Ciência Rural, Santa Maria, v.52:12, e20200770, 2022 http://doi.org/10.1590/0103-8478cr20200770
ISSNe 1678-4596
CROP PRODUCTION

Different nitrogen levels on vegetative growth and yield of conilon coffee (*Coffea canephora*)

Camilo Busato[1] Edvaldo Fialho dos Reis[2] Marcos Góes Oliveira[3] Giovanni de Oliveira Garcia[2] Cristiani Campos Martins Busato[4] Fábio Luiz Partelli[3*]

[1]Gerência Local de Colatina, Instituto de Defesa Agropecuária e Florestal do Espírito Santo (IDAF), Colatina, ES, Brasil.
[2]Departamento de Engenharia Rural, Centro Agropecuário (UFES-CAA), Universidade Federal do Espírito Santo (UFES), Alegre, ES, Brasil.
[3]Departamento Ciências Agrárias e Biológicas, Centro Universitário Norte do Espírito Santo (CEUNES), Universidade Federal do Espírito Santo (UFES), 29932-900, São Mateus, ES, Brasil. E-mail: partelli@yahoo.com.br. *Corresponding author.
[4]Campus Itapina, Instituto Federal de Educação, Ciência e Tecnologia do Espírito Santo (IFES), Colatina, ES, Brasil.

ABSTRACT: *The determination of nitrogen in plants by techniques that allow a fast diagnosis, based on plant growth characteristics, can be a useful tool for the nutritional management of coffee plants. Thus, this study evaluated growth and yield characteristics of irrigated conilon coffee in response to different nitrogen levels, resulting in the determination of the minimum N levels required to achieve the maximum yield, here called critical levels. The experiment was carried out in Colatina, Espirito Santo, Brazil, on plantations of conilon coffee, clonal variety Emcapa 8111, genotype 02. Six nitrogen levels were applied (0, 110, 220, 440, 880 and 1320 kg N ha^{-1}) and the response in growth and yield characteristics periodically evaluated. There was a positive effect of the increasing N levels on yield, in that the N levels that provided 95% of the maximum yield (137.4 bags ha^{-1} and 108.5 bags ha^{-1}) in the 2012/2013 and 2013/2014 growing seasons, respectively, were 420.7 and 543.1 kg N ha^{-1}. There was also a positive effect of N levels on the growth characteristics and nitrogen contents, indicating their use as tools for a rapid nutritional diagnosis, with a view to optimizing the nitrogen management in Conilon coffee.*
Key words: *fertilization, mineral nutrition, irrigation.*

Efeitos de diferentes níveis de nitrogênio sobre o crescimento vegetativo e produtividade do café conilon (*Coffea canephora*)

RESUMO: *A determinação do nitrogênio nas plantas por técnicas que permitem um diagnóstico rápido, baseado nas características de crescimento das plantas, pode ser uma ferramenta útil para o manejo nutricional das plantas de café. Assim, o objetivo deste estudo foi avaliar as características de crescimento e rendimento do café conilon irrigado em resposta à diferentes níveis de nitrogênio, resultando na determinação dos níveis mínimos de N necessárias para atingir o rendimento máximo, aqui chamadas de níveis críticos. O experimento foi realizado em Colatina, Espírito Santo, Brasil, em plantações de café conilon, variedade clonal Emcapa 8111, genótipo 02. Foram aplicados seis níveis de nitrogênio (0, 110, 220, 440, 880 e 1320 kg N ha^{-1}) e a resposta em características de crescimento e rendimento foi periodicamente avaliada. Houve um efeito positivo do aumento dos níveis de N sobre o rendimento, na medida em que os níveis de N que forneceram 95% do rendimento máximo (137,4 sacos ha^{-1} e 108,5 sacos ha^{-1}) nas estações de crescimento 2012/2013 e 2013/2014, respectivamente, foram de 420,7 e 543,1 kg de N ha^{-1}. Houve também um efeito positivo dos níveis de N sobre as características de crescimento e conteúdo de nitrogênio, indicando seu uso como ferramentas para um diagnóstico nutricional rápido, com o objetivo de otimizar o manejo de nitrogênio no café Conilon.*
Palavras-chave: *fertilização, nutrição mineral, irrigação.*

INTRODUCTION

The genus *Coffea* comprises more than 120 species, two of which are economically relevant, i.e., *C. arabica L.* and *C. canephora* Pierre ex A. Froehner. About 170 countries produce coffee and almost all nations consume the beverage, but despite this wide distribution of cultivation, approximately 70% of the world supply is provided by four countries: Brazil, Vietnam, Colombia and Indonesia (International Coffee Organization [ICO], 2020). Brazil is the world's largest coffee producer, both of arabica (*Coffea arabica*, ca. 65%) as well as conilon coffee (*Coffea canephora*, ca. 35%) (CONAB, 2020).

Received 08.16.20 Approved 11.15.21 Returned by the author 04.09.22
CR-2020-0770.R4
Editors: Leandro Souza da Silva Jackson Kawakami

Conilon coffee has a high yield potential and; consequently, a high nutritional requirement, mainly in terms of nitrogen (N), which is particularly relevant with regard to the quantity required and its functions in the plant. In case of deficiency, it is one of the most limiting mineral nutrients for plant growth and development (MARTINEZ et al., 2020). Plants cultivated at insufficient N levels, together with water stress, will not only have stunted growth, but the assimilate partitioning between different plant parts can be affected and physiological mechanisms altered (TAIZ et al., 2017).

Nitrogen is highly dynamic and has a particularly high mobility level. The dynamics of nitrogen in the soil-plant-atmosphere system is rather complex and the N content in tropical soils highly variable. Therefore, nitrogen fertilization of crops must be properly managed and the nitrogen fertilization program adjusted by correct monitoring and diagnosis of the plant nutritional status (PARTELLI et al., 2016; PARTELLI et al., 2018).

Normally, the nitrogen levels applied to coffee trees are defined based on a general recommendation, according to the yield expectation, and plant analysis is rarely taken into consideration. If done at all, this monitoring is based on the chemical analysis of the nitrogen content of leaf dry matter. These procedures are costly, time-consuming and must be carried out at appropriate locations, by persons with some degree of appropriate training (BUSATO et al., 2010; GOMES et al., 2016).

In this sense, the determination of the plant N content by rapid diagnostic techniques, including plant biometric or growth characteristics such as branch length, leaf area and dry weight, and N content related with crop yield (ASSIS et al., 2014; PEREIRA et al., 2016; MARTINS et al., 2019; DUBBERSTEIN et al., 2020), may be a useful and viable tool of nitrogen management in coffee.

Critical values of these characteristics or indices, in particular for certain developmental stages, when coffee is highly sensitive to nitrogen application and which influence the crop yield, are extremely practical and important for conilon coffee management and can easily be established in real time (PARTELLI et al., 2016; PARTELLI et al., 2018). This determination of growth characteristics or nitrogen contents of coffee trees in response to N fertilization levels can provide an estimation of the crop yield potential in the field, and also allows adjustments of the nitrogen fertilization management to optimize the fertilizer use efficiency and avoid unnecessary environmental impacts.

In spite of the technological development, diffusion of innovations and research advances regarding coffee cultivation, field information about coffee nutrition, growth and yield and the influence of nitrogen fertilization, together with biometric parameters and nitrogen data, associated with the N level and irrigated coffee yield, are so far unavailable for coffee plantations in Espírito Santo. Thus, this study evaluated the effect of N levels on the plant growth and yield of *Coffea canephora* in different evaluation periods.

MATERIALS AND METHODS

Experimental area

The experiment was carried out on a rural property in the county of Colatina, northwestern region of the state of Espírito Santo, Brazil (latitude 19° 35’ 47” S; longitude 40° 25’ 25” W; 83 m asl; with mean maximum and minimum daily temperatures 28.2 °C and 12.7 °C, respectively), from 2012 to 2014. The regional climate is tropical, with hot humid summers and dry winters, classified as Aw, by Köppen’s climate classification (ALVARES et al., 2013), and a mean annual rainfall of 1100 mm. During the experimental period, the relative humidity varied from a maximum of 92.1% to minimum of 49.4% (data collected in the study area with a data logger, Log Tag, HAXO-8, China).

The soil of the experimental area is classified as Latossolo Vermelho-Amarelo distrófico (SANTOS et al., 2018), with a flat topography. Prior to the experiment, soil of the 0 - 40 cm layer was analyzed (chemical properties in table 1).

Experimental design

Three-year-old *Coffea canephora* plants of the clonal variety Emcapa 8111, genotype 02 (BRAGANÇA et al., 2001) were grown in full sun, at a 3.5 x 1.0 m spacing, and treated with pruning and traditional thinning, leaving 5-6 branches plant^{-1}, i.e., 13,333 branches ha^{-1}. The applied management practices were the commonly used agronomic practices of fertigation, weeding and chemical insect and pathogen control. Liming and fertilization with the other nutrients aside from nitrogen were applied as recommended. Irrigation was done with a conventional fixed sprinkler system and irrigation management was done according to the recommendations of SILVA & REIS (2007), considering soil moisture, replenishing the necessary blade to reach soil moisture at field capacity. The total water availability was calculated by the difference

Table 1 - Chemical and grain-particle properties of the soil in the layers 0-20 and 20-40 cm, in samples collected before setting up the experiment.

Chemical properties	-----------------------------------Layer-----------------------------------	
	0-20 cm	20-40 cm
pH in water - 1: 2.5	5.80	4.60
Organic matter (OM) (dag kg^{-1}) [1]	1.70	1.10
P (mg dm^{-3})[2]	41.00	9.00
K (mg dm^{-3})[2]	64.00	36.00
Ca^{2+} ($cmol_c$ dm^{-3})[3]	1.50	0.80
Mg^{2+} ($cmol_c$ dm^{-3})[3]	0.70	0.30
Exchangeable acidity (Al^{3+}) ($cmol_c$ dm^{-3})[3]	0.00	1.10
Potential acidity (H + Al) ($cmol_c$ dm^{-3})[4]	2.90	4.20
Sum of bases (SB) ($cmol_c$ dm^{-3})	2.40	1.20
Effective CEC (t) ($cmol_c$ dm^{-3})	2.40	2.30
CEC at pH 7.0 (T) ($cmol_c$ dm^{-3}) [5]	5.30	5.40
Base saturation (V) (%)	44.90	22.10
------------------------------Particle size properties[6]------------------------------		
Coarse sand (dag kg^{-1})	35	-
Fine sand (dag kg^{-1})	10	-
Silt (dag kg^{-1})	7	-
Clay (dag kg^{-1})	48	-
------------------------------Physical-water properties------------------------------		
Field capacity (kg kg^{-1})[7]	0.201	-
Wilting point (kg kg^{-1})[8]	0.126	-
Soil density (kg kg^{-1})[9]	1.1	-

[1]OM = organic carbon *or* matter x 1.724 – Walkley-Black; [2] Mehlich-1 extractor; [3] 1 mol.L^{-1} KCl extractor; [4] 0.5 mol.L^{-1} Calcium acetate extractor pH 7.0; [5] CEC =Potential cation exchange capacity, [6] Pipette method" (Embrapa, 1997); [7] Potential -10 kPa; [8] Potential -1500 kPa; 9 Cylinder method.

between the moisture obtained at field capacity (10 kPa) and the moisture at a potential of 1500 kPa, considered to be the permanent wilting point. An availability factor (f) of 0.5 and an effective depth of the root system (z) of 30 cm were considered for the calculation of the blade to be applied. The irrigation shift was fixed and, before irrigation, soil samples were taken, placed in sealed containers and the current moisture was obtained by the microwave method. When precipitation occurred during the period, the difference between the calculated irrigation rate and precipitation was determined

A randomized block design with four replications in a split plot scheme was used, consisting of six nitrogen (N) levels: 0, 110, 220, 440, 880 and 1320 kg N ha^{-1} $year^{-1}$ (plots) and four evaluation periods: November 2012 (E1), December 2012 (E2), February 2013 (E3) and June 2013 (E4) (sub-plots). Each plot consisted of a row with seven plants, of which the five central ones were evaluated, but not the two border plants. The experiment was initiated in July 2012, when soil sampling, liming, fertilization with other nutrients and treatments were carried out, and ended in June 2014, after fruit harvest, thus evaluating the 1st growing season of 2012/2013 and 2nd growing season of 2013/2014.

Growth measures

Five plagiotropic and orthotropic branches of the upper middle third of the plant canopies of each tree were labeled for periodic length measurements. The branch length was measured from the outlined base to the branch tip with a measuring tape and the number of nodes on the branches on the side of the crop interrows were counted. The leaf area (PARTELLI et al., 2006) of the 3rd or 4th pair of leaves, counted from the tip of plagiotropic branches growing from the middle third of the coffee trees, was measured on the same branch, identified as diagnostic leaf (DL) and as the oldest leaf (OL), on either side of the tree. Based on these data, the vegetative growth level of the plagiotropic and orthotropic branches was calculated, subtracting the branch size of the previous from the current month, and dividing the difference by the number of days between each evaluation.

To determine leaf dry weight, the collected leaves were dried in a forced air convection oven at 70 ºC to constant weight and weighed on a precision digital scale (accuracy 0.01 g) (CTG-6H, Citizen Scale PLC., Parwanoo, India). The evaluations of the diagnostic leaf were performed in six periods (P): December 2012 (E1), February 2013 (E2), June 2013 (E3), October 2013 (E4), December 2013 (E5) and February 2014 (E6), and in four periods for the oldest leaf: December 2012 (E1), February 2013 (E2), June 2013 (E3), and October 2013 (E4), immediately before nitrogen fertilization of the plots, to analyze the effect of previous fertilizations.

Green coffee yield

To estimate coffee yield, the berries of the five labelled trees of each treatment were harvested by hand. The mean berry production per coffee tree was measured in liters of fresh fruit per plant. A relationship between coffee production and yield after green coffee processing was established for the sample and extrapolated to coffee harvested from the five useful plants per plot. The production data were then converted to yield (expressed in bags of 60 kg ha^{-1} of green coffee).

Establishment of critical levels of the evaluated characteristics

The criterion of FONTES (2011) was applied, where the values of each of the evaluated characteristics were associated with the N level that achieved 95% of the maximum yield, to calculate and establish the Critical Level (CL) of these characteristics. To determine the Critical Levels (CLs), the characteristics evaluated before the 1^{st} growing season (2012/2013) were associated with the N level that achieved 95% of the maximum yield in the 1^{st} growing season. The characteristics assessed after the 1^{st} growing season were associated with the N level that achieved 95% of the maximum yield in the 2^{nd} growing season (2013/2014).

Statistical analysis

The data were subjected to analysis of variance and when significant, quantitative data were subjected to regression analysis and the chosen models were based on significance of the regression coefficients (t test at 5% probability); coefficient of determination; and biological logic. Correlations between variables were established accomplished using the GENES applicative (CRUZ, 2013).

RESULTS AND DISCUSSION

There was a significant correlation between N levels and evaluation periods in all evaluated plant growth characteristics ($P < 0.05$). For conilon coffee, the different N levels had a positive effect on the accumulated growth of the plagiotropic (Figure 1A, B, C and D) and orthotropic branches (Figure 1E, F, G and H) and on the number of nodes on the branches, in each evaluation period (Table 2). The estimated CLs of growth and number of nodes on the plagiotropic and orthotropic branches were associated with the N level that achieved 95% of the maximum yield of Conilon coffee in the first growing season (420.7 kg N ha^{-1}) (Table 3).

As expected, the growth levels were highest in the early phase, when the branches were still young, followed by a growth decline as these branches become older (AMARAL et al., 2011; PARTELLI et al., 2010; 2013). The applied N levels considerably increased the growth of both orthotropic and plagiotropic branches and number of nodes, indicating a direct relationship with N fertilization, suggesting a potential use as auxiliary tool in the nutritional diagnosis of nitrogen in Conilon coffee.

Under increased plant growth in response to fertilization levels of 85.04% - 94.81% of the coffee demand, irrigation is required during crop cultivation (ASSIS et al., 2014), which in turn promotes higher yields and raises the nutrient demand over the year (COSTA et al., 2010; GUIMARÃES et al., 2010).

Throughout the year, the plant growth of coffee trees varied according to the season, a common fact for this crop both in this and other Arabica and Conilon coffee- producing regions in the country (PARTELLI et al., 2010; 2013; COVRE et al., 2013, 2016). In addition, particularly the number of plagiotropic and orthotropic branch nodes per plant were also affected by nitrogen over time (DUBBERSTEIN et al., 2017).

The variables length, width and area of the diagnostic and the oldest leaves of plagiotropic branches were also positively influenced by the N levels in the evaluated periods (Figure 2A, B and C). However, the effect of N levels on these biometric characteristics was more marked for the diagnostic than the older leaf (Table 2), and had a positive effect on these variables in all evaluation periods, except in December 2012 (E1) when the N levels

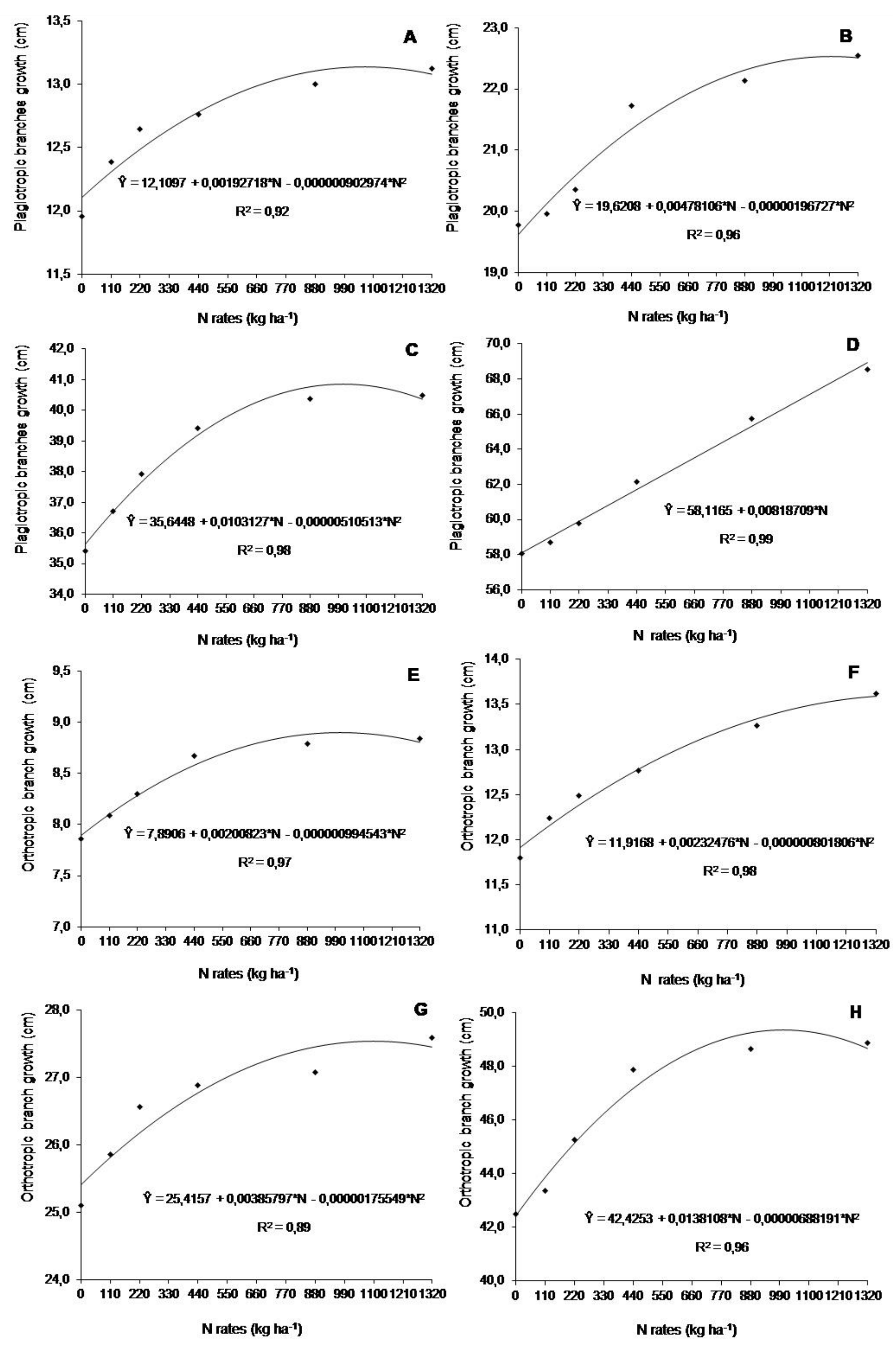

Figure 1 - Estimated accumulated plagiotropic and orthotropic branch growth of conilon coffee in response to N levels (kg ha^{-1}) in four evaluation periods. Letters A and E: Nov./2012; B and F: Dec./2012, C and G: Feb./2013; D and H: Jun./2013.

had no significant effect (Table 2). The estimated CLs of these variables, as well as the leaf area of the diagnostic and oldest leaves, were associated with the N level that achieved 95% of the maximum yield of Conilon coffee in the first growing season (420.7 kg N ha^{-1}) in December 2012 (E1) and February 2013 (E2). In the subsequent periods, the CL of the evaluated characteristics was associated with the N

Table 2 - Adjusted equations and determination coefficients for the number of nodes on the plagiotropic and orthotropic branches, leaf length, width and area of a conilon coffee tree, fresh and dry weight of the old leaf and nitrogen content of the diagnostic leaf of a conilon coffee tree, according to the applied N levels, in each evaluation period.

Evaluation period	--------Fitted equations--------	R^2
	----------Number of nodes on plagiotropic branches (unit)----------	
E1 (Nov./2012)	$\hat{Y} = 2.66567 + 0.000372493N - 0.000000149083N^2$	0.92
E2 (Dec./2012)	$\hat{Y} = 5.07661 + 0.00109895N - 0.000000446244N^2$	0.95
E3 (Feb./2013)	$\hat{Y} = 8.87834 + 0.00119973N - 0.000000553336N^2$	0.96
E4 (Jun./2013)	$\hat{Y} = 16.2846 + 0.00189364N - 0.000000492509N^2$	0.98
	----------Number of nodes on orthotropic branches (unit)----------	
E1 (Nov./2012)	$\hat{Y} = 2.08976 + 0.000672167N - 0.000000259798N^2$	0.95
E2 (Dec./2012)	$\hat{Y} = 3.76749 + 0.000790431N - 0.000000343164N^2$	0.97
E3 (Feb./2013)	$\hat{Y} = 8.09292 + 0.00104586N - 0.000000419977N^2$	0.93
E4 (Jun./2013)	$\hat{Y} = 13.5878 + 0.00434855N - 0.00000193378N^2$	0.93
	----------Length (cm)----------	
E1 (Dec./2012)	$\hat{Y} = \bar{Y} = 16.2768$	-
E2 (Feb./2013)	$\hat{Y} = 16.1078 + 0.00332729N - 0.00000161412N^2$	0.88
E3 (Jun./2013)	$\hat{Y} = 15.5381 + 0.00186201N - 0.000000690287N^2$	0.93
E4 (Oct./2013)	$\hat{Y} = 15.8068 + 0.00388155N - 0.00000189027N^2$	0.89
	----------Width (cm)----------	
E1 (Dec./2012)	$\hat{Y} = \bar{Y} = 6.2574$	-
E2 (Feb./2013)	$\hat{Y} = 6.07113 + 0.000876276N - 0.00000029478N^2$	0.92
E3 (Jun./2013)	$\hat{Y} = 6.09368 + 0.00133717N - 0.000000482732N^2$	0.94
E4 (Oct./2013)	$\hat{Y} = 6.20635 + 0.002248N - 0.000000995489N^2$	0.81
	----------Leaf area (cm^2)----------	
E1 (Dec./2012)	$\hat{Y} = \bar{Y} = 69.6355$	-
E2 (Feb./2013)	$\hat{Y} = 67.4837 + 0.0274079N - 0.000012933N^2$	0.87
E3 (Jun./2013)	$\hat{Y} = 61.0712 + 0.0173628N - 0.00000645754N^2$	0.95
E4 (Oct./2013)	$\hat{Y} = 64.0906 + 0.0320953N - 0.0000153664N^2$	0.90
	----------Fresh matter weight (g)----------	
E1 (Dec./2012)	$\hat{Y} = \bar{Y} = 2.0278$	-
E2 (Feb./2013)	$\hat{Y} = 2.01565 + 0.000732605N - 0.000000333812N2$	0.93
E3 (Jun./2013)	$\hat{Y} = 1.99308 + 0.00036693N - 0.000000150134N2$	0.86
E4 (Oct./2013)	$\hat{Y} = \bar{Y} = 2.1585$	-
	----------Dry matter weight (g)----------	
E1 (Dec./2012)	$\hat{Y} = \bar{Y} = 0.7309$	-
E2 (Feb./2013)	$\hat{Y} = 0.991418 + 0.000331015N - 0.000000183559N2$	0.80
E3 (Jun./2013)	$\hat{Y} = 1.25922 + 0.000169864N - 0.0000000829438N2$	0.83
E4 (Oct./2013)	-	

level that achieved 95% of the maximum yield of Conilon coffee in the 2nd growing season (543.1 kg N ha^{-1}) (Table 3).

The variable leaf area expansion was sensitive to the effect of nitrogen, which shows that the greater the availability of this nutrient, the greater the leaf area of Conilon coffee trees (FREITAS et al., 2011, 2012; SOUSA et al., 2013; OLIOSI et al., 2017). An adequate nitrogen supply (PARTELLI et al., 2016; 2018) is therefore essential for the continuous annual growth of coffee trees, even in the autumn-winter period, albeit at a lower level.

Regarding the fresh and dry weight of the diagnostic leaf, the N levels had a positive effect in all evaluation periods, except in December 2012 (E1), when no significant effect was observed (Figures 2D and E), due to the short time between N application and the first evaluation. The different N levels had a positive effect on the fresh and dry weight of the old leaf in the evaluation periods February 2013 (E2)

Table 3 - Estimates of critical levels (CLs) associated with the N levels that achieved 95% of the maximum coffee yield for plagiotropic branch length (PBL), number of plagiotropic branch nodes (NPBN), orthotropic branch length (OBL) (cm) and number of orthotropic branch nodes (NOBN); leaf fresh weight (FW) and dry weight (DW) (g); leaf length (cm), width (cm) and area (cm^2) of the diagnostic leaf and the old leaf, in each evaluation period.

Evaluation period	-----Growth characteristics-----			
	PBL	NPBN	OBL	NOBN
E1 (Nov./2012)	12.92	2.82	8.73	2.37
E2 (Dec./2012)	21.63	5.54	12.89	4.10
E3 (Feb./2013)	39.98	9.38	27.04	8.53
E4 (Jun./2013)	61.56	17.08	48.23	15.42

Evaluation period	-----Diagnostic leaf-----		-----Old leaf-----	
	FW	DW	FW	DW
E1 (Nov./2012)	-	-	-	-
E2 (Dec./2012)	1.95	1.00	2.32	1.13
E3 (Feb./2013)	1.95	1.23	2.19	1.35
E4 (Jun./2013)	1.86	0.71	-	-
E5 (Dec./2013)	2.41	1.40	-	-
E6 (Feb./2014)	2.34	1.39	-	-

Evaluation period	-----Diagnostic leaf-----			-----Old leaf-----		
	Length	Width	Leaf area foliar	Length	Width	Leaf area foliar
E1 (Nov./2012)	15.61	5.73	59.75	-	-	-
E2 (Dec./2012)	16.19	5.71	67.43	17.51	6.44	79.02
E3 (Feb./2013)	18.22	6.56	84.68	16.55	6.82	70.50
E4 (Jun./2013)	17.91	6.93	81.45	17.91	7.43	81.52
E5 (Dec./2013)	19.71	7.02	99.42	-	-	-

and June 2013 (E3), and remained at the same level in December 2012 (E1) and October 2013 (E4) (Table 2).

The estimated critical levels of the fresh and dry weight of the diagnostic and old leaf were associated with the N level that achieved 95% of the maximum Conilon coffee yield in the first growing season (420.7 kg N ha^{-1}) in December 2012 (E1) and February 2013 (E2). For the following periods, the CL of the evaluated characteristics was associated with the N level that achieved 95% of the maximum Conilon coffee yield in the 2nd growing season (543.1 kg N ha^{-1}) (Table 3).

These results showed that older and more mature leaves are physiologically less sensitive and; therefore, less influenced by the applied treatments. Possibly, the observed period was also insufficient to provide significant changes in the leaf weight in the first evaluation. Analogous to the leaf area, for the use of the characteristic dry weight increase the diagnostic leaf was more appropriate than the oldest leaf. However, fresh matter weight can be very variable, mainly due to the loss of turgor after harvesting a plant or part of it, depending mainly on the conditions of relative air humidity from the sampling to the weighing site. Thus, as an auxiliary tool in the nutritional diagnosis of nitrogen in coffee, dry matter weight is preferable.

The application of the highest N level did not result in a higher yield; although, the branch length and weight and diagnostic leaf area increased. Conversely, at zero or low N levels, leaf growth was reduced, since dry matter accumulation is reduced at limiting nitrogen levels, which restricts leaf expansion and radiation interception (CLEMENTE et al., 2013, TAIZ et al, 2017). In this way, certain plant growth characteristics (leaf area, height and dry weight, and branch growth) that are sensitive to nitrogen application and easily measurable in a non-destructive way, can also be used as indirect indices for the diagnosis of the nitrogen nutritional status. In addition, we emphasized the importance of using new technologies such as NIR for foliar and soil analysis because they can help in an efficient way due to their agility in correcting plant nutrition (MARTINS & SARGENTELLI, 2021).

A significant effect ($P \leq 0.05$) of the interaction between N levels and the evaluated

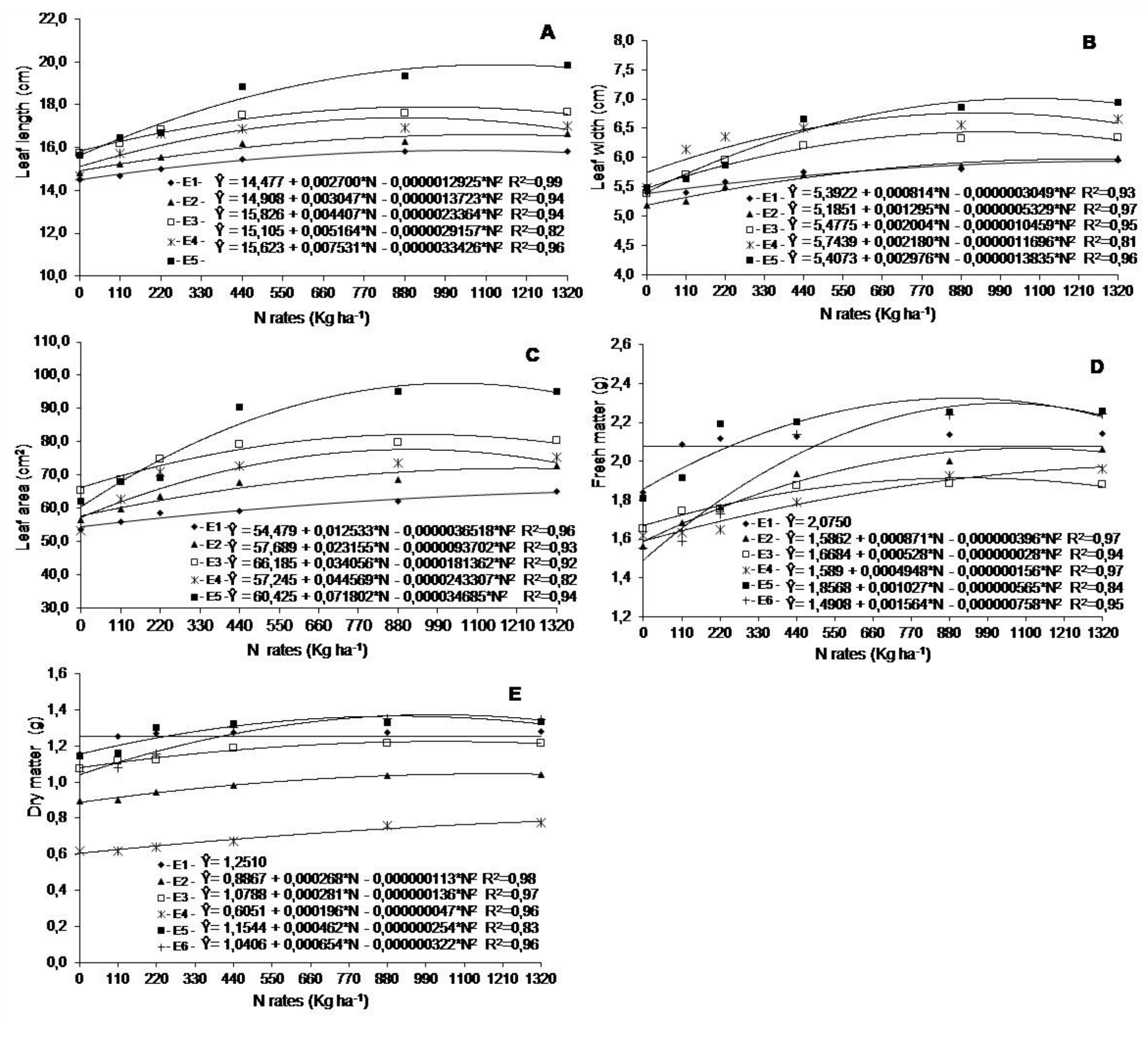

Figure 2 - Estimated growth characteristics leaf length (A), width (B) and area (C); fresh matter (D) and dry matter (E) of the diagnostic leaf of a conilon coffee tree, in response to N levels (kg ha^{-1}), in different evaluation periods. E1 (Nov./2012), E2 (Dec./2012), E3 (Feb./2013), E4 (Jun./2013), E5 (Dec./2013) and E6 (Feb./2014).

growing seasons was observed (Figure 3A and B). In the 1st growing season, the mean yield was 130.4 bags of 60 kg ha^{-1}, and the level of 830.2 kg N ha^{-1} achieved the highest green coffee yield (144.8 bags of 60 kg ha^{-1}) of the studied levels. To achieve 95% of the maximum yield (137.4 bags of 60 kg ha^{-1}), a nitrogen level of 420.7 kg ha^{-1} was needed.

These results showed that a 5% lower yield could be achieved at 49.3% lower N levels, representing a considerable saving in nitrogen fertilization, reducing the cost per bag of coffee. A relevant fact is that the N level required to achieve 90% of the maximum yield (130.1 bags of 60 kg ha^{-1}) was 251.3 kg N ha^{-1}, i.e., a 10% lower maximum yield was achieved at a 69.7% lower N level.

In the 2nd growing season, the mean yield was 94.5 bags of 60 kg ha^{-1}. The level of 815.2 kg N ha^{-1} achieved the highest green coffee yield of all studied levels (120.5 bags of 60 kg ha^{-1}). In this growing season, 95% of the maximum yield (with

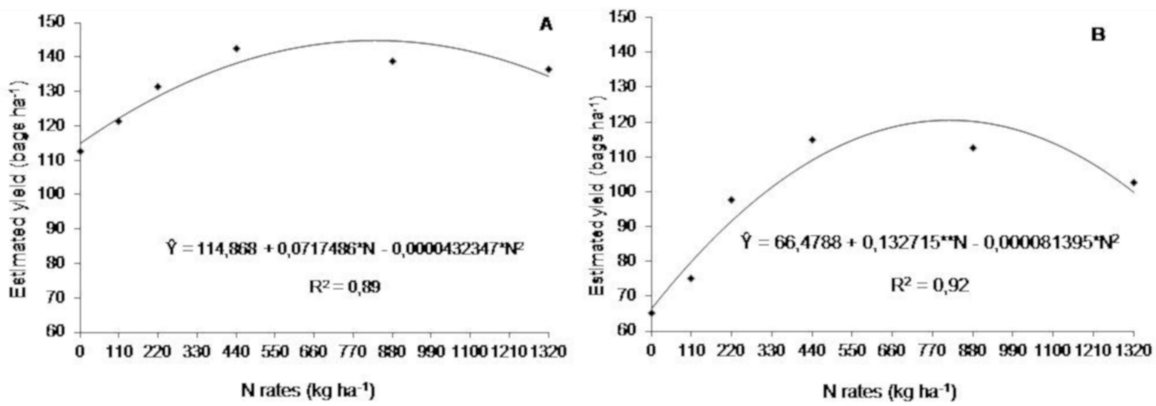

Figure 3 - Estimated yield (bags of 60 kg ha^{-1}) of conilon coffee in response to N levels (kg ha^{-1}), in the 1st (A) (2012/2013) and 2nd (B) evaluated growing seasons (2013/2014).

114.5 bags of 60 kg ha^{-1}) was achieved at a level of 543.1 kg N ha^{-1}, and 90% of the maximum yield (108.5 bags of 60 kg ha^{-1}) at 430.3 kg N ha^{-1}.

In relation to the previous growing season, a 47.2% lower applied N level achieved a 10% reduction in maximum yield. This drastic reduction may be associated with the greater canopy density or higher plant age (GALLO et al. 1999), as well as an increase in plant growth and consequently, increased self-shading, which in turn influences the photosynthetic level and production of photoassimilates used in coffee grain production (CLEMENTE et al., 2013; OLIOSI et al., 2017).

In the 1st growing season, the mean yield was 27.47% higher than in the 2nd, mainly because the plants of the 1st growing season were notably more vigorous, with a higher number of productive branches. Due to pruning, the plant architecture was changed, and in the 2nd growing season, and there were more and therefore younger branches in the vegetative stage. A coffee tree with a higher number of branches and leaves and; consequently, a better structure, can achieve a higher yield in the first compared to the second growing season (CARVALHO et al., 2010). Moreover, the vigor of productive branches declines after the second or third growing season and there is no compensatory growth to maintain yields high (BRAGANÇA et al., 2018).

For Arabica coffee, a positive linear response to nitrogen in low-yield years is frequently observed in the region, mainly due to the need to replace the vegetative biomass, affected by the higher nutrient transference to fruits in years of high production (PREZOTTI & ROCHA, 2004). Thus, even in low-yield years, the nutrient demand is roughly the same, mainly allocated to sustain the growth of plagiotropic branches and formation of new branches, leaves and roots that consequently replace the fruit as carbohydlevel and nutrient sink and ensure the production of the following year (NEVES et al., 2006).

Nitrogen accumulation is normally accompanied by an increase in crop biomass (NEVES et al., 2006), which means that the nutritional requirement varies little according to the yield (VALADARES et al., 2013, PARTELLI et al., 2014). In this way, the possible effect of fertilization of the previous yield on that of the next crop can have a supportive effect, because mineral nutrition affects all vital plant functions and not exclusively reproduction-related aspects. Fertilization should not be calculated to meet only the nutritional needs associated with the pending fruit load, since this could hamper the production in the following growing season (VALADARES et al., 2013).

Another important factor to be considered is the bienniality of coffee production, since over several growing seasons, the yield stability of coffee trees treated with higher N levels (VALADARES et al. 2013) may be greater (CARVALHO et al., 2020). Therefore, as a higher N fertilization reduces the yield bienniality, it is worth emphasizing that in the analysis of bienniality, the relationship between fertilization and higher yield stability can essentially be attributed to nitrogen fertilization.

CONCLUSION

The increase in the N levels provided a significant increase in branch growth and in leaf size and weight of irrigated Conilon coffee. The growth characteristics and N indices were related to nitrogen fertilization, which confirms the possibility of their use as auxiliary tool for a faster and more practical nitrogen nutritional diagnosis of irrigated coffee trees.

The yield of Conilon coffee increased with increasing N levels. The N level to achieve 95% of the maximum yield of Conilon coffee corresponded to 420.78 kg N ha^{-1}, with a yield of 137.40 bags of 60 kg ha^{-1} in the 1^{st} growing season (2012/2013), and to 543.09 kg N ha^{-1}, with a yield of 114.54 bags of 60 kg ha^{-1} in the 2^{nd} growing season (2013/2014). To draw conclusions about the N nutritional status, the diagnostic leaf proved to be more adequate than the oldest leaf for the evaluation of growth characteristics and N indices.

ACKNOWLEDGEMENTS

The T.R.T. was partial funded by the Brazilian Federal Agencies: “Coordenação de Aperfeiçoamento de Pessoal de Nível Superior” (CAPES), Brazil – Finance Code 001.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS’ CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

REFERENCES

ALVARES, C. A., et al. Köppen’s climate classification map for Brazil. **Meteorologische Zeitschrift**, v.22, n.6, p.711-728. 2013. Available from: <https://doi.org/10.1127/0941-2948/2013/0507>. Accessed: Jul. 10, 2019. doi: 10.1127/0941-2948/2013/0507.

AMARAL, J. F. T., et al. Nutrients use efficiency by coffee cultivars. **Ciência Rural**, Santa Maria, v.41, n.4, p.621-629, 2011. Available from: <https://doi.org/10.1590/S0103-84782011005000027>. Accessed: Jul. 12, 2019. doi: 10.1590/S0103-84782011005000027.

ASSIS, G. A., et al. Correlation between coffee plant growth and yield as function of water supply regime and planting density. **Bioscience Journal**. v.30, p.666-676, 2014.

BRAGANÇA, S. M., et al. Clonal varieties of Conilon coffee for the Espírito Santo State, Brazil. **Pesquisa Agropecuária Brasileira**, v.36, n.5, p.765-770, 2001. Available from: <https://doi.org/10.1590/S0100-204X2001000500006>. Accessed: Jul. 10, 2019. doi: 10.1590/S0100-204X2001000500006.

BRAGANÇA, S. M., et al. Acumulation of macronutrients for the Conilon coffee tree. **Journal of Plant Nutrition**, v.31 n.1, p.103-120, 2018. Available from: <https://doi.org/10.1080/01904160701741990>. Accessed: Jun. 10, 2019. doi: 10.1080/01904160701741990.

BUSATO, C., et al. Seasonal variation and threshold values for chlorophyll meter readings on leaves of potato cultivars. **Journal of Plant Nutrition**, v.33, p.2148-2156, 2010. Available from: <http://dx.doi.org/10.1080/01904167.2010.519087>. Accessed: Jun. 18, 2019. doi: 10.1080/01904167.2010.519087.

CARVALHO, H. F. et al. The effect of bienniality on genomic prediction of yield in arabica coffee. **Euphytica**, v.216, p.101, 2020. Available from: <https://doi.org/10.1007/s10681-020-02641-7>. Accessed: Jun. 18, 2019. doi:10.1007/s10681-020-02641-7.

CARVALHO, A. M., et al. Correlation between growth and yield of coffee cultivars in different regions of the state of Minas Gerais, Brazil. **Pesquisa Agropecuária Brasileira**, Brasília, v.45, n.3, p.269-275, 2010. Available from: <https://doi.org/10.1590/S0100-204X2010000300006>. Accessed: Jun. 18, 2019. doi: 10.1590/S0100-204X2010000300006.

CLEMENTE, J. M., et al. Effect of N and K levels in nutritive solution on growth, production and coffee bean size. **Revista Ceres**, Viçosa, v.60, n.2, p.279-285, 2013. Available from: <http://dx.doi.org/10.1590/S0034-737X2013000200018>. Accessed: Jun. 18, 2019. doi: 10.1590/S0034-737X2013000200018.

CONAB - Companhia Nacional do Abastecimento. Acompanhamento da safra brasileira. 2020 https://www.conab.gov.br/info-agro/safras. Available from: <https://www.conab.gov.br/info-agro/safras>. Accessed: Jun. 18, 2020.

COSTA, A. R., et al. Number of primary branches and productivity of two cultivars of coffee using drip irrigation. **Revista Ciência Agronômica**, Fortaleza, v.41, n.4, p.571-581, 2010. Available from: <http://dx.doi.org/10.1590/S1806-66902010000400009>. Accessed: Jun. 18, 2019. doi: 10.1590/S1806-66902010000400009.

COVRE, A. M., et al. Vegetative growth of Conilon coffee plants under two water conditions in the Atlantic region of Bahia State, Brazil. Acta **Scientiarum. Agronomy**, v.38, n.4, p.535, 2016. Available from: <http://dx.doi.org/10.4025/actasciagron.v38i4.30627>. Accessed: Jun. 18, 2020. doi: 10.4025/actasciagron.v38i4.30627.

COVRE, A. M., et al. Initial growth and development of Conilon coffee genotypes. **Revista Agro@mbiente Online**, Boa Vista, v.7, n.2, p.193-202, 2013. Available from: <http://dx.doi.org/10.18227/1982-8470ragro.v7i2.944>. Accessed: Jun. 18, 2019. doi: 10.18227/1982-8470ragro.v7i2.944.

CRUZ, C. D. GENES: a software package for analysis in experimental statistics and quantitative genetics. **Acta Scientiarum. Agronomy**, v.35, p.271–276, 2013.

DUBBERSTEIN, D., et al Influence of fertilization on coffee trees vegetative growth in west south Amazon. **Coffee Science**, v.12, n.2, p.197-206, 2017. Available from: <https://doi.org/10.25186/cs.v12i2.1228>. Accessed: Jul. 10, 2019. doi: 10.25186/cs.v12i2.1228.

DUBBERSTEIN, D., et al. Biometric traits as a tool for the identification and breeding of *Coffea canephora* genotypes. **Genetics and Molecular Research**, v.19 gmr18541, 2020. Available from: <http://dx.doi.org/10.4238/gmr18541>. Accessed: Mar. 20, 2020. doi: 10.4238/gmr18541.

FONTES, P. C. R. **Nutrição mineral de plantas: avaliação e diagnose**. Viçosa: UFV, 2011. 296p.

FREITAS, J. C. O., et al. Morphophysiological characteristics of clonal plants *Passiflora alata* grown in different levels of nitrogen and shading levels. **Revista Brasileira de Fruticultura**, v.34, n.3, p.859-872, 2012. Available from: <https://doi.org/10.1590/S0100-29452012000300028>. Accessed: Jun. 10, 2019. doi: 10.1590/S0100-29452012000300028.

FREITAS, J. C. O., et al. Deficiency symptoms of macronutrientes and boron in sweet passion fruit plant. **Revista Brasileira de Fruticultura**, v.33, n.4, p.1329-1341, 2011. Available from: <https://doi.org/10.1590/S0100-29452011000400034>. Accessed: Jun. 15, 2019. doi: 10.1590/S0100-29452011000400034.

GALLO, P. B., et al. NPK fertilization for high tree density coffee plantations. **Bragantia**, v.58, n.2, p.341-351, 1999. Available from: <https://doi.org/10.1590/S0006-87051999000200014>. Accessed: Jun. 16, 2019. doi: 10.1590/S0006-87051999000200014.

GOMES, W. R., et al. Genetic diversity of standard leaf nutrients in *Coffea canephora* genotypes during phenological phases. **Genetics and Molecular Research**, v.15 n.4, p.1-13, 2016. Available from: <https://doi.org/10.4238/gmr.15048839>. Accessed: Jun. 16, 2020. doi: 10.4238/gmr.15048839.

GUIMARÃES, R. J., et al. Fertilization (N and K_2O) of fertirrigated coffee in the first year after planting in the southern region of Minas Gerais state. **Coffee Science**, v.5, n.2, p.137-147, 2010. Available from: <https://doi.org/10.25186/cs.v5i2.336>. Accessed: Jun. 16, 2020. doi: 10.25186/cs.v5i2.336.

ICO - **International Coffee Organization**. Trade Statistics. 2020. Available from: <http://www.ico.org/trade_statistics.aspsection=Statistics>. Accessed: Apr. 20, 2020.

MARTINS, M. Q., et al. Genetic variability on nutrient contents in *Coffea canephora* genotypes cultivated at 850 meters of altitude in two crop seasons. **Funcional Plant Breeding Journal**, v.1, p.1- 12, 2019. Available from: <https://dx.doi.org/10.35418/2526-4117/v1n1a6>. Accessed: Jun. 16, 2020. doi: 10.35418/2526-4117/v1n1a6.

MARTINS, J. A; SARGENTELLI, V. Near infrared in the Quantitative leaf assessment. **Revista Prospectus**, v.3, p.33-55, 2021. Accessed: Jul. 28, 2021.

MARTINEZ, H. E. P., et al. Water deficit changes nitlevel uptake and expression of some nitrogen related genes in coffee-plants (*Coffea arabica* L.), **Scientia Horticulturae**, v.267, p.109254, 2020. Available from: <https://doi.org/10.1016/j.scienta.2020.109254>. Accessed: Jun. 16, 2020. doi: 10.1016/j.scienta.2020.109254.

NEVES, Y. P., et al. Produtividad y acumulación de materia seca, N, P y K por cultivares de *Coffea arabica* L. **Coffee Science**, v.1, n.2, p.156-167, 2006. Available from: <https://doi.org/10.25186/cs.v9i1.554>. Accessed: Jun. 16, 2020. doi: 10.25186/cs.v9i1.554.

OLIOSI, G., et al. Chlorophyll *a* fluorescence transient and vegetative growth in conilon coffee under different nitrogen sources. **Coffee Science**, v.12 n.2, p.101-112, 2017. Available from: <https://doi.org/10.25186/cs.v12i2.1268>. Accessed: Jun. 05, 2020. doi: 10.25186/cs.v12i2.1268.

PARTELLI, F. L., et al. Nutritional standards and nutritional diagnosis of the Conilon coffee plants in phenological growth stages. **Journal of Plant Nutrition**, v.41, n.19, p.1-11, 2018. Available from: <https://doi.org/10.1080/01904167.2018.1510513>. Accessed: Jun. 03, 2020. doi: 10.1080/01904167.2018.1510513.

PARTELLI, F. L., et al. Norms and nutrition diagnosis of coffee conilon in flowering and graining in Espirito Santo. **Coffee Science**, v.11, p.544-554, 2016. Available from: <https://doi.org/10.25186/cs.v11i4.1177>. Accessed: Jun. 10, 2020. doi: 10.25186/cs.v11i4.1177.

PARTELLI, F. L., et al. Root system distribution and yield of "conilon" coffee propagated by seeds or cuttings. **Pesquisa Agropecuária Brasileira**, v.49, p.349–355, 2014. Accessed: Jun. 10, 2020. doi: 10.1590/s0100-204x2014000500004.

PARTELLI, F. L., et al. Seasonal vegetative growth in genotypes of *Coffea canephora*, as related to climatic factors. **Journal of Agricultural Science**, v.5, p.108-116, 2013. Available from: <https://doi.org/10.5539/jas.v5n8p108>. Accessed: Jun. 10, 2020. doi: 10.5539/jas.v5n8p108.

PARTELLI, F. L., et al. Seasonal vegetative growth of different age branches of conilon coffee tree. **Semina: Ciências Agrárias**, v.31, n.3, p.619-626, 2010. Available from: <http://dx.doi.org/10.4025/actasciagron.v38i4.30627>. Accessed: Jun. 10, 2020. doi: 10.4025/actasciagron.v38i4.30627.

PARTELLI, F. L., et al. Estimative of leaf foliar area of *Coffea canephora* based on leaf length. **Revista Ceres**, v.53, n.306, p.204-210, 2006. Available from: <http://dx.doi.org/10.1590/S1806-66902010000400026>. Accessed: Jun. 10, 2020. doi: 10.1590/S1806-66902010000400026.

PEREIRA, A. A., et al. Modeling of the diameter of the canopy pruned coffee tree cultivated in different densities and water regimes. **Coffee Science**, v.11, p.495-501, 2016. Available from: <https://doi.org/10.25186/cs.v11i4.1145>. Accessed: Jun. 10, 2020. doi: 10.25186/cs.v11i4.1145.

PREZOTTI, L. C., ROCHA, A. C. Coffee nutrition as a function of plant density and NPK fertilization. **Bragantia**, v.63, n.2, p.239-251, 2004. Available from: <https://doi.org/10.1590/S0006-87052004000200009>. Accessed: Jun. 08, 2020. doi: 10.1590/S0006-87052004000200009.

SANTOS, H. G., et al. **Sistema brasileiro de classificação de solos**, 5 th. ed., Brasília Embrapa, Brasília, 2018.

SILVA, J. G. F.; REIS, E. F. Irrigação do Cafeeiro Conilon. In: FERRÃO, R. G.; FONSECA, A. F. A.; BRAGANÇA. S. M.;

FERRÃO, M. A. G.; MUNER, L. H. **Café Conilon**. Vitória: Incaper, Cap.13, 2007. p.345-373.

SOUSA, L. B., et al. Growth, mineral composition and total phenol of Passiflora species as affected by nitrogen sources. **Bragantia**, v.72, n.3, p.247-254, 2013. Available from: <https://doi.org/10.1590/brag.2013.034>. Accessed: Jun. 01, 2020. doi: 10.1590/brag.2013.034.

TAIZ, L, et al. **Plant Physiology & Development** . 7th. ed., Artmed, 2017.

VALADARES, S. V., et al. Yield and production bienniality of dense coffee plantations under different levels of N and K. **Pesquisa Agropecuária Brasileira**, v.48, n.3, p.296-303, 2013. Available from: <https://doi.org/10.1590/S0100-204X2013000300008>. Accessed: Jun. 01, 2020. doi: 10.1590/S0100-204X2013000300008.