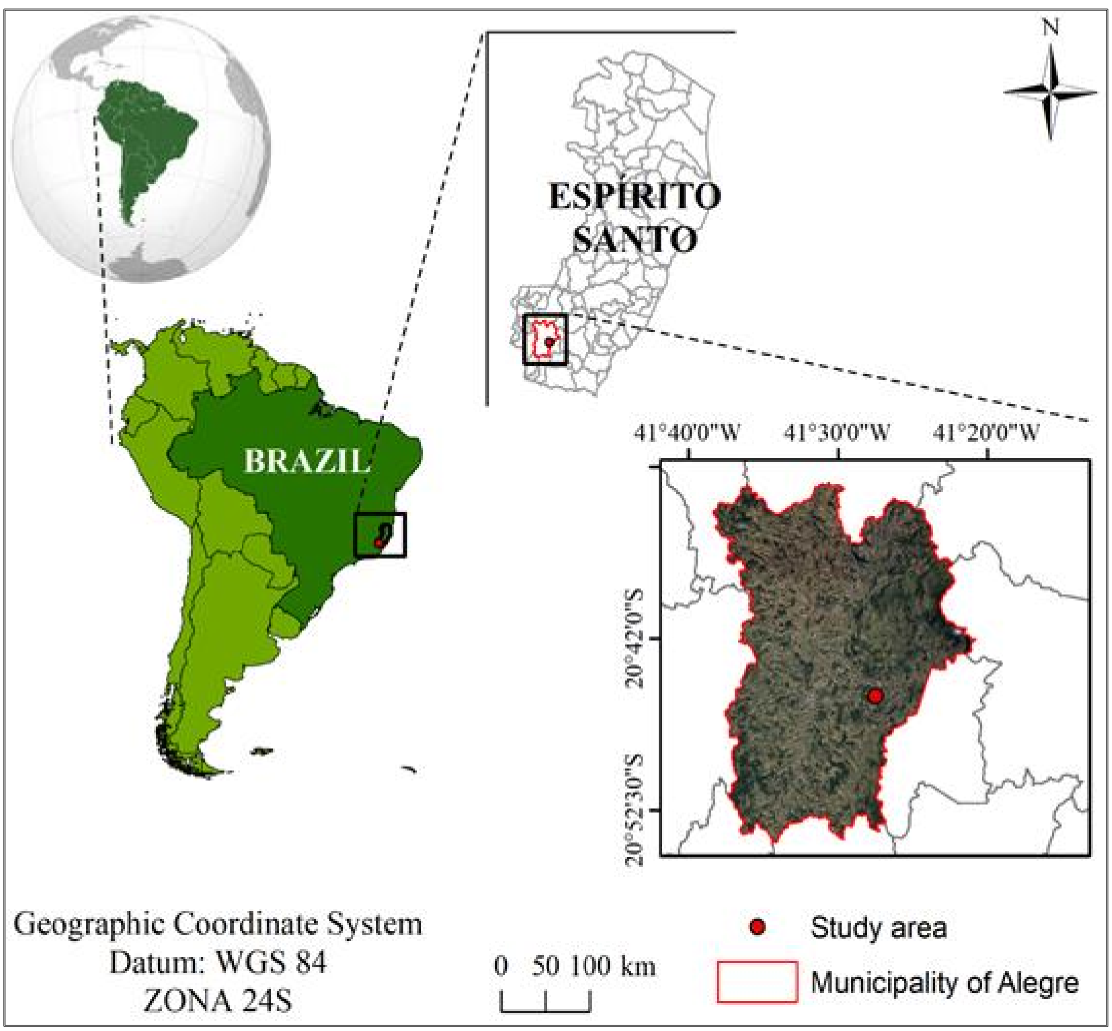

Fig. 1. Location of the study area

The experiment was carried out in the field followed by the method of sampling in a pre-established coffee plantation, installed in soil with a slope of 11%, in the South Region of the State of Espírito Santo. The green fertilizer species, intercropped with the coffee tree were pigeon pea, jack bean, velvet bean, and wild Mexican sunflower plus a control treatment without green fertilizers. The experimental unit consisted of a coffee plant, clonal variety "Incaper 8142" Conilon Vitoria, clone 12V (precocious) with a spacing of 2.30 x 2.60 meters, at the age of seven years, using a hair border least one coffee plant between the experimental units. Five replicates were used for each treatment.

The legumes were sown 50 cm from the stem diameter of the coffee trees in furrows spaced 50 cm apart, totalling two rows of 10 m in length. Seed density and cultural practices followed the technical recommendations for each legume [12].

Weed management was performed with semi-mechanized manual trimmer when necessary. The cutting of the green fertilizer was carried out in the phase before full flowering. The species under study were grazed with the aid of the portable brush cutters and remained on the soil surface. The pruning of the legumes, or thinning, depending on the cycle the leguminous plants were in, were carried out with the intention of not letting the species compete, due to the luminosity-water-nutrients, with the coffee tree. Only the pigeon pea and the wild Mexican sunflower were pruned maintaining the size of 0,60 cm of height of the soil, whereas the other species used as green fertilizers velvet bean and jack bean after the cycle were chopped and planted again, with new seeds.

The morphoagronomic characteristics evaluated in the coffee plants were:

1. Plant height (H), obtained by the distance between the insertions of the two new branches with the old and its apical meristems (cm);
2. Orthotropic branch diameter (OBD), with standardized measurement in the central region of the second training of each branch (mm);
3. Plagiotropic branch diameter (PBD) measured in the second node from the center of the plant to the tip of the selected branch;
4. Number of leaves (NL) thrown in the plagiotropic branches, obtained by the monthly and cumulative count, in the branches;
5. Number of nodes (NN) of the plagiotropic branches, obtained by direct counting in the selected branches;
6. Number of orthotropic branches (NOB), counted from the marked plants;
7. Number of plagiotropic branches (NPB), obtained by direct counting in each orthotropic branch in two branches per plant;
8. Number of productive nodes (NPN) of the plagiotropic branches, obtained by direct counting of the nodes in the selected branches;
9. Kilograms of cherry coffee produced per plant (kg) by weighing the coffee after harvest using a digital scale.

The measurements were performed with a digital caliper and manual scale, being used in the evaluations throughout the experiment.

With the help of the GENES computational application [13], the correlation matrix between the morphoagronomic characteristics evaluated was constructed. Given the presence of collinearity between characteristics (high degree of interrelation), a multicollinearity analysis was performed, with correlation matrix eigenvalues analysis, to identify the nature of the linear dependence between the characters and to detect which ones contributed to the emergence of multicollinearity. When necessary, some of the characteristics were discarded, choosing among those considered redundant, by maintaining the one that offered the greatest contribution to explaining productivity.

In the sequence, a path analysis was performed, having as main dependent variable, the productivity obtained in the harvest of 2015 (kg), as primary explanatory the characteristics were: plant height (H), orthotropic branch diameter (OBD), diameter of (NPP), number of nodes (NN), number of orthotropic branches (NOB), number of plagiotropic branches (NPB), number of productive nodes (NPN). The unfolding of the correlations between the primary and secondary explanatory characteristics, in direct and indirect effects on the productivity character, were used to explain the results obtained.

3. RESULTS

In the evaluation of the determination coefficients (R2) positive effects were observed for the tested fertilizers, being 0.99 for jack bean, 0.41 for pigeon pea, 0.96 for velvet bean, 0.96 for wild Mexican sunflower and 0.99 for conventional mineral fertilization, showing that almost all of the basic variable (production) is explained by the primary components, except when the coffee tree was fertilized with pigeon pea (Table 1).

4. DISCUSSION

These results (Table 1) corroborate with those of Dalcolmo [14], who obtained a coefficient of determination equal to 1.00 by means of trail analysis in conilon coffee genotypes. The coefficients of determinations R^2, considered high, showed that the variations occurred in the basic variable were explained by the variables measured.

In the coffee plants fertilized with wild Mexican sunflower, a direct effect with a negative magnitude of height over productivity was observed. In addition, there were indirect effects with high magnitude by height, on productivity, plagiotropic branch diameter (PBD), number of leaves (NL), number of orthotropic branches (NOB) and number of plagiotropic branches (NPB), indicating that these important characters for coffee production, and should be considered in the case of indirect selection of characters. For the coffee plants fertilized with jack bean, there was an indirect effect with high negative magnitude, of PRD via H and indirect effect with a high positive magnitude of the number of nodes (NN) via height overproduction. However, in plants fertilized with conventional mineral fertilization, the NN influenced indirectly with negative magnitude, via coffee height, on productivity (kg).

According to Nogueira et al. [15], in the interpretation of correlations, three aspects should be considered: magnitude, direction and significance. Estimation of the positive correlation coefficient indicates the tendency of one variable to increase when the other also increases, and negative correlations indicate a tendency for one variable to increase while the other one decreases.

The coffee plants fertilized with velvet bean had a direct effect of very high negative magnitude of OBD on productivity. However, there was an indirect effect with a high positive magnitude of NL via OBD on productivity (Table 1). However, for coffee plants fertilized with wild Mexican sunflower, there was a direct effect of the high positive magnitude of OBD and positive indirect effect of height (H) of the orthotropic branch and negative via NOB and highly negative of NPB. For coffee plants fertilized with jack bean, a negative indirect effect of PBD and high positive magnitude of NN was obtained (Table 1).

According to Dalcolmo [14], the greatest associations with coffee productivity occurred via indirect effects of OBD, which indicates that the direct intensified selection pressure on this characteristic may not provide satisfactory gains in productivity, since the high values were consequences, mainly of these indirect effects.

The coffee plants fertilized with jack bean had a positive direct PBD effect on productivity. Also, there was a negative indirect effect of NN via PBD. For coffee plants fertilized with wild Mexican sunflower, a highly negative direct effect of PBD and highly positive indirect ELT via PBD was obtained (Table 1). For coffee plants fertilized with velvet bean, a highly negative indirect effect of NL via PBD and positive NPB via PBD was obtained.

Chaves Filho [16] observed the opposite effect of the fertilization with jack bean in the fertilizations in coffee trees in which the effects were negative to increase the diameter of the plagiotropic branch. According to the same authors, this factor is related to the low nitrogen supply provided by the green fertilizer, which was below the nutritional demand of the coffee tree.

The coffee plants fertilized with velvet bean had highly negative direct effects of NL on PROD and indirect positive effect of OBD and highly positive NPB via NL (Table 1). In the plants fertilized with wild Mexican sunflower, we observed a highly negative direct effect of NL on PROD and highly positive indirect of H via NL and negative of NOB and highly negative of NPB (Table 1). For the coffee plants fertilized with jack bean, a positive indirect effect of NN via NL on PROD was obtained. However, the plants fertilized with conventional fertilization obtained the negative indirect effect of NN via NL on PROD.

Certainly, the direct negative effects are associated with the nutritional effects of coffee plants, due to the competition for water and light in the period of vegetative growth of the green fertilizers, causing competition.

Table 1. Estimates of the direct and indirect effects of the measured morphoagronomic variables on the basic coffee productivity variable (kg plant^{-1})

kg/plant		**Jack bean**	**Pigeon pea**	**Velvet bean**	**Wild Mexican sunflower**	**Conventional**
Direct effect H	**Via**	0.3797951	-0.0667986	-0.3344779	**-1.0000000**	0.1473389
Indirect effect H	OBD	-0.4526606	-0.0694719	0.2259135	-0.3424713	-0.0887094
Indirect effect H	PBD	**-0.8599545**	-0.0497825	-0.0134634	**0.9488719**	0.4289038
Indirect effect H	NL	-0.3260438	0.2140486	0.0470916	**1.1824141**	0.0110086
Indirect effect H	NN	**1.0000000**	0.1991964	-0.1640081	-0.1589544	**-0.6521535**
Indirect effect H	NOB	0.2952332	-0.0362022	0.0914075	**0.7035183**	-0.0780771
Indirect effect H	NPB	0.2216671	0.0120106	0.0105732	**1.0000000**	0.1423407
Indirect effect H	NPN	-0.0078867	0.0332501	-0.2373236	-0.6472743	0.1323805
Total – Dir. and Indir. effect		-0.3283727	0.2362504	-0.3742871	0.3133799	0.0414036
Direct effect OBD	**Via**	-0.5460018	-0.1638316	**-1.1335188**	**1.5901909**	-0.1654968
Indirect effect OBD	H	-0.3148676	-0.0283256	0.0666624	**0.7965874**	0.0789764
Indirect effect OBD	PBD	**-0.8350603**	-0.0144393	-0.0065310	-0.0520391	0.0109534
Indirect effect OBD	NL	-0.3211612	0.2722416	**1.5133340**	-0.4636207	-0.0391427
Indirect effect OBD	NN	**1.1813293**	0.0668105	0.4992327	-0.0253701	0.0668892
Indirect effect OBD	NOB	0.3916156	-0.0054637	-0.0719767	**-0.9626072**	0.1746725
Indirect effect OBD	NPB	0.1783420	0.0463674	-0.5916483	**-1.1642132**	0.1776261
Indirect effect OBD	NPN	0.0409970	0.0108805	-0.2764873	0.3334804	-0.2115877
Total – Dir. and Indir. effect		-0.2248070	0.1842399	-0.0009329	0.0524085	0.0931837
Direct effect PBD	**via**	**1.2331865**	0.0909418	0.0465673	**-2.0444039**	-0.6147461
Indirect effect PBD	H	0.2648476	0.0365663	0.0967036	**1.7167198**	-0.1027972
Indirect effect PBD	OBD	0.3697287	0.0260124	0.1589747	0.0404774	0.0029488
Indirect effect PBD	NL	0.2213203	-0.0759583	**-1.0725441**	-0.3797650	-0.0702246
Indirect effect PBD	NN	**-1.4831252**	0.0028676	-0.1390560	0.0826978	0.3156462
Indirect effect PBD	NOB	-0.2352309	0.0369354	-0.0707388	-0.0042619	0.2322309
Indirect effect PBD	NPB	-0.2025974	-0.1148148	**0.7162218**	-0.0915689	0.1833462
Indirect effect PBD	NPN	0.0715904	-0.0171103	0.0046496	0.1516964	-0.0105558
Total – Dir. and Indir. effect		0.2397200	-0.0145600	-0.2592219	-0.5284083	-0.0610556

kg/plant		Jack bean	Pigeon pea	Velvet bean	Wild Mexican sunflower	Conventional
Direct effect NL	**via**	-0.5869551	0.4748077	**-2.2568620**	**-1.4333219**	-0.1298828
Indirect effect NL	H	-0.2109699	-0.0301136	0.0069792	**3.0512966**	-0.0124881
Indirect effect NL	OBD	-0.2987529	-0.0939365	**0.7600786**	0.5143614	-0.0498756
Indirect effect NL	PBD	-0.4649916	-0.0145486	0.0221305	-0.5416739	-0.3323787
Indirect effect NL	NN	**0.8509697**	0.1356520	-0.4995919	0.0875731	**-0.6557647**
Indirect effect NL	NOB	0.2485850	-0.0225857	-0.0109861	**-0.7638209**	0.0885747
Indirect effect NL	NPB	0.0413783	0.0798211	**1.0690365**	**-1.8626638**	0.2099223
Indirect effect NL	NPN	0.1318692	0.0280049	0.4159668	0.5514345	0.1220207
Total – Dir. and Indir. effect		-0.2888672	0.5571011	-0.4932485	-0.3968149	-0.7581610
Direct effect NN	**via**	**-1.6899839**	0.3084154	-0.5750567	0.6073563	**1.2968750**
Indirect effect NN	H	0.2654249	-0.0431433	-0.0953942	**0.9680274**	-0.0740916
Indirect effect NN	OBD	0.3816651	-0.0354900	**0.9840589**	-0.0664244	-0.0085359
Indirect effect NN	PBD	**1.0822410**	0.0008456	0.0112606	-0.2783665	-0.1496229
Indirect effect NN	NL	0.2955537	0.2088371	**-1.9606938**	-0.2066669	0.0656752
Indirect effect NN	NOB	-0.1927173	-0.0028589	0.0284789	-0.1178148	0.1552644
Indirect effect NN	NPB	-0.2125224	-0.0936466	**0.8879332**	**-0.9687714**	-0.1769120
Indirect effect NN	NPN	-0.0236264	0.0127284	0.4033121	0.0745935	-0.4277850
Total – Dir. and Indir. effect		-0.0939653	0.3556877	-0.3161010	0.0119333	0.6813320
Direct effect NOB	**via**	**0.6815290**	0.0741319	0.2403166	**1.4949020**	-0.3168945
Indirect effect NOB	H	-0.1645244	0.0326210	-0.1272230	**-1.7406891**	0.0363016
Indirect effect NOB	OBD	-0.3137399	0.0120747	0.3394976	**-1.0239663**	0.0912220
Indirect effect NOB	PBD	-0.4256364	0.0453107	-0.0137074	0.0058285	0.4505064
Indirect effect NOB	NL	-0.2140896	-0.1446593	0.1031725	**0.7323564**	0.0363033
Indirect effect NOB	NN	0.4778802	-0.0118938	-0.0681476	-0.0478664	-0.6354116
Indirect effect NOB	NPB	0.0296641	-0.0745825	-0.3938004	**1.1895804**	-0.2347003
Indirect effect NOB	NPN	0.0096873	-0.0215395	0.0000000	-0.3977984	0.1909926
Total – Dir. and Indir. effect		0.0807704	-0.0885367	0.0801084	0.2123471	-0.3842341

kg/plant		**Jack bean**	**Pigeon pea**	**Velvet bean**	**Wild Mexican sunflower**	**Conventional**
Direct effect NPB	**via**	-0.2938234	0.2795102	**1.1769642**	**-3.1172151**	0.4453125
Indirect effect NPB	H	0.2865261	-0.0028703	-0.0030048	**2.7600179**	0.0470957
Indirect effect NPB	OBD	0.3314067	-0.0271777	0.5698087	0.5939023	-0.0660133
Indirect effect NPB	PBD	**0.8503076**	-0.0373563	0.0283377	-0.0600548	-0.2531062
Indirect effect NPB	NL	0.0826592	0.1355931	**-2.0499076**	**-0.8564686**	-0.0612273
Indirect effect NPB	NN	**-1.2223645**	-0.1033309	-0.4338381	0.1887548	-0.5152174
Indirect effect NPB	NOB	-0.0688064	-0.0197808	-0.0804075	-0.5704791	0.1670181
Indirect effect NPB	NPN	0.0815423	0.0242226	0.2865389	**0.8951343**	0.2876056
Total – Dir. and Indir. effect		0.0474475	0.2488098	-0.5055085	-0.1664084	0.0535031
Direct effect NPN	**via**	-0.2695668	-0.0594494	**0.7594355**	**-1.0320759**	-0.5346680
Indirect effect NPN	H	-0.0111117	0.0373605	0.1045243	**-2.3197184**	-0.0364802
Indirect effect NPN	OBD	0.0830384	0.0299847	0.4126796	-0.5138164	-0.0654932
Indirect effect NPN	PBD	-0.3275042	0.0261743	0.0002851	0.3004903	-0.0121368
Indirect effect NPN	NL	0.2871322	-0.2236679	**-1.2361544**	**0.7658188**	0.0296416
Indirect effect NPN	NN	-0.1481202	-0.0660330	-0.3053943	-0.0438968	**1.0376228**
Indirect effect NPN	NOP	-0.0244918	0.0268592	0.0000000	0.5761879	0.1132002
Indirect effect NPN	NPB	0.0888798	-0.1138862	0.4440745	**2.7036055**	-0.2395400
Total – Dir. and Indir. effect		-0.3217442	-0.3426578	0.1794504	0.4365949	0.2917608
Residual effect		0.0141	0.7679	0,1740	0,1843	0,0141
Determination coefficient (R^2)		0.9992685	0.4102781	0.9697136	0.9660771	0.9998790

Plant height (H), orthotropic branch diameter (OBD), plagiotropic branch diameter (PBD), number of leaves (NL), number of nodes (NN), number of orthotropic branches (NOB), number of plagiotropic branches (NPB), number of productive nodes (NPN)

According to Cruz and Carneiro [17], characters that present a direct effect contrary to the correlation with the main variable indicate the absence of cause and effect, suggesting that the auxiliary character is not the main determinant of the changes in the basic variable, and others may provide greater selection gain.

However, the effect of green fertilizer may modify the microclimate in which the coffee tree is present and, depending on the intensity and duration of the consortium, causes physiological, anatomical and reproductive changes in the coffee plants and may adversely affect the production. The productivity of a crop, in addition to its genetic expression and other conditions such as nutritional status, water supply, sanitation, weed control, and soil characteristics, is also a result of the efficient use of photosynthetic radiation [14,15,13].

The coffee plants fertilized with jack bean had a highly negative direct effect via NN on PROD. Also, a highly positive indirect effect was observed via NN on PROD (Table 1). In plants fertilized with conventional fertilization, a highly positive direct effect of NN on PROD was observed (Table 1). In the plants fertilized with velvet bean, there was a positive indirect effect of OBD and NPB via NN over PROD and negative of NL via NN (Table 1). For the coffee plants fertilized with wild Mexican sunflower, the positive indirect effect of H via NN and negative of NPB via NN over PROD was obtained (Table 1).

Certainly the negative direct effect with the number of nodes (NN), observed in the plants fertilized with jack bean, is associated to the period of consortium and management times, and the jack bean is usually used as the rotation of culture.

Cruz and Carneiro [17] observed that the jack beans' significantly reduced the crown diameter, number of leaves, and number of nodes of the coffee trees according to the consortium time. Both results are similar to those obtained in this work for the variable number of nodes (NN) demonstrating competition of this crop in a consortium with the coffee tree, being these vegetative characteristics sensitive to competition.

The coffee plants, fertilized with jack bean, had a direct effect of NOB on PROD (Table 1). For the plants fertilized with wild Mexican sunflower, a highly positive direct effect of NOB on the PROD (Table 1) was observed. There was a highly negative indirect effect of H, OBD, and NL positive and highly positive NPB via NOB on the PROD (Table 1).

Species with a tall bearing, such as wild Mexican sunflower, can shade the coffee tree and, consequently, resulting in height increase, which would not be expected in work with low legumes. However, Ferrão et al. [18], working with pigeon pea, reported that treatments influenced negatively not only the height but also the stem diameter of *Coffea arabica*.

In coffee plants fertilized with velvet bean, there was a direct positive effect of NPB on the PROD. However, there was a highly negative indirect effect of NL via NPB on the PROD. In the plants fertilized with wild Mexican sunflower showed a highly negative direct effect of NPB and a positive indirect effect via H and NPN and negative of NL via NPB on PROD (Table 1). The coffee plants fertilized with jack bean presented positive indirect effect via PBD and highly negative via NN (Table 1).

According to Chaves Filho et al. [19], the positive effects are related to the nutritional demand of the coffee plants, where the macro and micronutrient values are in equilibrium in the plant reducing the mortality rate of the plagiotropic branches, called potato drought.

In the coffee plants fertilized with velvet bean presented the positive direct effect of NPN and indirect effect highly negative via NN on the PROD (Table 1). In the plants fertilized with wild Mexican sunflower, there was a highly negative direct effect of NPN on PROD and highly negative indirect effect of H via NPN on PROD and indirect positive effect of NL and highly positive NPB (Table 1). The plants fertilized with conventional fertilizer showed a highly positive indirect effect of NN on the PROD.

Ferrão et al. [18] also found a negative correlation between the accumulation of dry legume matter and coffee yield. According to the same authors, pigeon pea was the one that accumulated more dry matter. However, the productivities in their treatments were smaller, with a reduction of up to 67%, when compared to the control.

5. CONCLUSION

The path analysis was efficient in identifying the characteristics that exerted the greatest influence on the productivity of *Coffea canephora* in consortium with green fertilizers.

The characteristics that exerted the greatest influence on the productivity of *Coffea canephora* intercropped with green fertilizers were the number of orthotropic branches (NOB) and several plagiotropic branches (NPB).

The characteristics of greater direct contribution were a number of nodes (NN) and the number of productive nodes (NPN). The green fertilizer wild Mexican sunflower was the one that provided a highly negative direct effect on the main variables related to the production, due to its greater competition.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. CONAB. National Supply Company, Follow-up of the Brazilian Crop (Coffee), Harvest; 2017;117. First Estimate. Available:https://www.conab.gov.br/info-agro/safras/cafe/boletim-da-safra-de-cafe (Accessed 23 April, 2017)
2. Ferrão MAG, Ferrão RG, Fornazier MJ, Prezotti LC, Fonseca AFA, Alexandre FT, Ferrão LFV. Advances in genetic improvement of conilon coffee. Seminar for the Sustainability of Coffee Growers. Alegre, ES: UFES, Center of Agrarian Sciences. 2013;Cap.7:110.
3. Carvalho AM, Mendes ANG, Carvalho GR, Botelho CE, Gonçalves FMA, Ferreira AD. Correlation between growth and productivity of coffee cultivars in different regions of Minas Gerais, Brazil, Brazilian Agricultural Research. 2010;45:269–275. Portuguese.
4. Bonomo P, Cruz CD, Viana JMS, Pereira AA, Oliveira VR, Carneiro PCS. Early selection of progenies of coffee timor X catuaí yellow e catuaí red. Acta Scientiarum Agronomy. 2004;26:91–96.
5. Cruz CD, Regazzi AJ, Carneiro PCS. Track analysis. Viçosa, Minas Gerais: UFV; 2004.
6. Severino LS, Sakiyama NS, Pereira AA, Vieira G, Zambolim L, Barros V. Productivity associations with other agronomic characteristics of coffee (*Coffea arabica* L. “Catimor”). Acta Scientiarum. 2002;24:1467–1471.
7. Sobreira FM, Fialho GS, Sánchez CFB, Matta FP. Post-harvest track analysis of salted tomato. Research National Faculty of Agronomy. 2012;62:4983–4988. Spanish.
8. Vieira EA, Carvalho FIF, Oliveira AC, Martins LF, Benin G, Silva JAG, Coimbra J, Martins AF, Carvalho MF, Ribeiro G. Track analysis between the primary and secondary components of grain yield in wheat. Brasilian Agro-science Research. 2003;13:169–174.
9. Wright S. Correlation and causation. Journal of Agricultural Research. 1921;20: 557–585.
10. Gondim TCDO, Rocha VS, Sediyama CS, Miranda GV. Track analysis for yield components and agronomic traits of wheat under defoliation. Brazilian Agricultural Research. 2008;43:487–493. Portuguese.
11. Alegre. Prefeitura Municipal de Alegre. Geographical Features; 2017. Available:http://alegre.es.gov.br/site/index.php/acidade/historia/caracteristicasgeograficas (Accessed 23 April, 2017)
12. Marcolan AL, Ramalho AR, Mendes AM, Teixeira CAD, Fernandes CF, Costa JNM, et al. Cultivation of conilon and robusta coffee trees for Rondônia. Ed. 3; 2009.
13. Cruz CD. Genes - a software package for analysis in experimental statistics and quantitative genetics. Acta Scientiarum Agronomy. 2013;35:271–276.
14. Dalcolmo JM. Biometry of conilon coffee growth after scheduled cycle pruning. Doctoral thesis. State University of North Fluminense, Campos dos Goytacazes, Brazil; 2012.
15. Nogueira APO, Sediyama LB, Sousa OT, Hamawaki AF, Cruz CD, Pereira DG, Matsuo É. Track analysis and correlations

between characters in soybean cultivated in two sowing seasons. Bioscience Journal. 2012;28:877–888.
16. Chaves Filho JT. New paradigms for coffee cultivation; 2007.
17. Cruz CD, Carneiro PCS. Biometric models applied to genetic improvement. Viçosa, Minas Gerais: Federal University Viçosa (UFV); 2013.
18. Ferrão RG, Cruz CD, Ferreira A, Cecon PR, Ferrão MAG, Fonseca AFA, Silva MF. Genetic parameters in Conilon coffee. Brazilian Agricultural Research. 2008;43: 61–69. Portuguese.
19. Chaves Filho JT, Oliveira RF. Seasonal variation of starch stored in plagiotropic branches of coffee. Research. 2008;35: 85–102.

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