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Growth and production of conilon coffee under fertilization of nitrogen and molybdenum (Mo)

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Abstract

Nitrogen is the most applied nutrient in *Coffea canephora* crops, due to the high requirement of the crop and low availability in most soils. The efficiency of nitrogen fertilization can be maximized by applying molybdenum, due to the role of molybdenum in the nitrate's metabolism. This study was conducted during two coffee production cycles under field conditions. It aimed to evaluate the effects of applying molybdenum on the growth and production of conilon coffee, subjected to different amounts of nitrogen. The experiment was conducted from June 2018 to May 2020. The experimental design used was in randomized blocks, in a 2 x 5 factorial scheme, the first factor being the absence and presence of molybdenum fertilization (4 kg ha^{-1} $year^{-1}$) and the second factor, nitrogen doses (300, 500, 700, 900 and 1,100 kg ha^{-1} $year^{-1}$) applied in five plots, during fruit development. We evaluated the conilon growth variables in each agricultural year, in addition to the yield of processed coffee and grain yield. The length of plagiotropic branches, number of nodes per side branch, number of rosettes and fruits per productive branch were closely related to the coffee yield and were influenced by the nitrogen fertilization. Increasing doses of nitrogen promoted quadratic increases in coffee yield, with addition of 35.3% and 88.9% for the 2019 and 2020 harvests, respectively, indicating that maximum coffee productivity is genetically defined and affected by environment conditions and management. For the harvest 2020, the application of molybdenum resulted in an increase in the length of the orthotropic stem and plagiotropic branches, in addition to providing increase of 3.7% in the yield of *C. canephora.* This suggested that there was a reduction in micronutrient availability in the soil, throughout the experimental period, limiting the growth and production of coffee in the second year.

Keywords: *Coffea canephora;* molybdenum nutrition; nitrogen nutrition; yield; vegetative growth.

Abbreviations: Al_aluminun; B_boron; BS_base saturation; Ca_calcium; CEC_cation exchange capacity; cm_centimeter; $cmol_c$_cmol.charge; Conab_National Supply Company; Cu_copper; dm^{-3}_cubic decimeter; ETc_crop evapotranspiration; ETo_reference evapotranspiration; FC_field capacity; Fe_iron; g_gram; GY_grain yield; H+Al_hydrogen+aluminun; ha_hectare; HEI_plant height; Ifes_Federal Institute of Espírito Santo; K_potassium; kc_crop coefficient; kg_kilogram; L_liter; Mg_magnesium; mg_miligram; mL_microlitre; mm_millimeter; Mn_manganese; Mo_molybdenum; N_nitrogen; NFB_number of fruits per branch; NNPB_number of nodes per plagiotropic branch; NPPB_number of productive plagiotropic branch; NRB_number of rosettes per branch; OIL_orthotropic internode length; OM_organic matter; P_phosphorus; PBL_plagiotropic branch length; PCY_processed coffee yield; pH_hydrogen potential; S_sulfur; SB_sum of bases; SD_stem diameter; Zn_zinc

Introduction

Coffee has great social and economic importance in Brazil, which stands out as the world's largest coffee producer. In 2018, the Brazilian production reached 62.92 million 60-kg bags of processed coffee, with *Coffea canephora* responsible for 29.85% of this total, placing the country as the world's second largest producer of this species (ICO, 2019).
According to data from Conab (2019), the average yield of conilon/robusta coffee reached 41.35 bags ha^{-1}, 74.8% higher than that obtained by arabica coffee. However, in irrigated conilon the yield may exceed 100 bags ha^{-1}, when pest and disease management, balanced nutrition, responsive genetic materials and adequate crop treatments are offered (Partelli et al., 2016).
The great productive potential of *C. canephora* results in high nutritional requirements. Among these nutrients, nitrogen (N) stands out, as it is the nutrient required in greater quantity in conilon crops (Covre et al., 2018). In plant tissues, N is used in the synthesis of various biomolecules such as amino acids, proteins, nucleic acids, chlorophyll, adenosine triphosphate, indole acetic acid, and coenzymes

such as Nicotinamide Adenine Dinucleotide and B vitamins (Taiz et al., 2014). It is known that N is closely related to the growth and production of coffee due to its roles in vegetative growth.

We verified that nitrogen fertilization has positive responses to characteristics of the growth of conilon coffee such as the stem diameter (Colodetti et al., 2015), the leaf area (Colodetti et al., 2014), the growth of plagiotropic branches (Magiero et al., 2017) and the accumulation of dry matter (Machado et al., 2016). According to Partelli et al. (2013), the components of the vegetative development of coffee trees have a close link with reproductive growth (flowering and fruiting) and production. Busato et al. (2016) explained the effects of nitrogen fertilization on the development of *C. canephora*, as well as the relationship between the elements of vegetative growth and plant production.

In most Brazilian soils, the availability of N is insufficient to meet the demand for crops (Ribeiro et al., 2019), which makes nitrogen fertilization of conilon coffee essential for achieving high yields. Even though, the supply of N to the soil through fertilization does not guarantee the proper nutrition of the plants. Efficiency of nitrogen fertilization can be compromised by processes that occur in the soil or in the plant tissue, reducing the availability of N to plants and their assimilation, respectively.

These processes depend on the availability of molybdenum (Mo), because this nutrient plays a central role in the process of assimilation of nitrate reduction even in very low concentrations in vegetables, as it is a constituent of the enzyme nitrate reductase. When assessing the induced effects of Mo on N metabolism enzymes in wheat. Imram et al. (2019) revealed that the assimilation of N in plants deficient in Mo was compromised due to the lower activity of nitrate reductase, resulting in accumulation of nitrate in the tissues. Santos et al. (2019) concluded that the efficiency of nitrogen fertilization in sugarcane can be maximized with the supply of Mo to the plants, due to the role of Mo in the metabolism of N.

There are few studies on molybdenum fertilization of conilon coffee associated with the supply of N. This study, carried out during two productive cycles under field conditions to evaluate the effects of applying Mo on the vegetative growth and production of *C. canephora* subjected to doses of N.

Results and discussion

Analysis of variance

The analysis of variance showed no significant interaction between the qualitative (Mo) and the quantitative (N) factors for the observed variables during the agricultural years of 2018/2019 and 2019/2020. However, in the evaluated period, there was an isolated effect of molybdenum fertilization, as well as the application of N doses for the growth and production components of *C. canephora*.

Orthotropic branch characteristics evaluated

Nitrogen fertilization influenced the height of the coffee tree in the two evaluated years (Figure 1A). It is observed that the application of N doses during the first year of experiment provided a linear increase in plant height. An increase of 1.23 cm can be seen in the growth of the orthotropic stem for each 100 kg of N applied using the equation of the obtained adjustment model. As a result, plants subjected to 1,100 kg ha^{-1} of N showed 5.7% higher growth than those fertilized with 300 kg ha^{-1} of N.

In an evaluation carried out in May 2020, it appears that the application of N promoted quadratic increments for plant height. There was a positive response for growth of the orthotropic stem up to the estimated dose of 880 kg ha^{-1} of N. At this dosage, the plants reached 228.88 cm, being 10.11 cm higher than those fertilized with 300 kg ha^{-1} of N. Similar results were presented by Busato et al. (2016). They investigated the vegetative development and production of irrigated *C. canephora*, subjected to increasing doses of N. The authors observed that N positively influenced the growth of plants up to 1,003 kg ha^{-1}, in the analysis carried out at the end of the second year of conduction of conilon coffee.

The number of productive plagiotropic branches of *C. canephora* is shown in Figure 1B. There was no effect of N doses on the number of productive branches. It is noteworthy that the high growth of conilon coffee achieved in the highest doses of N did not provide an increase in the number of productive branches in both observations. The results obtained in 2019 are understandable, while the anthesis occurred in the productive branches between July and September 2018, which were before application of treatments. However, the same behavior was maintained in the analysis carried out in May 2020. It should be noted that, for the 2020 harvest, the number of productive plagiotropic branches was 38.5% higher than that verified in the 2019 harvest.

The literature provides conflicting information about the relationship between stem growth and emission of plagiotropic branches in *Coffea*. Jaeggi et al. (2019), evaluated the development of adult conilon coffee plants intercropped with green fertilizers and observed that the greater supply of pigeon peas to the soil provided superior growth of the orthotropic stem. However, no significant increase in the number of lateral branches was observed. Similar divergent results and data were reported by Araújo et al. (2014) and Machado (2015). The latter, studied the initial development of 13 genetic materials of *C. canephora* subjected to doses of N. They observed that nitrogen fertilization provided growth of the orthotropic stem and a greater number of nodes in the orthotropic branch.

Despite the absence of significant interaction between Mo and N for the growth and production variables of *C. canephora*, it is verified that the length of the orthotropic stem was influenced by molybdenum fertilization, when the simple effects were analyzed. Table 1. shows that the application of Mo provided an increase of 3.9% in plant height in the first and 2.4% in the second year evaluated compared to the treatment without fertilization.

Mo's contribution to coffee was initially described by Malavolta et al. (1961), when investigating the development of arabica grown in nutrient solution. Although several authors report the importance of molybdenum nutrition for the genus *Coffea*, there are few studies that evaluate the performance of the crop in response to the application of Mo.

The results presented for the number of productive plagiotropic branches can be explained by evaluating Figure 2A. It is verified that the increase in N supply from the estimated dose of 511 kg ha^{-1} resulted in a longer average length of the orthotropic internode of the coffee tree in the evaluation of May 2020. Comparison of the value recorded at the vertex of the parabola with that obtained at the dose of 1,100 kg ha^{-1} shows that for the maximum dose of N, there was an increase of 3.07 mm in the average length of the orthotropic internode. In view of the above, the growth of the orthotropic stem promoted by nitrogen fertilization did not result in a greater number of lateral branches due to the elongation of the orthotropic internode. Taiz et al. (2014) reported that several factors, such as shading and nitrogen nutrition, can favor plant growth by lengthening internodes, resulting in the reduction of lateral ramifications.

The results of the orthotropic stem diameter are shown in Figure 2B. It is noticed that there was no significance for N doses at the end of the first-year study. However, in the evaluation carried out in May 2020, it appears that nitrogen fertilization negatively influenced the stem diameter. Comparison of average values of 2019 with 2020 using the linear adjustment model showed that the increased supply of N to the coffee tree resulted in a smaller increase in the diameter of the orthotropic stem. In 12 months, an increase of 4.83 mm was obtained in plants fertilized with 300 kg ha^{-1} of N, while for the dose of 1,100 kg ha^{-1} of N the increase was only 3.31 mm. The orthotropic internode elongation observed for the highest doses of N (Figure 2A) may explain the displayed data in part.

The relationship between the high supply of N and the smallest increase in the diameter of the orthotropic stem of conilon coffee was presented by Machado (2015). The author observed that doses of N higher than those recommended negatively affected the stem diameter of 9 of the 13 genetic materials of *C. canephora* studied.

Plagiotropic branch characteristics evaluated

Nitrogen fertilization significantly influenced the length of plagiotropic branches, in the two years of conduction of *C. canephora* (Figure 3A). In 2019, we found that supply of 1,100 kg ha^{-1} of N resulted in an increase of 30.9% in the length of the lateral branches compared to the lowest dose of N, fit to linear adjustment model. In the second year of evaluations, it appeared that the application of N promoted quadratic increments for the variable, with a positive response for the length of plagiotropic branches up to the estimated dose of 712 kg ha^{-1} of N. At this dosage, the lateral branches reached 70.52 cm, 10.89 cm greater than the branches of plants fertilized with 300 kg ha^{-1} of N. It is noteworthy that the length of branches observed in 2020 was lower than that recorded in 2019, for all doses of N.

Busato et al. (2016) carried out evaluations in November, December and February and observed that increasing doses of N promoted quadratic increments for the length of productive branches of *C. canephora*. However, the authors verified that the plagiotropic branches reached maximum length with the supply of N greater than 1,000 kg ha^{-1}. Magiero et al. (2017) studied the vegetative growth of fertigated conilon coffee with different applications and doses of N and showed positive responses for the length of lateral branches with the application of up to 116.3% of the recommended nitrogen fertilization with a decrease at the highest doses of N. Partelli et al. (2013) stated that development of plagiotropic branches in *C. canephora* is accentuated between October and May. However, the intensity of growth is dependent on the genetic material and influenced by temperature, water availability and plant nutrition.

Table 1 shows that molybdenum fertilization provides a significant increase in the length of plagiotropic branches of conilon coffee in the evaluation carried out in 2020. The application of 4 kg ha^{-1} of Mo resulted in an increase of 7.1% in the length of lateral branches compared to plants that did not receive the micronutrient.

The results obtained for the number of nodes per plagiotropic branch of *C. canephora* are shown in Figure 3B. It is worth noting that the values shown were collected in the months of July 2018 and 2019. This explains the lack of significance for the first year, since the evaluation of the coffee tree occurred before the application of treatments. However, it appears that the fertilization of conilon coffee with increasing doses of N positively influenced the number of nodes per lateral branch for the year 2019. There is an increase of one node per plagiotropic branch for each 227 kg of N applied, using the equation of the adjustment model obtained. As a result, plants subjected to 1,100 kg ha^{-1} of N showed growth 19.5% higher than those fertilized with 300 kg ha^{-1} of N. It is important to highlight the similarity in the behavior of the data obtained for length and number of nodes per plagiotropic branch, demonstrating the close relationship between the variables described by DaMatta et al. (2007).

There was no effect of nitrogen fertilization on the number of rosettes per plagiotropic branch in the 2019 assessment (Figure 4A). In the analysis carried out in the second year on coffee trees, the quadratic adjustment model was the one that best represented the behavior of the data obtained. It is verified that the application of increasing doses of N provided an increase in the number of rosettes per productive branch, up to the estimated dose of 884 kg ha^{-1} of N.

Analysis of data obtained for the number of nodes and rosettes per lateral branch in the second year of observation showed a certain similarity in the data, as they were collected from the same plagiotropic branches in July 2019 and May 2020. However, there is a substantial difference between the components in plants submitted to low levels of N. For the lowest dose of N, it appears that the number of rosettes was four units lower than the number of nodes per productive branch. For higher levels of N, the variables showed similarities with a number of nodes slightly higher than the number of rosettes per lateral branch.

In plants fertilized with low levels of N, the lowest number of rosettes can be attributed to the deficient nitrogen nutrition. The low concentration of N in conilon coffee may have affected the different stages of the flowering process, compromising anthesis. In addition, if flower opening has occurred, the N deficiency may have impaired setting and fruit development, resulting in fruitless nodes and fewer rosettes per productive branch. Dubberstein et al. (2016) investigated the accumulation of macronutrients during the fruiting process of *C. canephora* and concluded that N is the mineral element present in the highest concentration in the fruits.

Although the effect of nitrogen fertilization on the number of nodes and rosettes per plagiotropic branch was not observed in the first year, there is, an increase in the number of fruits per productive branch of conilon coffee within the limits evaluated, when submitted to increasing N levels (Figure 4B). It is important to note that the fruits accounted for in the analysis of May 2019 come from the anthesis that occurred between July and September 2018, i.e., before the application of treatments.

Table 1. Growth and production variables of coffee conilon in response to molybdenum fertilization.

Variables	Harvest 2018/2019			Harvest 2019/2020		
	+ Mo (4 kg ha^{-1})	- Mo	Mean	+ Mo (4 kg ha^{-1})	- Mo	Mean
HEI* (cm)	181.44 a	174.66 b	178.05	227.94 a	222.50 b	225.22
NPPB^{ns}	30.40 a	30.50 a	30.45	42.28 a	42.08 a	42.18
OIL^{ns} (cm)	3.82 a	3.81 a	3.82	3.76 a	3.80 a	3.78
SD^{ns} (mm)	17.68 a	17.52 a	17.60	21.66 a	21.65 a	21.66
PBL* (cm)	86.79 a	86.73 a	86.76	67.70 a	63.22 b	65.46
NNPB^{ns}	13.45 a	13.51 a	13.48	20.22 a	19.44 a	19.83
NRB^{ns}	13.23 a	13.16 a	13.20	18.74 a	18.63 a	18.69
NFB^{ns}	214.34 a	219.21 a	216.78	288.54 a	291.10 a	289.82
PCY* (bags ha^{-1})	95.04 a	95.93 a	95.49	127.53 a	123.02 b	125.28
GY^{ns} (%)	24.16 a	24.49 a	24.33	25.43 a	25.31 a	25.37

Means followed by the same uppercase letter in the rows (for each harvest) do not differ by the Tukey test at 5% of probability. *significant and ^{ns}non significant at 5% of probability, by the F test. Plant height (HEI); number of productive plagiotropic branch (NPPB); orthotropic internode length (OIL); stem diameter (SD); plagiotropic branch length (PBL); number of nodes per plagiotropic branch (NNPB); number of rosettes per branch (NRB); number of fruits per branch (NFB); processed coffee yield (PCY); grain yield (GY).

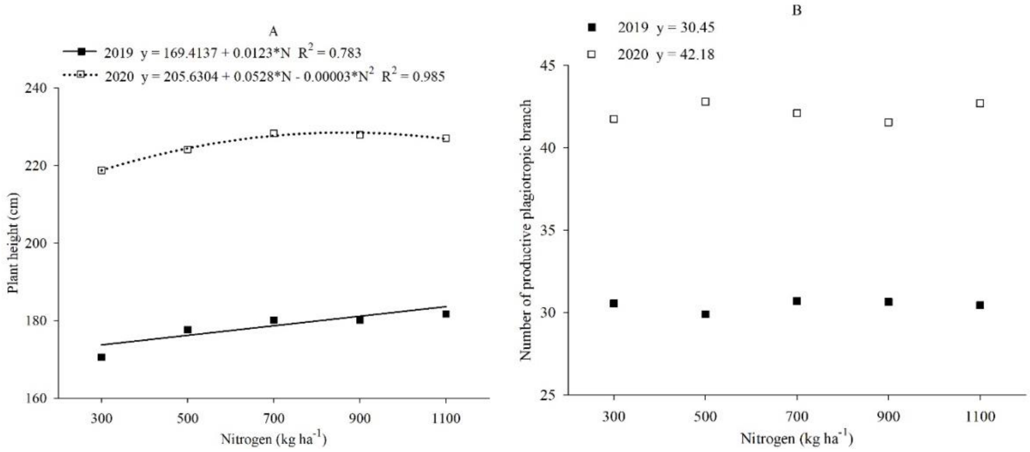

Fig 1. Plant height values (A) and number of productive plagiotropic branch (B) of conilon coffee in response to two molybdenum fertilization regimes (fertilized and unfertilized) and nitrogen (N) doses, in the 2019 e 2020 agricultural years. Santa Teresa, Espírito Santo State, Brazil.

Table 2. Chemical soil characterization of the experimental area at depths of 0-20 and 20-40 cm.

								June 2018										
Depth	pH	Ca	Mg	Al	H+Al	CEC	SB	P	K	S	Cu	Fe	Zn	Mn	B	Mo	OM	BS
(cm)		-----------------------cmol$_c$ dm^{-3}---------------						-------------------------------mg dm^{-3}-----------------------									----%----	
0-20	6.3	5.0	1.0	0.0	2.9	9.9	7.0	123	350	16	3.0	137	14	139	0.6	0.7	2.4	70.8
20-40	6.1	4.0	0.6	0.0	2.5	7.9	5.4	55	280	8	2.0	175	12	120	0.4	0.5	1.7	68.5
								June 2019										
Depth	pH	Ca	Mg	Al	H+Al	CEC	SB	P	K	S	Cu	Fe	Zn	Mn	B	Mo	OM	BS
(cm)		--------------------cmol$_c$ dm^{-3}-----------------						---------------------------mg dm^{-3}-----------------------									----%----	
0-20	5.9	4.6	1.2	0.0	3.3	10.0	6.7	108	335	19	7.2	142	9.3	151	0.8	3.1	2.1	67.0
20-40	5.8	3.8	0.6	0.1	2.9	8.1	5.2	45	316	9	3.8	156	9.1	109	0.4	1.4	1.5	64.2

pH in H_2O 1:2.5; Ca, Mg and Al: extracted by KCl; H+Al: extracted by calcium acetate; P: extracted by anion exchange resins; K, Cu, Fe, Zn, Mn and Mo: extracted by Mehlich; S-SO_4^{2-}: extracted by calcium phosphate; B: extracted by barium chloride; CEC: cation exchange capacity at pH 7.0; SB: sum of bases; OM: organic matter; BS: percentage saturation by bases.

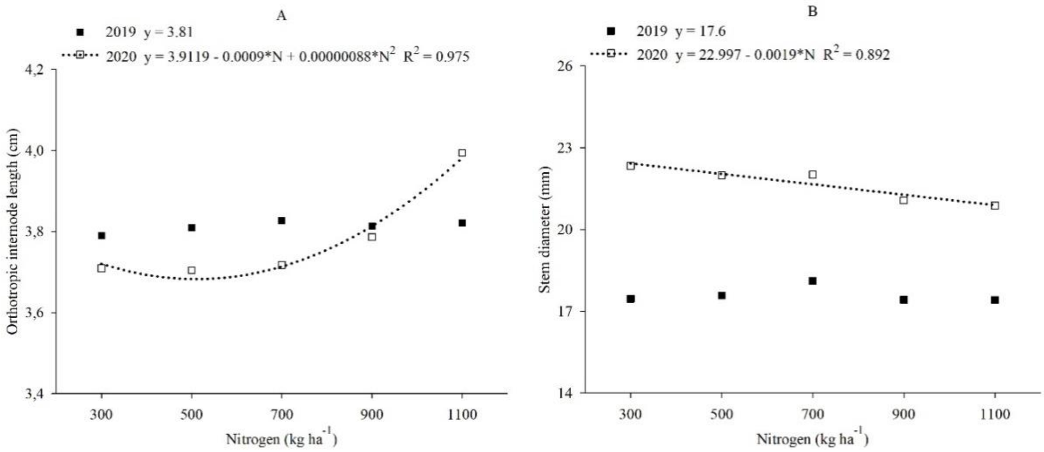

Fig 2. Orthotropic internode length values (A) and stem diameter (B) of conilon coffee in response to two molybdenum fertilization regimes (fertilized and unfertilized) and nitrogen (N) doses, in the 2019 and 2020 agricultural years. Santa Teresa, Espírito Santo State, Brazil.

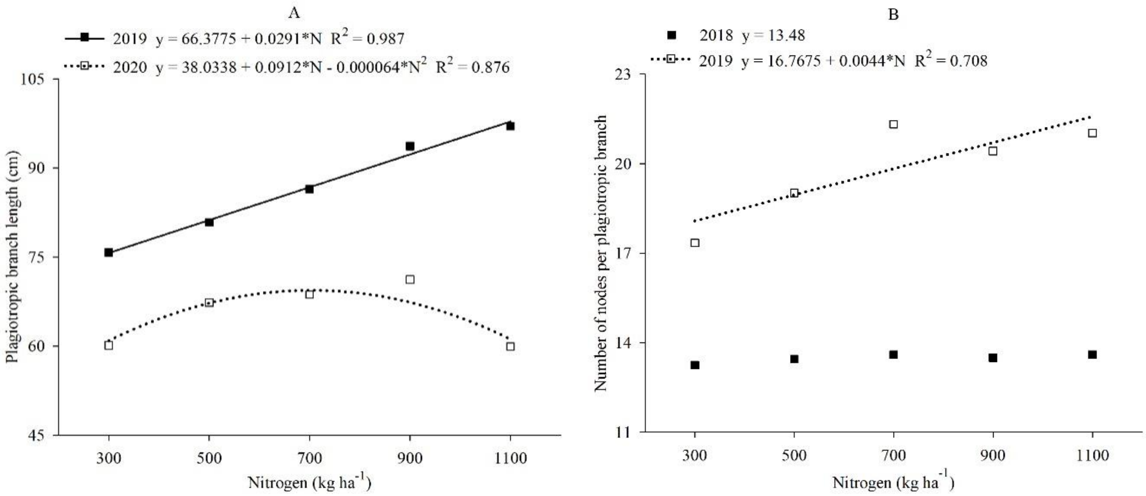

Fig 3. Plagiotropic branch length values (A) and number of nodes per plagiotropic branch (B) of conilon coffee, in response to two molybdenum fertilization regimes (fertilized and unfertilized) and nitrogen (N) doses, in the 2019 and 2020 agricultural years. Santa Teresa, Espírito Santo State, Brazil.

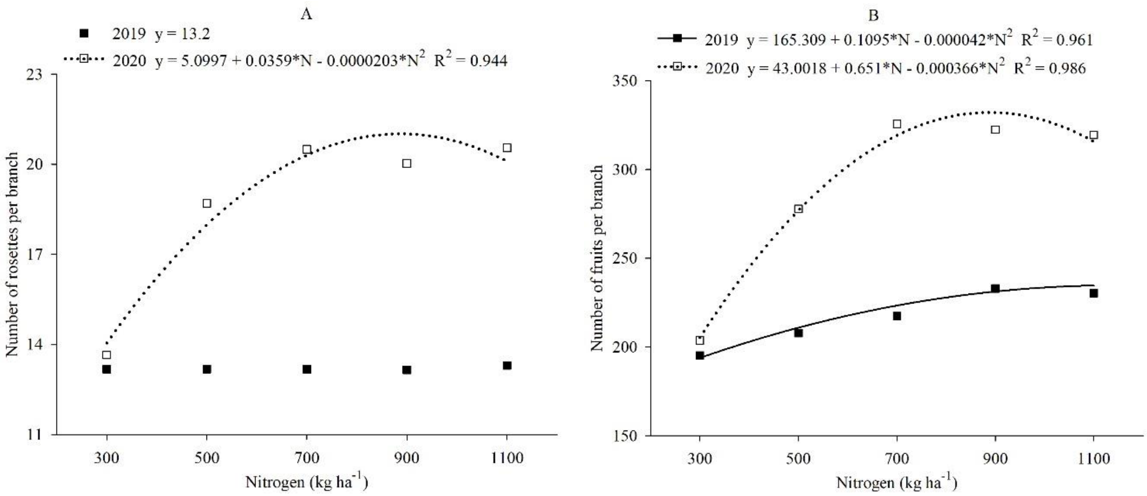

Fig 4. Number of rosettes per branch values (A) and number of fruits per branch (B) of conilon coffee in response to two molybdenum fertilization regimes (fertilized and unfertilized) and nitrogen (N) doses, in the 2019 and 2020 agricultural years. Santa Teresa, Espírito Santo State, Brazil.

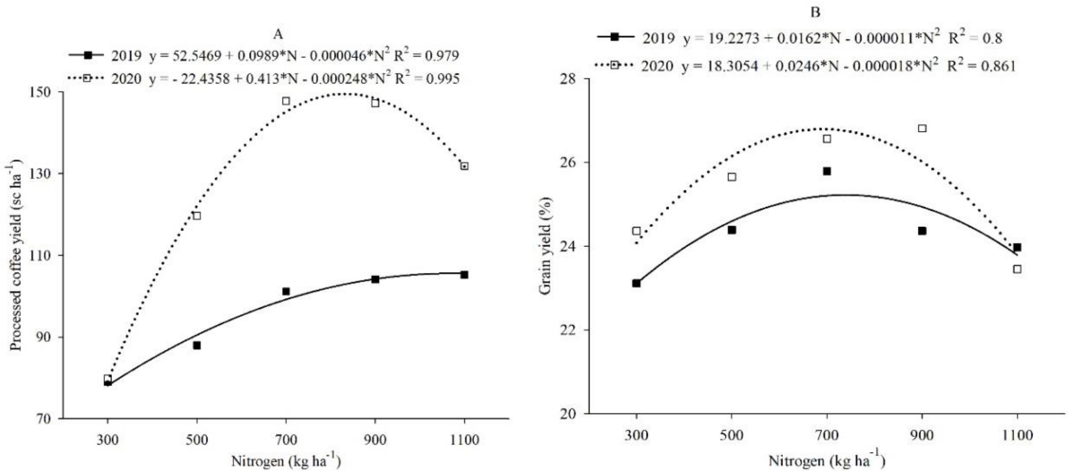

Fig 5. Processed coffee yield, in 60-kg bags per hectare (A) and grain yield (B) of conilon coffee, in response to two molybdenum fertilization regimes (fertilized and unfertilized) and nitrogen (N) doses, in the 2019 and 2020 agricultural years. Santa Teresa, Espírito Santo State, Brazil.

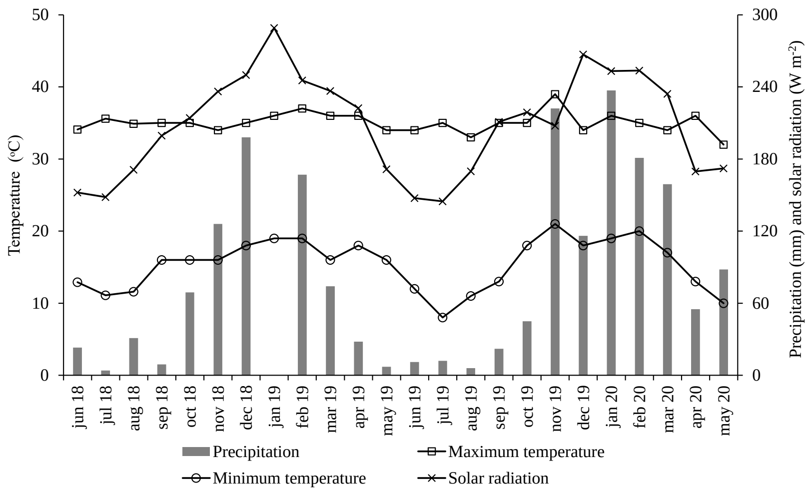

Fig 6. Values of climatic variables observed during the study period (June/2018 to May/2020).

This shows that the differences obtained for the number of fruits per branch are not due to the flowering process of the coffee tree. The results confirm that the supply of N favored the setting and development of the fruits, reducing the abscission or fall of this organ.

Dubberstein et al. (2017) demonstrated that fruit drop is a phenomenon that occurs naturally in *C. canephora*, especially in the first three months after flowering. The authors verified that during the initial development, the fruits compete for space in the rosettes of the productive branches, causing the detachment of smaller and weaker organs. However, DaMatta et al. (2007) report that fruit drop may be related to biotic and abiotic factors. Among the abiotic stresses, Custódio et al. (2014) highlight water restriction and nutritional deficiencies as the most relevant.

In the second year of evaluation, it appears that the application of N promoted an increase in the number of fruits per lateral branch, with a quadratic adjustment for the data collected. These results corroborate those presented by Magiero (2013), who evaluated the vegetative growth and the production of *C. canephora* fertigated with different frequency and N levels and observed the highest number of fruits per branch when supplying 158.9% of the recommended N dosage divided into 15 times.

Comparing the adjustment model obtained for the number of rosettes and the number of fruits per branch, there is a similarity in the behavior of the variable data. For the number of rosettes per productive branch, the vertex of the parabola was reached at the estimated dose of 884 kg ha^{-1} of N, while the highest number of fruits per plagiotropic branch was reached with the estimated application of 889 kg ha^{-1} of N.

Productivity and grain yield

Figure 5 shows the results of processed coffee yield and grain yield, as a function of doses of N. Figure 5A indicates that the yield of processed coffee for the 2019 and 2020 crops followed a quadratic adjustment model with decrease in values for the highest levels of N. For the harvest carried out in 2019, the maximum yield, of 105.71 bags ha^{-1} was obtained with the estimated application of 1,075 kg ha^{-1} of N. In the second year of grow, the yield was increase up to the estimated dose of 833 kg ha^{-1} of N, reaching 149.51 bags ha^{-1}. In the first year evaluated, fertilization with 1,075 kg ha^{-1} of N resulted in an increase in yield of 35.3% compared to the lowest dose of N. In 2020 harvest, there was an increase of 88.9% in yield, when plants were fertilized with 833 kg ha^{-1} of N.

Evaluating the results presented in Figure 5A and the data obtained for the growth variables of *C. canephora*, it appears that the vegetative growth influenced the yield of the plants. It is noteworthy that the length of the plagiotropic branch, number of nodes per lateral branch, number of rosettes and fruits per productive branch were closely related to the yield of conilon coffee, especially for the second year of experiment. However, it appears that the plant height did not affect coffee yield, in contrast to the results shown by Busato et al. (2016). Also, the number of plagiotropic branches did not have a significant influence on yield, diverging from the data presented by Jaeggi et al. (2019), for *C. canephora*.

The quadratic increments of the processed coffee yield corroborate with those presented by Busato et al. (2016), when analyzing the production of conilon coffee submitted to doses of N of up to 1,320 kg ha^{-1}. It is also noticed that there is a great similarity between the data shown by the authors in the first year of evaluation and those obtained in this study for the 2020 harvest. The researchers found that the maximum yield of 144.63 bags ha^{-1} was reached when the coffee plant received 829 kg ha^{-1} of N.

It is noteworthy that the supply of 4 kg ha^{-1} of Mo resulted in a significant increase in the yield of *C. canephora* in 2020 (Table 1). Molybdenum fertilization provided a 3.7% increase in the yield of processed coffee. Despite the paucity of studies on coffee, recent studies have shown that the application of Mo promoted increases in yield in crops such as sugarcane (Santos et al., 2018) and corn (Caioni et al., 2016).

Table 1 shows that molybdenum fertilization did not result in significant differences for the growth and production of conilon coffee in the first year of evaluations, except for the height of the plants. However, for the second year, it appears that the application of Mo provided superior results for plant height, length of plagiotropic branches and yield of processed coffee. These results point to the reduction of micronutrient availability in the soil, indicating that molybdenum fertilization could provide more expressive responses as the study continues.

The results shown in Figure 5B show that nitrogen fertilization affected the yield of conilon coffee. It appears that the highest grain yield for the 2019 harvest was obtained with the estimated application of 736 kg ha^{-1} of N, requiring 3.97 kg of coffee from the farm to obtain 1 kg of processed coffee. In 2020, the maximum yield of 26.7% was achieved with the estimated supply of 683 kg ha^{-1} of N, resulting in a ratio of 3.74: 1.

Magiero (2013) evaluated the yield of *C. canephora* submitted to doses of N and observed a quadratic adjustment for the variable and concluded that the highest yield was obtained with the application of 118.9% of the recommended dose of N. They reported a reduction in grain yield due to N deficiency or excess under nitrogen imbalance. Araújo et al. (2014) found that the Arabica yield fertilized with 100% of the N dose was 76.3% higher than that registered in plants at only 30% of the indicated fertilization.

It is noteworthy that the coffee yield for the 2020 harvest was higher than that obtained in the 2019 assessment for the different N evaluated doses. Favorable climatic conditions in the 2019/2020 harvest, with emphasis on rainfall during the period of fruit and grain growth, were decisive for the presented results.

Materials and methods

The experimental site, environmental and soil conditions

The experiment was carried out from June 2018 to May 2020 in the municipality of Santa Teresa, state of Espírito Santo, Brazil, located between the coordinates 19° 47' 15'' south latitude and 40° 38' 52'' west longitude of Greenwich, and average altitude of 165 meters. The climate of the region is humid temperate with dry winter and hot summer, Cwa, according to the classification of Köppen. The soil was classified as dystrophic Yellow Latosol (Embrapa, 2018), with a depth of 0-20 cm, 436, 243 and 321 g kg^{-1} of sand, silt and clay, respectively; and 367, 265 and 368 g kg^{-1} sand, silt and clay, respectively, at a depth of 20-40 cm.

Plant materials and conduction of study

The crop was implanted in April 2016, with spacing of 3.0 x 0.9 meters, and conducted with three stems per plant. Two-year-old plants of clone 108P belong to *Cultivar Diamante ES8112* were evaluated. The soil fertility management was carried out in accordance with the recommendations of Prezotti et al. (2017). After the first harvest, in June 2018, soil was collected in the experimental area for chemical characterization, at depths of 0-20 and 20-40 cm (Table 2).

The fertilization of conilon coffee (except for N and Mo) during the experimental period followed the recommendations of Prezotti et al. (2017), for crops with estimated yield between 131-170 processed 60-kg bags per hectare. The crop handling methods used in the coffee trees, concerning growth, pruning, phytosanitary management and control of weeds followed the technical recommendations of Ferrão et al. (2017).

Throughout the experimental period, whenever rainfall was insufficient, the coffee crop was irrigated with the applied irrigation depth calculated based on the crop evapotranspiration (ETc), obtained by the reference evapotranspiration product (ETo) and the crop coefficient (kc) at each stage of development. ETo was calculated using the Penman-Monteith-FAO56 method (Allen et al., 1998), using meteorological data obtained from an automatic meteorological station installed at Ifes - *Campus* Santa Teresa, located 3.8 km from the experimental area. For kc, values suggested by Bonomo et al. (2017) were employed.

A drip irrigation system was used, with a 30 cm spacing between drippers, resulting in a continuous irrigated strip. The fixed irrigation interval was adopted with the irrigations carried out every three days, aiming to raise the soil moisture to the field capacity (FC). Figure 6 shows the values of the meteorological data observed during the experimental period.

Experimental design and treatments

The experimental design was randomized blocks in a 2 x 5 factorial scheme. The first factor was the absence and presence of molybdenum fertilization and the second factor, N doses (300, 500, 700, 900 and 1,100 kg ha^{-1} year $^{-1}$), with four replications, totaling 40 experimental units. The experimental plot was composed of 21 plants, arranged in three rows, considering the five plants of the central line useful, since the two plants at the ends, as well as the two lateral rows served as a border.

During the agricultural years of 2018/2019 and 2019/2020, the treatments (N and Mo) were applied between October and February. In each agricultural year, the N dose proposed for the different treatments was divided into five applications and performed in the months of October, November, December, January and February. As a source of N, agricultural urea (46% N) was used, as it has high solubility and has a lower cost per kilogram of N.

For the application of N, after weighing on an electronic digital scale, urea was dissolved in water, obtaining a homogeneous solution with 129.1 g L^{-1} of urea. Subsequently, the solution was applied to the soil, parallel to the irrigation hose using polyethylene cups. In each of the five applications, each plant received 272, 454, 636, 818 and 1,000 mL of solution, referring to the treatments 300, 500, 700, 900 and 1,100 kg ha^{-1} of N, respectively. Immediately after the supply of N, irrigation of conilon coffee was carried out, aiming to promote the rapid incorporation of urea into the soil, favoring absorption of N by plants, in addition to reducing N losses by ammonia volatilization.

In each agricultural year, the proposed Mo dose (4 kg ha^{-1} year^{-1}) was divided into two applications, carried out in the months of November and January, using the sodium molybdate fertilizer (39% Mo) as a source of Mo. After weighing on a precision digital scale, sodium molybdate was dissolved in water, obtaining a homogeneous solution with 55.4 g L^{-1} of sodium molybdate. Each plant received 25 mL of the solution using a fixed volume semi-automatic pipette. Subsequently, the irrigation system was activated, allowing the incorporation of fertilizer and the rapid absorption of Mo by the plants.

Agronomic traits evaluated

In the first year of conducting the experiment, the growth assessments of *C. canephora* started in July 2018, through the analysis of the five useful plants that make up each experimental unit. Initially, the first plagiotropic branch facing the line was identified from the base of the plant, which had not produced fruits in the previous harvest. Then, the branch was marked using a colored ribbon and the number of nodes was counted.

In May 2019, before the harvest of conilon coffee, other growth assessments were carried out. The number of rosettes (nodes with the presence of fruits), as well as the number of fruits by plagiotropic branches were achieved by direct counting, examining the same marked branch to determine the number of nodes. The height of *C. canephora* was measured using a topographic ruler, graduated in centimeters, measuring from the plant's neck to the orthotropic apical meristem. The diameter of orthotropic branches (stem diameter) was obtained with measurements taken at 100 cm from the plant's neck, using a digital caliper. The value per plant was the result of the average of the three stems. The number of plagiotropic branches per orthotropic stem was evaluated by counting all the primary productive plagiotropic plants, with the value presented as a result of the average of the three stems. The average length of the orthotropic internode was found using the orthotropic stem length values, divided by the number of pairs of plagiotropic branches minus one.

In order to obtain the length of plagiotropic branches, the first branch without fruits, facing the line, was selected from the base of the plant. Next, the branch was marked with a colored ribbon and measured with a measuring tape. The evaluations for the second year of experiment followed the same methodology described previously, being carried out in the same months.

The harvest of conilon coffee for the 2019 and 2020 harvests was carried out in the last week of May for both years, when the crop presented approximately 80% of cherry fruits. The harvest of all five useful plants that make up each experimental unit was carried out by means of manual stripping on the cloth. Then, the fruits were packed in raffia bags and weighed on an electronic digital scale, obtaining the mass of ripe coffee, harvested in each plot. The production of processed coffee was achieved after drying and processing the fruits.

Statistical analysis

The data were submitted to analysis of variance and regression equations were established after detection of significance for the variables. The significance level of 5% ($P < 0.05$) was adopted for all statistical tests using the R (2017) program.

Conclusions

The application of Mo resulted in a longer length of the orthotropic stem and productive branches of conilon coffee, in addition to promoting increased yield. The length of lateral branches, number of nodes, rosettes and fruits were closely related to coffee yield and were influenced by the application of N. The best yield results were obtained with doses of 1,075 and 833 kg ha^{-1} of N, in the 2019 and 2020 harvests, respectively. The growth of the orthotropic stem due to nitrogen fertilization did not result in a greater number of plagiotropic branches in *C. canephora*.

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References

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration: guidelines for computing crop water requirements. Rome: FAO. 300p.

Araujo JBS, Rodrigues LB, Rodrigues MC, Martinez HEP, Santos RHS (2014) Adubação nitrogenada em cafeeiros com biomassa de feijão-de-porco. Coffee Sci. 9:336-346.

Bonomo DZ, Bonomo R, Partelli FL, Souza JM (2017) Genótipos de café conilon sob ajuste de diferentes coeficientes de cultura ajustados. Irriga. 22:236-248.

Busato C, Busato CCM, Reis EF, Partelli FL (2016) Água e nitrogênio. Rev Cult Gran Cul. 17:8-11.

Caioni S, Lazarini E, Parente TL, Pivetta RS, Souza LGM (2016) Nitrogênio e molibdênio para milho irrigado em região de cerrado de baixa altitude. Rev Bras Milho Sorgo. 15:419-428.

Colodetti TV, Rodrigues WN, Martins LD, Tomaz MA (2014) Differential tolerance between genotypes of conilon coffee (*Coffea canephora*) to low availability of nitrogen in the soil. Aust J Crop Sci. 8:1648-1657.

Colodetti TV, Rodrigues WN, Martins LD, Brinate SVB, Tomaz MA, Amaral JFT, Verdin Filho AC (2015) Nitrogen availability modulating the growth of improved genotypes of *Coffea canephora.* Afr J Agr Res. 10:3150-3156.

CONAB - Companhia Nacional de Abastecimento (2019) Acompanhamento da safra brasileira: café. Brasília: CONAB. 44p.

Covre AM, Partelli FL, Bonomo R, Gontijo I (2018) Impacts of water availability on macronutrients in fruit and leaves of conilon coffee. Pesqui Agropecu Bras. 53:1025-1037.

Custódio AAP, Lemos LB, Mingotte FLC, Barbosa JC, Pollo GZ, Santos HM (2014) Florescimento de cafeeiros sob manejos de irrigação, faces de exposição solar e posições na planta. Coffee Sci. 9:245-257.

DaMatta FM, Ronchi CP, Maestri M, Barros RS (2007) Ecophysiology of coffee growth and production. Braz J Plant Physiol. 19:485-510.

Dubberstein D, Partelli FL, Dias JRM, Espindola MC (2016) Concentration and accumulation of macronutrients in leaf of coffee berries in the Amazon, Brazil. Aust J Crop Sci. 10:701-710.

Dubberstein D, Partelli FL, Schmidt R, Dias JRM, Covre AM (2017) Matéria seca em frutos, folhas e ramos plagiotrópicos de cafeeiros cultivados na Amazônia Ocidental. Coffee Sci. 12:74-81.

Embrapa - Empresa Brasileira de Pesquisa Agropecuária (2018) Sistema brasileiro de classificação de solos. 5 ed. Brasília: Embrapa. 355p.

Ferrão RG, Fonseca AFA, Ferrão MAG, De Muner LH (2017) Café conilon. 2 ed. Vitória: Incaper. 784p.

ICO - International Coffee Organization (2019) Historical data: total production. London: ICO. <http://www.ico.org/pt/new_historical_p.asp?section=Estat%EDstica>

Imran M, Sun X, Hussain S, Ali U, Rana MS, Rasul F, Saleem MH, Moussa MG, Bhantana P, Afzal J, Elyamine AM, Hu CX (2019) Molybdenum-induced effects on nitrogen metabolism enzymes and elemental profile of winter wheat (*Triticum aestivum* L.) under different nitrogen sources. Int J Mol Sci. 20:1-17.

Jaeggi MEPC, Coelho FC, Pereira IM, Zacarias AJ, Gravina GA, Lima WL, Pereira LL, Moreira TR, Silva SF, Parajara MC (2019) Path analysis of vegetative characteristics in conilon coffee production consortiated with green fertilizers in tropical climate. J Exp Agric Int. 40:1-11.

Machado LS (2015) Eficiência nutricional de clones de cafeeiro conilon no estádio inicial de crescimento quanto ao nitrogênio (Master's thesis). Federal University of Espirito Santo, Alegre, Brazil.

Machado LS, Martins LD, Rodrigues WN, Ferreira DS, Côgo AD, Tomaz MA, Amaral JFT (2016) Efficiency and response of conilon coffee genotypes to nitrogen supply. Afr J Biotechnol. 15:1892-1898.

Magiero M (2013) Parcelamentos e doses de nitrogênio e potássio aplicados no cafeeiro conilon, via fertirrigação (Master's thesis). Federal University of Espirito Santo, Alegre, Brazil.

Magiero M, Bonomo R, Partelli FL, Souza JM (2017) Crescimento vegetativo do cafeeiro Conilon fertirrigado com diferentes parcelamentos e doses de nitrogênio e potássio. Rev Agro@mbiente. 11:31-39.

Malavolta E, Haag HP, Johnson CM (1961) Estudos sobre a alimentação mineral do cafeeiro: VI Efeitos das deficiências de micronutrientes *em Coffea arabica* L. var. Mundo Novo cultivado em solução nutritiva. An Esalq. 18:147-167.

Partelli FL, Marré WB, Falqueto AR, Vieira HD, Cavatti PC (2013) Seasonal vegetative growth in genotypes of *Coffea canephora*, as related to climatic factors. J Agr Sci. 5:108-116.

Partelli FL, Gomes WR, Oliveira MG, Dias JRM, Espindula MC (2016) Normas foliares e diagnóstico nutricional do cafeeiro conilon na pré-florada e granação, no Espírito Santo. Coffee Sci. 11:544-554.

Prezotti LC, Guarçoni MA, Bragança SM, Lani JA (2017) Calagem e adubação do café conilon. In Ferrão RG, Fonseca AFA, Ferrão MAG, De Muner LH (Ed.), Café conilon. Vitória: Incaper. 347-357.

R Core Team (2017) R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.

Ribeiro JM, Frazão LA, Cardoso PHS, Oliveira ALG, Sampaio RA, Fernandes LA (2019) Fertilidade do solo e estoques de carbono e nitrogênio sob sistemas agroflorestais no Cerrado Mineiro. Cienc Florest. 29:913-923.

Santos RL, Freire FJ, Oliveira ECA, Simões Neto DE, Medeiros MRFA, Bezerra PC, Moura MJA, Barbosa JA, Lopes NRC, Santos NL (2018) Productivity and technological quality of sugarcane under fertilization of nitrogen and molybdenum. J Soil Sci Plant Nut. 18:1002-1020.

Santos RL, Freire FJ, Oliveira ECA, Freire MBGS, West JB, Barbosa JA, Moura MJA, Bezerra PC (2019) Nitrate reductase activity and nitrogen and biomass accumulation in sugarcane under molybdenum and nitrogen fertilization. Rev Bras Cienc Solo. 43:1-19.

Taiz L, Zeiger E, Moller IM, Murphy A (2014) Plant physiology & development. 6 ed. Sunderland: Sinauer Associates. 761p.