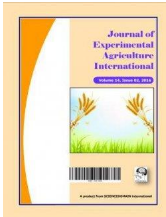

Journal of Experimental Agriculture International

27(4): 1-13, 2018; Article no.JEAI.42345
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Repercussions of the Level of Shading and the Type of Container in the Seedling Stage on the Growth of Irrigated and Non-irrigated Coffee Plants in the Field

Maria Christina Junger Delôgo Dardengo[1], Lucas Rosa Pereira[2*], Elias Fernandes de Sousa[3] and Edvaldo Fialho dos Reis[2]

[1]Federal Institute of Espírito Santo, Campus Alegre, CEP: 29500-000 - Alegre, ES, Brazil.
[2]Center for Agrarian Sciences and Engineering, Federal University of Espírito Santo, Alto Universitário Street, S/no, Guararema, CEP: 29500-000, Alegre, ES, Brazil.
[3]Center for Agricultural Sciences and Technologies, Laboratory of Agricultural Engineering, University State of the North Fluminense Darcy Ribeiro, CEP: 28013-602 Campos dos Goytacazes, RJ, Brazil.

Authors' contributions

This work was carried out in collaboration between all authors. Authors MCJDD and LRP designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors and university professors EFS and EFR managed the analyses of the study, orientation of the execution stages and elaboration of the data. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2018/42345
Editor(s):
(1) Dr. Marco Aurelio Cristancho, Professor, National Center for Coffee Research, CENICAFÉ, Colombia.
(2) Dr. Rusu Teodor, Professor, Department of Technical and Soil Sciences, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Romania.
Reviewers:
(1) Mustafa Ünlü, Cukurova University, Turkey.
(2) S. Metin Sezen, Çukurova University, Turkey.
(3) Nontuthuko Rosemary Ntuli, University of Zululand, South Africa.
(4) Anonymous, Instituto Agronômico do Paraná, Brazil.
Complete Peer review History: http://www.sciencedomain.org/review-history/26980

Original Research Article

Received 26 May 2018
Accepted 26 October 2018
Published 01 November 2018

ABSTRACT

The present investigation aims to evaluate the vegetative and reproductive growth along with the root distribution of irrigated and non-irrigated coffee plants, obtained from seedlings formed in two containers under different levels of shading. For this purpose, the experiments were carried out at

**Corresponding author: E-mail: lucasrosapereira@hotmail.com;*

the Federal Institute of Espírito Santo, Alegre Campus, in field conditions. With the intention of assessing the vegetative and reproductive development of branches, various features of the plants were evaluated such as (i) the growth of the orthotropic branch, (ii) growth of plagiotropic branches, (iii) number of flowers revenged by plagiotropic branch, (iv) number of nodes, (v) number of fruits per node, (vi) number of fruits per branch, (vii) fruit aborted per branch, (viii) fresh fruit mass per branch, (ix) internodes, production, and (x) yield. Additionally, the estimation of the roots was carried out at four different depths: (a) 0-10 cm, (b) 10-20 cm, (c) 20-30 cm, and (d) 30-40 cm. Apart from root depths, the root surface area, diameter, and length were also analysed. In response to the above experiments, the irrigated plants exhibited a higher number of (1) nodes, (2) flowers set, (3) fruits per plagiotropic branch, and per node, in addition to, higher yield per plant. Also, a better distribution of the root system in the soil profile, with a higher root concentration in the 0-20 cm layer was found to occur due to irrigation. The total numbers of fine roots were found to be more superior in the case of irrigated plants than rainfed plants. On the other hand, shading used in seedling production was found to exhibit its effect only on the root diameter of irrigated plants. However, the type of container used in the seedling formation exerted no influence on the growth of branches and development of roots of conilon coffee.

Keywords: Coffea canephora; reproductive development; vegetative development; the root system.

1. INTRODUCTION

One of the most planted coffee species in the State of Espírito Santo in Brazil is the coffee conilon (Coffea canephora Pierre ex Froenher), whose average production is 25.1 bags benefited from 60 kg ha^{-1}. On the state level, production of 5.9 million bags in 2017 corresponded to 55.2 % of Brazilian conilon coffee [1].

Primarily, the cultivation of conilon coffee has expanded to areas where water deficiency acts as a crucial factor for their production. With an aim to improve the coffee yield in environments with water restriction, either breeder need to select genotypes that produce well in these environments [2,3], or irrigation technique should be adopted, as 58 % of the cultivated area of the State of Espírito Santo presents a high climatic risk regarding water supply required for flowering, granulation, and vegetative growth [4].

Several researchers upon studying the periodicity of the vegetative growth of conilon coffee [5,6,7], found it to be in association with various environmental factors, and among them, the supply of water and nutrients are vital factors. Further, Partelli et al. [8] observed that the low growth phase seems to depend on the minimum air temperature, as the active growth rate was witnessed when the average minimum air temperature was greater than 17°C and the average maximum temperature was lower than 31.5°C.

Moreover, to understand the performance of cultivated plants, evaluation of the root systems, regarding their structures and functions, is immensely important because, for optimal use of available resources, it must depict sizeable architecture along with significant development in volume. However, one needs to invest a lot of time and work for measuring length, volume, area, and root diameter. Furthermore, the root system of the coffee varies depending on (i) species, (ii) genotype, (iii) plant age, (iv) season, (v) crop density, (vi) biotic stresses, (vii) texture, and (viii) soil structure [9,10].

Further, to prevent erroneous estimation of the depth of the root system, which may lead to either underestimation or overestimation of the value of the irrigation blade, the root development studies are imperative [11]. Apart from this, the investigation of root development also plays a vital role in reducing the depth of penetration, affecting the root growth pattern, and stimulating the development of roots in the more superficial layers of the soil [12]. In this context, Ronchi et al. [10] reported that the maximum portion of the root system gets distributed in the topsoil. Additionally, Silva et al. [13], stated that the roots in this layer are highly essential for the extraction of water in coffee plants.

On the other hand, various species characteristics of the seedlings, such as root development, get affected by the type of containers, which in turn influences seedling growth and the percentage of field survival and productivity [14]. Indeed, larger vessels can impart several negative impacts such as (i) unnecessary laboratory costs, (ii) increased demand for substrates and transportation, (iii) engaging a larger area in the nursery, (iv) elevating production costs, (v) delaying the planting of seedlings in the field, due to the quality and quantity of the root system [15].

Additionally, the primary effect of the excess radiation that causes thermal stress is observed in the plants, regarding the destabilisation of membranes and proteins, along with several side effects such as photosynthetic inhibition, production of reactive oxygen species (ROS), thereby ultimately leading to cell death [16]. Further, to eliminate abovementioned repercussions of radiation on plants, investigation of the growth of coffee conilon under the different level of shading was carried out. From this perspective, Tatagiba et al. [17] upon analysing the young plants of conilon coffee, in the molting phase, under 88%, 22%, and 50 % of the shade, found that total accumulation of dry matter in plants kept below 88 % of the shade was highest with further plants under 22 % and 50 % of shading level following the sequence. On the contrary, the seedlings maintained in full sun registered the lowest values. Thus, it indicates that the adaptation of plants to the light environment depends on the setting of everyone's photosynthetic condition, which in turn allows efficient utilisation of the ambient light. Globally, the responses of this adaptation will be reflected, in the growth of the plant. Nevertheless, a very limited number of studies, until now, describe the association of seedlings produced under different levels of shade or in different containers, with characteristics of vegetative growth, reproductive and distribution of the root system of adult plants in the field.

The current work aims to evaluate the vegetative and reproductive growth, in addition to, the distribution of roots of both irrigated and non-irrigated plants obtained from seedlings formed in two containers under different levels of shading.

2. MATERIALS AND METHODS

In the present study, the experiments were carried out under field conditions at the Federal Institute of Education, Science and Technology of Espírito Santo (IFES), Alegre-ES Campus, Fazenda Caixa D'Água located at an altitude of 136.82 m. Geographically, the location is situated at 20º 25 '51, 61 "S latitudinally and 41 ° 27 '24.51" W longitudinally. Further, the average annual precipitation is found to be 1,250 mm, and the climate is classified as Aw by Köppen [18], having an average annual temperature of 26°C. Moreover, the species used for the study was Coffea canephora Pierre, variety "Robusta Tropical- EMCAPER 8151", seed propagation.

The experiment was set up in a sub-divided plots scheme, where 2 management (irrigated and non-irrigated), with the utilisation of 2 different containers (tube and bag) for the production of seedlings, under the different level of shadings such as 0 %, 30 %, 50 %, and 75 %, with three replicates were block designed completely in a random manner

The production of the coffee seedlings was carried out in polyethene tubes (120 mL) and plastic bags (770 mL), filled with standard substrates (70 % sieved earth + 30 % bovine manure + chemical fertilisers, such as simple superphosphate and potassium chloride) under different levels of shading (0 %, 30 %, 50 %, and 75 %). In the field, the seedlings were planted on December 13, 2007, with spacing 3.0 m x 1.1 m in a soil classified as Red-Yellow Oxisol, with chemical and physical characteristics of the soil described in Table 1.

With the desired productivity of 80 bags benefited per hectare, the chemical analysis of the soil acted as a decisive factor regarding the application of the fertilisers. In the irrigated plot, a total of 359 kg ha^{-1} of nitrogen, 88 kg ha^{-1} of phosphorus (as P2O5) and 323 kg ha^{-1} of potassium (as K2O), were applied. On the other hand, in the non-irrigated plot, 360 kg ha^{-1} of N and 308 kg ha^{-1} of the K2O were consumed. Further, three application were carried out; with first being in October/2008, second in December/2008, and third in February 2009. Additionally, cultural and phytosanitary treatments were performed as per the crop requirement [19].

The plantation of the seedlings in the field (04/13/2008), was followed by irrigation of all the plants for four months for ensuring their adhesion. Subsequently, a conventional sprinkler irrigation system was implemented only in the irrigated plot, consisting of two lateral lines, each with two sectoral sprinklers, spaced 18m apart, with a flow rate of 2.17 m^3 h^{-1}, whose Christiansen Uniformity Coefficient was 81 % and the mean blade was 13.68 mm. The adoption of this irrigation system was managed through the soil, with a fixed irrigation shift once a week.

Table 1. Chemical and physical soil attributes in the cultivated area with conilon coffee plants, produced in tubes and bags under different shading levels, in irrigated (I) and non-irrigated (NI) plot

Parameters	Depth (cm)			
	0 - 20		20 – 40	
	I	NI	I	NI
pH[a]	6.0	5.5	5.5	5.3
S[b] (mg dm^{-3})	16.0	23.0	3.0	20.0
P[c] (mg dm^{-3})	5.9	19.8	12.0	18.0
K[c] (mg dm^{-3})	51.0	65.0	48.0	93.0
Ca[d] ($cmol_c$ dm^{-3})	2.7	2.1	3.1	1.1
Mg[d] ($cmol_c$ dm^{-3})	1.0	0.8	0.7	0.6
Al[d] ($cmol_c$ dm^{-3})	0.0	0.2	0.1	0,2
H+Al[e] ($cmol_c$ dm^{-3})	4.0	6.1	2.3	3,2
Na[c] ($cmol_c$ dm^{-3})	-	-	3.0	4,0
MO[f] (g kg^{-1})	2.3	2.2	1.0	1,3
CEC[g] ($cmol_c$ dm^{-3})	7.8	9.2	6.2	5.41
SB[h] ($cmol_c$ dm^{-3})	3.8	3.1	3.85	2,.7
V[i] (%)	48.9	33.5	62.3	40.0
m[j] (%)	-	-	3.7	8.5
Fe[c] (mg dm^{-3})	31.0	35.0	27.0	57.0
Cu[c] (mg dm^{-3})	0.9	0.6	0.7	3.4
Zn[c] (mg dm^{-3})	3.6	2.9	1.6	10.2
Mn[c] (mg dm^{-3})	30.0	36.9	20.0	76.0
B (mg dm^{-3})	0.2	0.2	0.4	0.03
Ds (g cm^{-3})	1.73	1.75	1.63	1.84
Total sand (%)	53		48	
Silt(%)	6		7	
Clay (%)	41		45	

**Extraction methods: (i) pH: pH in water having ratio of 1: 2.5; (ii) sulfur: extracted monocalcium phosphate into acetic acid; (iii) phosphorus, potassium, sodium, zinc, copper, iron, and manganese: measured using Mehlich method 1; (iv) boron: extracted in hot water; (v) calcium, magnesium, and aluminum: KCl-1 mol/L; 9 vi) H + Al: extracted with calcium acetate at pH 7 [20]. For the quantification of MO, wet oxidation of organic matter using 0.167 mol/L of the $K_2Cr_2O_7$ in the sulfuric medium was carried out, followed by titration with ammoniacal ferrous sulfate [21]. Further, soil density, silt, sand, and clay were determined, according to [20]. Moreover, CEC stands for cation exchange capacity at pH 7.0; SB represents the sum of bases; V indicates base saturation index, and ds denotes the density of soil*

For calculating the irrigation blade (Li), required for elevating the soil moisture content (Ua) to the field capacity of 23.8 %, the method described by Sousa et al. [22], was employed, where the effective depth value of the root system was 35 cm, and the soil density was 1.68 g cm^{-3}. On the other hand, the direct method illustrated by Mantovani, Bernardo, and Palaretti [23], was utilised for the determination of soil moisture from samples collected in the projection of the crown with a minimum weight of 40g, in six replicates, being subjected to drying in an electric oven at a temperature that falls in the range of 180-200°C.

Likewise, the precipitation was measured using pluviometer installed in the experimental area, in daily measurements performed at 9 o'clock, with the measurement of maximum and minimum temperature being carried out on a digital thermometer E 7427 (CALARM).

Establishing eight seasons, from August 2010 to April 2011, the vegetative and reproductive growth was evaluated every 30 days, by selecting the central plant of each experimental plot. In this central region, the length of the orthotropic branch having a larger diameter was measured, with the aid of a graduated ruler. Shortly, the longest plagiotropic branch of this branch was identified, which was subsequently measured using a flexible metallic wire. In December 2010, the number of flowers set present on the plagiotropic branch was counted.

Finally, in April 2011, the removal of plagiotropic branches from the plants was carried out, followed by subsequent counting of the number of nodes, the number of fruits per node, and the number of fruits per branch. Further, for determination of the fresh mass of the fruits per branch, a digital scale was employed. The calculation of the ratio between the length and number of nodes of the plagiotropic branch established the internodes measurement, and the number of fruits aborted was evaluated, from the difference of the total of flowers set and the number of fruits per branch.

The production was estimated, from the individual harvest by weighing and obtaining the amount of harvest per plant. From the total harvest collected in the experimental plot, a sample of 2 kg of freshly harvested coffee was subjected for drying, up to ± 12 % moisture, in a suspended yard. Subsequently, the sample of coconut coffee was benefited and weighed, thereby transforming the data obtained from the benefited coffee per plant, into kg. Further, the yield was obtained, by calculating the ratio of kilograms of freshly harvested coffee per kilogram of benefited coffee.

Moreover, the evaluation of the root system was carried out only once (12/13/2010), followed by the collection of soil sample having a volume of 27 cm^3. In each irrigated and non-irrigated plot, twenty-four experimental units were sampled where 55 cm from the trunk of the central plant of the plot was removed using Dutch auger, in the direction of the line at four different depths such as 0-10 cm, 10- 20 cm, 20-30 cm, and 30-40 cm. The samples obtained were stored in plastic bags and kept in a cold room. After being separated from the soil, the roots were dried using an absorbent paper. Further, the samples to be washed were conditioned, in previously identified transparent cups, with washing being carried out under running water using a 30 mesh sieve. The washing step followed digitisation of the roots in a scanner (30 x 21 x 0.2 cm). The images obtained were subjected to SAFIRA version 1.1 [24], for quantification of the length, surface area, and root diameter, according to Partelli et al. [25]. For analysis, roots smaller than 1 mm in diameter were used, with estimation of data in dm^3 of soil. Further, obtained results determined the percentage distribution of roots at different depths.

The experimental data were studied using analysis of variance (ANOVA) technique, under normality and homoscedastic conditions, and the means of the container were compared by the Tukey test, at a probability of 5 %, followed by the analysis of the levels of shading with regression method, using SAEG.

3. RESULTS AND DISCUSSION

In both the management, the analysis of the variance of the stretching of the orthotropic and plagiotropic branches did not exhibit any significant effect of the container, employed for the formation of the seedlings, on the growth of branches of the conilon coffee. Further, in the estimation of the growth curve of the branches, no mathematical model was fitted for the quantitative factors, shade and time. Therefore, in both irrigated and non-irrigated management, the elongation of the branches can be represented by the mean values (see Fig. 1).

In the current investigation, a similarity in the growth responses of irrigated and non-irrigated plants (see Fig. 1), was observed with the elongation of the branches following precipitation and temperature curves (see Fig. 2). Moreover, regions of high altitude illustrated intense growth phase in spring/summer associated with longer and warmer days, and subsequently coinciding with the commencement of the rainy season. Alternatively, autumn/winter season characterised by the dry and cold period, in addition to, shorter days demonstrated lower vegetative growth rates [26].

The temperature feasible for the active growth of the plants coincided with minimum and maximum temperatures of 17.5ºC and 32ºC, respectively, thereby illuminating that the average temperatures in the range of 22.5ºC- 26.2ºC, in addition to, the season of greater precipitation, to be more suitable for the growth. Additionally, the highest pluviometric indexes occurred from October to December months, while August and September months exhibited minimum values. The observation of the decrease in growth intensity, between December and February months, can be explained by the presence of higher average temperature (30.3 °C) during this period, which far exceeds the average values falling in the range of 22 °C-26 °C, considered by Rena and Maestri [26] as being the temperature range suitable for the vegetative development of conilon coffee. According to Amaral et al. [6], decreases in the intensity of growth during January and February is attributable to the fast filling of the grains, and the fruits being the strongest grain allows less coffee formation in this phase.

In irrigated plants, the minimal stretching of the branches occurs in the September month, in addition to, the months from December to April.

However, the maximum growth rate of 2.38 and 1.55 mm day-¹ in orthotropic and plagiotropic branches, respectively, occurred in October. Similarly, the occurrence of maximum growth (3.3 mm day-¹) in coffee conilon of the irrigated plot in October month was also observed by Silveira [27]. Thus, these results are in agreement with the observations described by Libardi et al. [5], Partelli et al. [8]; Dalcomo et al. [7], thereby indicating that in the State of Espírito Santo, the growth phase for the coffee conilon commences in September with the occurrence of maximum growth rate of the branches in the warmer months.

On the other hand, a huge variation in the growth of non-irrigated plants was observed throughout the year, with the lowest growth being in September, increased with the onset of rainfall and reached maximum values in November, being 3.58 and 2.3 mm day^{-1} in orthotropic and plagiotropic branches, respectively; reduced in

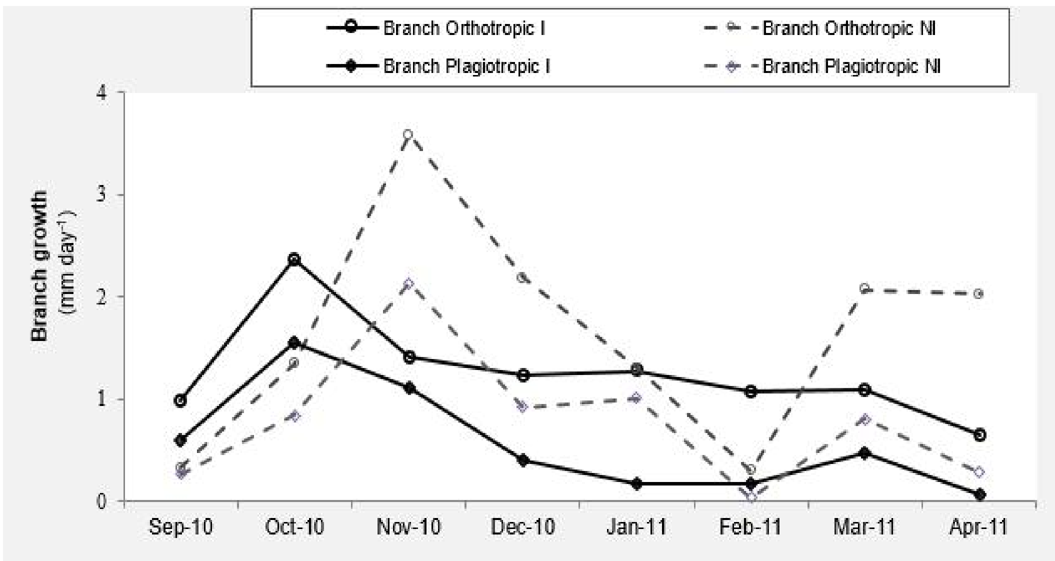

Fig. 1. The growth of the orthotropic and plagiotropic branches of conilon coffee plants in irrigated (I) and non-irrigated (NI) plots, from September 2010 to April 2011

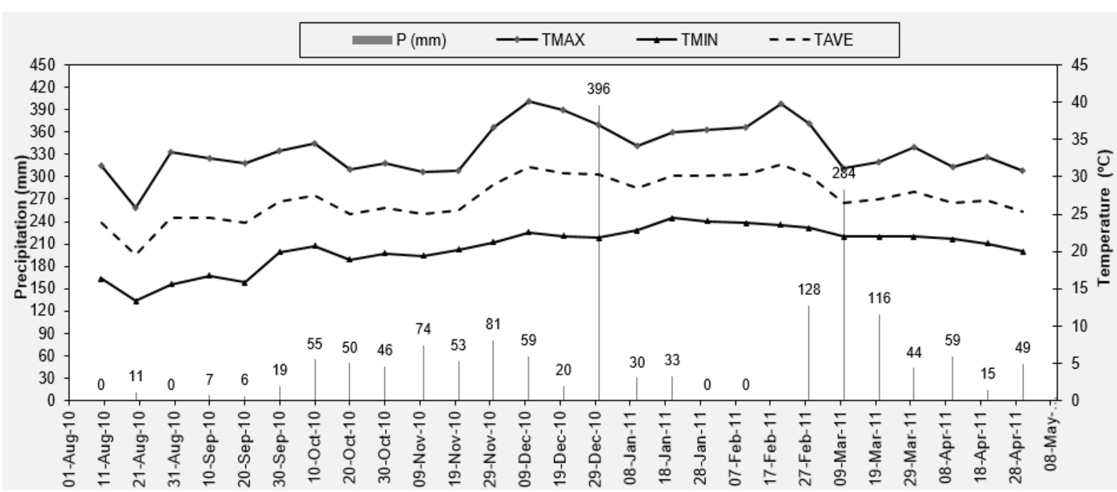

Fig. 2. The figure depicts the averages of maximum temperature, along with average and minimum air temperature and precipitation, which occurred from August 2010 to April 2011

December with minimum values reaching in February; followed by an increase in March due to high rainfall with ultimately returning to declining values in April. Although the duration of growth in the irrigated plant was observed to be higher, the rainfed plants showed maximum rates of branch stretching (see Fig. 1).

Statistically, upon comparing the reproductive growth variables, the length of the plagiotropic branches of irrigated and non-irrigated plants found to be the same. In all the other evaluated characteristics, the values obtained in irrigated plants surpasses non-irrigated plants, such as less number of aborted fruits and internodes, which in turn leads to higher fresh fruit mass, thereby resulting in higher coffee yield and irrigated plant yield (see Table 2). Thus, one can infer that irrigation provided higher growth of the conilon coffee, leading to higher productivity because according to Rena and Damatta [28], conilon coffee production occurs in the branches developed in the current year, being completely valid in the present case as there exists a direct relationship between development, productivity, and vegetative growth.

Further, Vilella and Faria observed a significant increase in plant height, stem diameter, crown diameter, number of internodes, length of primary branches, and yield of irrigated arabica coffee [29]. Likewise, Carvalho et al. [30], Gomes, Lima, and Custódio [31], reported an increase in these growth characteristics while carrying out studies in coffee plants irrigated with growing water replenishing slides. Additionally, Carvalho et al. [32] upon evaluating the early stages of development in different environmental conditions deduced a positive correlation between production and growth characteristics, except for the number of nodes.

On the contrary, the root system of the conilon coffee exhibited a significant effect associated with the container concerning (i) root diameter of irrigated plants, (ii) surface area of non-irrigated plants, (iii) for shade levels in surface area and diameter of irrigated plants, (iv) in-depth for surface area and root length, in both managements, less for the diameter. Therefore, significant interaction occurs between shade and container only in the case of irrigated plant diameter. However, as indicated by Table 3, the triple interaction between the factors was not observed.

Upon evaluation of the influence of shade levels and containers, employed for the formation of seedling, on conilon root development, the surface area and length exhibited no significant effect on these variables (see Fig. 3). However, statistical differences, at 0 % and 75 % of shading levels, were observed between containers only for root diameter of irrigated plants (see Fig. 3E). Further, the tubers showed a linear growth curve, whereas no model was adjusted, for the bags, in the estimation of root growth, being represented by the mean values (see Figs. 3G and 3H). A similar phenomenon occurred for surface area and root length in irrigated and non-irrigated plants (see Figs. 3A to 3D).

On the contrary, Rena [33] observed poorly formed along with stunted roots in the clonal seedlings of the conilon coffee maintained for long periods in tubes, leading to its limited use with no further recommendations by the extensionists of the State of Espírito Santo. Additionally, Amaral et al. [6] found that the formation of seedlings initially in tubes, for a period less than 60 days, does not affect the vegetative growth, nor the productivity of conilon coffee. Thus, confirming that under the conditions of this study, in general, the type of container and shading level did not influence the development of conilon coffee roots in both managements.

The containers (tubes and bags), demonstrated no significant differences regarding depth in the root system analysis carried out for conilon coffee plants. Additionally, no mathematical model was adjusted to express root growth regarding surface area and length. Further, the total number of fine roots of irrigated plants surpasses in 32.4 % of the surface area and 39.4% of the length obtained in non-irrigated plants (see Figures 4A and 4B). According to Sakai et al. [34], in comparison to non-irrigated arabica coffee plants, irrigated plants showed greater rooting in the soil profile, which implies that rainfed plants have higher mean values for the root diameter (see Fig. 4C). However, Soares et al. [35] outlined that the content and location of soil water are capable of altering the overall plan of root development, as well as plant age, fruit load, planting density, climate, pests and diseases, pruning, cropping methods, soil type, and fertility.

Table 2. Length of the plagiotropic branch (CP), number of nodes of the plagiotropic branch (NOS), number of flowers set per branch (FLV), number of fruits per branch (FR), number of fruits aborted per branch (FA), number of fruits per node (FNÓ), internode (IN), fresh fruit matter (MFF), production (PROD), and yield (REND) of coffee conilon in irrigated and non-irrigated plots

Management	CP	NOS	FLV	FR	FA	FNÓ	IN	MFF	PROD*	REND**
	(cm)			Nº			(cm)	(g)	(kgCR pl-¹)	(kgCR : kgCB)
Irrigated	74.8 A	14.7 A	177.5 A	154.3 A	25.1 B	10.5 A	5.1 B	109.8 A	6.7 A	4.4: 1
Non-irrigated	69.6 A	11.4 B	122.1 B	74.1 B	47.8 A	6.5 B	6.1 A	37.8 B	2.1 B	10.8:1
CV (%)	13.95	20.35	43.69	49.53	53.76	38.21	32.63	47.29	32.38	-

Means followed by the same letter in the column, do not differ by the Tukey test at the 5% probability level PROD (kgCR pl-¹): kg of coffee crop per plant; REND ** (kgCR: kgCB): kg of coffee per kg of coffee benefited*

Table 3. Comparison of the analysis of variance for the surface area variable, length, and diameter of fine roots of irrigated and non-irrigated conilon coffee plants.

Variation source	GL	Mean Square					
		Superficial Area		Lenght		Diameter	
		Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated
Block	2	33978.19^{ns}	2986.784**	42.568^{ns}	5.690^{ns}	0.005*	0.004^{ns}
Container	1	35583.01^{ns}	320.865**	15.278^{ns}	6.922^{ns}	0.037**	0.027^{ns}
Error (A)	2	131131.6	18.36034	277.1237	3.414187	0.001174	0.009747
Shadow	3	247128.3**	28249.84^{ns}	293.793^{ns}	32.131^{ns}	0.0453**	0.0109^{ns}
Shadow x Container	3	14919.36^{ns}	26503.86^{ns}	7.182^{ns}	44.508^{ns}	0.0303*	0.0061^{ns}
Error (B)	12	43558.72	26929.41	113.9093	41.84474	0.0086884	0.013307
Depth	3	541257.6**	447754.8**	859.255**	722.680**	0.007^{ns}	0.0189^{ns}
Depth x Container	3	33323.37^{ns}	13960.12^{ns}	13.504^{ns}	32.270^{ns}	0.009^{ns}	0.0107^{ns}
Depth x Shadow	9	19934.98^{ns}	14556.85^{ns}	23.077^{ns}	17.606^{ns}	0.003^{ns}	0.0100^{ns}
Depth x Container x Shadow	9	37980.02^{ns}	4922.28^{ns}	60.121^{ns}	6.867^{ns}	0.003^{ns}	0.0142^{ns}
Residue	48	23980.48	9062.537	31.22042	13.34174	0.00424009	0.009551
General Mean	-	254.27	192.08	10.96	7.86	0.485	0.536
CV (%)	-	60.90	49.56	50.99	46.25	13.44	18.24

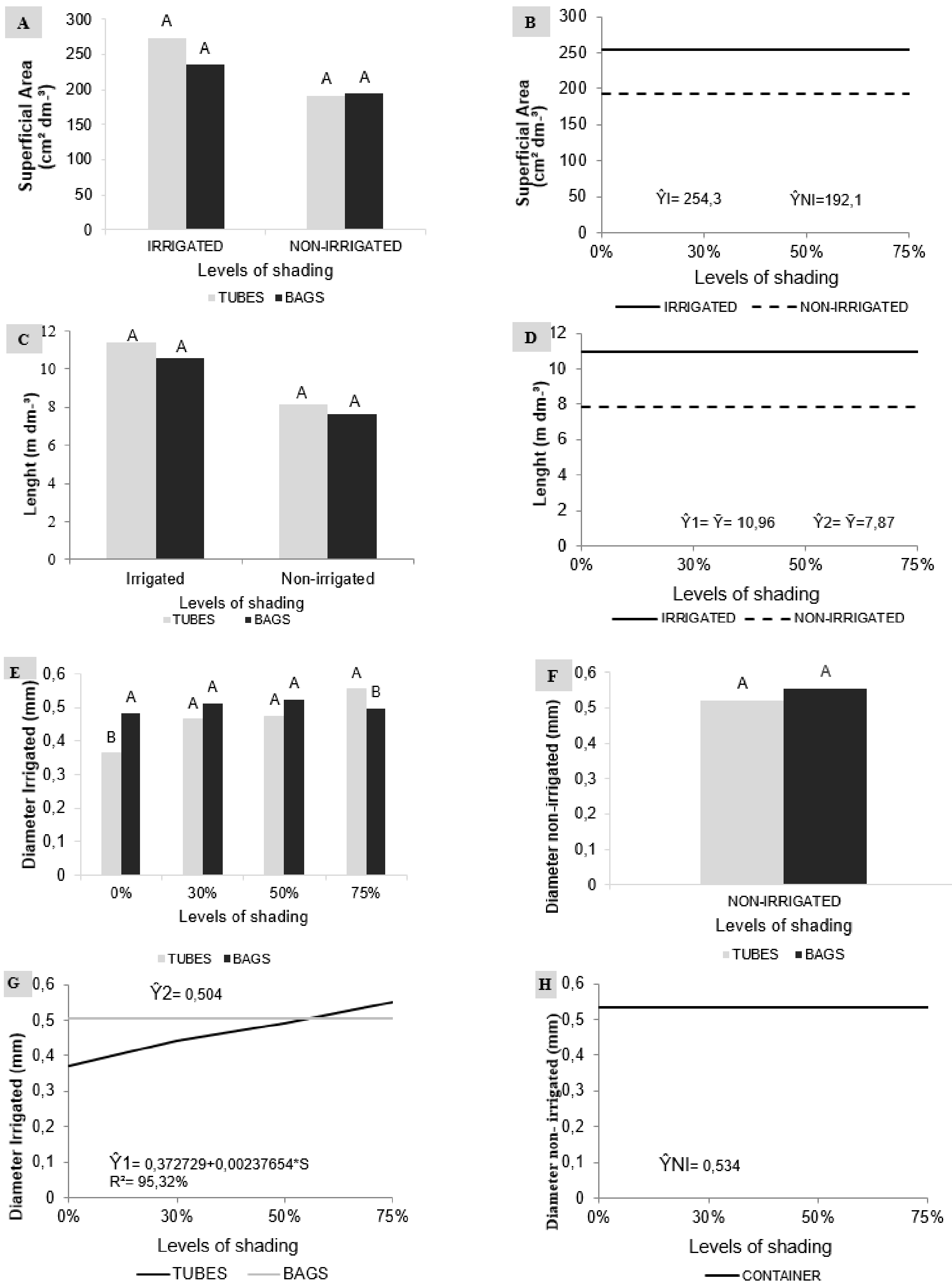

Fig. 3. Surface area, length, and diameter of roots of conilon coffee plants under irrigated and non-irrigated conditions, derived from seedlings formed in tubes and bags at different levels of shading

Means followed by the same letter in the line, do not differ by Tukey test at the 5% probability level

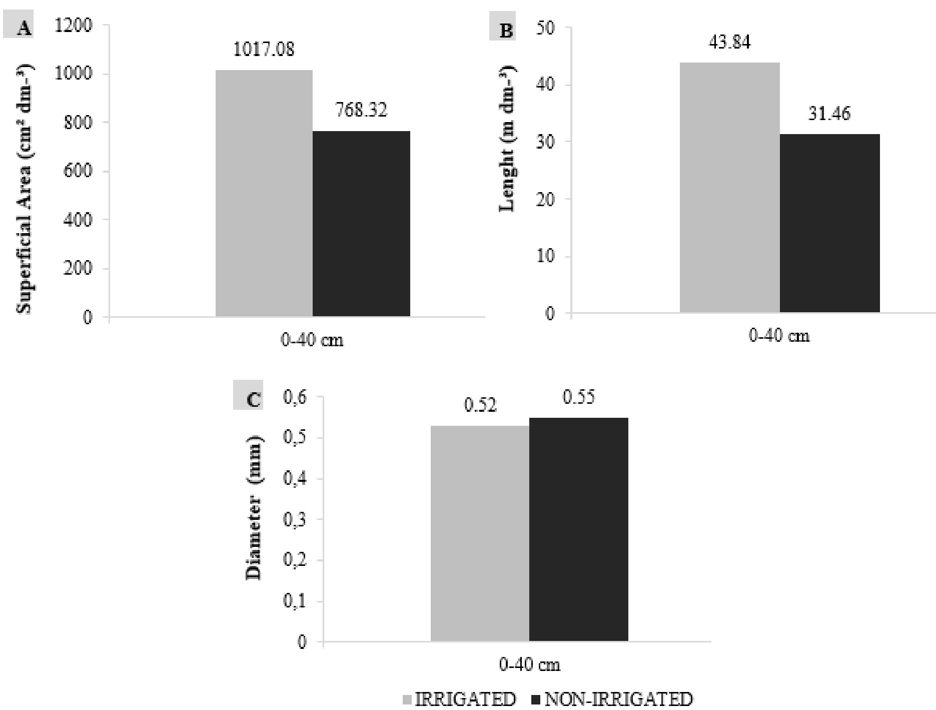

Fig. 4. Total surface area, length, mean diameter of fine roots of irrigated and non-irrigated conilon plants, in the 0-40 cm depth profile

In case of irrigated plants, approximately 47% of the roots reach a depth of 0-10 cm, with more than 65% of roots at 0-20 cm, and about 35% of roots at 20-40 cm of depth. In contrast, about 51% of the roots of the non-irrigated plants were found to reach the 0-10 cm layer, with more than 70% in the 0-20 cm layer, and only 30% in the 20-40 cm deep layer (see Table 4). Further, by evaluating the distribution of the root system of the coffee conilon variety Emcapa 8111, Covre et al. [36] confirmed that about 47 % and 32 % of the roots of irrigated plants were found at depths of 0-20 and 20-40 cm, respectively, while in case of non-irrigated plants, 55 % and 27 % of the roots reaches 0-20 and 20-40 cm deep layer, respectively. Predominantly, one can expound the difference in the distribution of the root system between the two research by elucidating that the root system of the plants used by the authors was evaluated 66 months after transplanting, with the evaluation being carried out up to 60 cm deep layer, while in the present investigation the roots were evaluated 36 months after transplanting. Recently, Souza et al. [37] found the wet bulb along with the depletion of the root system of conilon coffee under localised irrigation, which in turn verifies the concentration of 68% of the surface area up to the depth of 30 cm.

Partelli et al. [9] also confirmed a better root distribution of non-irrigated conilon coffee plants (Coffea canephora), with higher values of surface area and length in the upper layers, which decreases with increase in the depth. The increase in soil density, as well as the decrease in fertility in the 20-40 cm layer (see Table 1), can further explain the reduction in growth with an increase in depth. In this context, Santinato, Fernandes, and Fernandes [38] outlined that the soil density above 1,5 g cm^{-3} affects the root system of the coffee especially the radicals. However, the presence of toxic aluminium contents (Al3+) in the subsurface layers, in addition to the physical impairment, may also cause a reduction in the deepening of the conilon coffee root system. Hence, there is a strong possibility of its root system to be superficial in several regions of its cultivation [39].

Upon evaluating the irrigated young crops (27 to 39 months after transplanting), Ronchi et al. [10] found that their root system displays full growth in the deeper layers (40 cm). Further, it was validated in the current work, as the examination of the root system was carried out after 36 months, with no pruning of the orthotropic branches of the crop until this period.

Table 4. Average roots percentage of irrigated (I) and non-irrigated (NI) plants of conilon coffee, for surface area and length, at four depths

Depth (cm)	Superficial area (%)		Length (%)	
	I	NI	I	NI
0 – 10	47.14	51.43	45.37	50.92
10 - 20	18.06	19.29	20.12	19.68
20 - 30	17.55	15.74	17.65	15.22
30 - 40	17.25	13.54	16.86	14.18
Total (0 – 20)	65.20	70.72	65.49	70.60
Total (20 – 40)	34.80	29.28	34.51	29.40

Means followed by the same letter in the column, do not differ by the Tukey test at the 5% probability level

4. CONCLUSIONS

Conclusively, the growth of the branches was in agreement with the precipitation and temperature curves. Further, the irrigated plants demonstrated higher nodes, flowers set, fruits per plagiotropic branch and per node, in addition to, higher yield per plant and production. The better values of all the parameters in the irrigated plants indicate that a better distribution of the root system in the soil profile is facilitated by irrigation, thereby leading to higher root concentration in the 0-20 cm layer. Additionally, in comparison to non-irrigated plants, the total numbers of fine roots were higher in irrigated plants. Upon evaluating the effect of shading levels in the formation of seedlings, the only root diameter of irrigated plants was found to experience its impact. On the other hand, the type of container employed for the seedling formation did not impart any effect on the growth of branches and development of roots of conilon coffee.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Companhia Nacional de Abastecimento – CONAB. Acompanhamento da safra brasileira de café: V. 5 - Safra 2018, N.1 - Primeiro Levantamento. 2018;1-73. Portuguese.
2. Silva VA, Antunes WC, Guimarães BLS, Paiva RMC, Silva VF, Ferrã MAG, Damatta FM, Loureiro ME. Resposta fisiológica de clone de café Conilon sensitivity to deficiencies in a cortex of the port-enxerto tolerant. Pesquisa Agropecuária Brasileira. 2010;45(5):457-464. Portuguese.
3. Partelli FL, Marré, WB, Falqueto AR, Vieira HD, Cavatti PC. Seasonal vegetative growth in genotypes of *Coffea canephora*, as related to climatic factors. Journal of Agricultural Science. 2013;5(8):108‑116.
4. Pezzopane JRM, Castro FS, Pezzopane JEM, Bonomo R, Saraiva GS. Zoneamento de risco climático para a cultura do café Conilon no Estado do Espírito Santo. Revista Ciência Agronômica. 2010;41(3): 341-348. Portuguese.
5. Libardi VCM, Amaral JAT, Amaral JFT. Crescimento vegetativo sazonal do cafeeiro (Coffea canephora Pierre var. Conilon) no sul do estado do Espírito Santo. Revista Brasileira de Agrometeorologia. 1998;6(1):23-28. Portuguese.
6. Amaral JAT, Lopes JC, Amaral JFT, Saraiva SH, Junior WCJ. Crescimento vegetativo e produtividade de cafeeiros conilon propagados por estacas emulsi. Ciência e Agrotecnologia. 2007;31(6): 1624-1629. Portuguese.
7. Dalcolmo, JM, Vieira HD, Ferreira A, Partelli FL. Growth comparison of 22 genotypes of conilon coffee after regular pruning cycle. African Journal of Agricultural. 2017;12(1): 63-70.
8. Partelli FL, Vieira HD, Silva MG, Ramalho JC. Seasonal vegetative growth of different age branches of conilon coffee tree. Ciências Agrárias. 2010;31(3):619-626.
9. Partelli FL, Covre AM, Oliveira MG, Alexandre RS, Vitória EL, Silva MB. Root system distribution and yield of 'Conilon' coffee propagated by seeds or cuttings. Pesquisa Agropecuária Brasileira. 2014;49(5):349‑355.
10. Ronchi CP, Sousa Júnior JM, Ameida WL, Souza DS, Silva NO, Oliveira LB, Guerra AMN de M, Ferreira PA. Morfologia radicular de cultivar de café arábica submetidas a diferentes arranjos

espaciais. Pesquisa Agropecuária Brasileira. 2015;50(3):187-195. Portuguese.

11. França Junior AC. Análise de métodos simplificados de estimativa da ETo e da sensibilidade das variáveis do cálculo da lâmina de irrigação para a cultura do café. 2003, 87p. Dissertação (Mestre em Engenharia Agrícola), Universidade Federal de Viçosa, Viçosa; 2003. Portuguese.
12. Ronchi CP, Damatta FM. Aspectos fisiológicos do café Conilon In: Ferrão RG, Fonseca AFA da, Bragança SM, Ferrão MAG, De Muner LH (eds.) Café Conilon Vitória: Incaper: 2007;95-119. Portuguese.
13. Silva AL, Bruno IP, Reichardt K, Bacchi OOS, Dourado-Neto D, Favarin JL, Costa FMP, Timm LC. Soil water extraction by roots and Kc for the coffee crop. Revista Brasileira de Engenharia Agrícola e Ambiental. 2009;13(3):257-261.
14. Vallone HS, Guimarães RJ, Mendes ANG, Souza CAS, Cunha RL, Dias FP. Diferentes recipientes e substratos na produção de mudas de cafeeiros. Ciência e Agrotecnologia. 2010;34(1):55-60. Portuguese.
15. Dias R, Melo B. Proporção de material orgânico no substrato artificial para a produção de mudas de cafeeiro em tubetes. Ciência e Agrotecnologia. 2009;33(1):144-152. Portuguese.
16. Taiz L, Zeiger E. Fisiologia vegetal. 2013;4:848.
17. Tatagiba SD, Santos EA, Pezzopane JEM, Reis EF. Mudas de C*offea canéfora* cultivadas sombreadas e a pleno sol. Engenharia na Agricultura. 2010;18(3): 219-226. Portuguese.
18. Koppen W. Climatologia: Con un estúdio de los climas de la tierra. México: Fondo de cultura econômica; 1948. Spanish.
19. Ferrão RG, Fonseca AFA, Bragança SM, Ferrão MAG, De Muner LH (eds). Café conilon Vitória: Incaper, 2007. Portuguese.
20. Embrapa. Centro Nacional de Pesquisa de Solos. Manual de métodos de análise de solo. Brasília: Embrapa. 1997;212. Portuguese
21. Yeomans JC, Bremner JMA. Rapid and precise method for routine determination of carbon in soil. Soil Science. 1988;19(1): 1467-1476.
22. Sousa MBA, Mantovani EC, Souza LO, Buffon VB, Bonomo R. Avaliação de irrigação em propriedades de café conilon no norte do Espírito Santo. In: Irrigação do cafeeiro: informações técnicas e coletâneas de trabalhos. Associação dos Engenheiros Agrícolas de Minas Gerais. 2003;87-91. Portuguese.
23. Mantovani EC, Bernardo S, Palaretti LF. Irrigação: princípios e métodos. 3th ed. Viçosa: Editora da UFV. 2009. Portuguese.
24. Jorge LAC, Silva DJCB, Rodrigues AFO. SAFIRA: software para análises de fibras e raízes. Embrapa Instrumentação / MAPA, São Carlos, SP; 2010. Portuguese.
25. Partelli FL, Vieira HD, Santiago AR, Barroso DG. Produção e desenvolvimento radicular de plantas de café 'Conilon' propagadas por sementes e por estacas. Pesquisa Agropecuária Brasileira. 2006;41(6):949-954. Portuguese.
26. Rena AB, Maestri M. Fisiologia do Cafeeiro. In: Rena, AB, Malavolta E, Rocha M, Yamada T. (ed.). Cultura do cafeeiro*:* fatores que afetam a produtividade. Piracicaba: PATAFOS, 1986;13-85. Portuguese.
27. Silveira JSM. Irrigação em café: café conilon irrigado no Espírito Santo. In: Simpósio Estadual de Café, 2, 1996, Vitória, ES. Anais... Vitória: Cetcaf. 1996; 66-83. Portuguese.
28. Rena AB, Damatta FM. O sistema radicular do cafeeiro: morfologia e ecofisiologia. In: Zambolim L. (ed.). O estado da arte de tecnologias na produção de café. Viçosa: UFV. 2002;11-92. Portuguese.
29. Vilella WMC, Faria MA. Crescimento de cafeeiros submetidos a cinco lâminas de irrigação e três parcelamentos de adubação. Revista Irriga. 2003;8:168-177. Portuguese.
30. Carvalho CHM, Colombo A, Scalco MS, Morais AR. Evolução do crescimento do cafeeiro (*Coffea arabica* L.) irrigado e não irrigado em duas densidades de plantio. Ciência e Agrotecnologia. 2006;30(2): 243-250. Portuguese.
31. Gomes NM, Lima LA, Custódio AP. Crescimento vegetativo e produtividade do cafeeiro irrigado no Sul do Estado de Minas Gerais. Revista Brasileira de Engenharia Agrícola e Ambiental. 2007; 11(2):564-570. Portuguese.
32. Carvalho AM, Mendes ANG, Carvalho GR, Botelho CE, Gonçalves FMA, Ferreira AD. Correlação entre crescimento e produtividade de cultivares de café em diferentes regiões de Minas Gerais, Brasil.

Pesquisa Agropecuária Brasileira. 2010; 45(3):269-275. Portuguese.
33. Rena AB. A água na fisologia do cafeeiro In: Simpósio Estadual do Café 1998, Vitória, ES. Anais ... Vitória: Cetcaf. 1998;132-152. Portuguese.
34. Sakai E, Barbosa EAA, Silveira JMC, Pires RCM. Coffee productivity and root systems in cultivation schemes with different population arrangements and with and without drip irrigation. Agricultural Water Management. 2015;148(1):16‐23.
35. Soares AR, Mantovani EC, Soares AA, Batista RO, Coelho MB, Rena AB. Produção e distribuição de raízes em cafeeiros irrigados por gotejamento. Engenharia na Agricultura. 2007;15(2): 130-140. Portuguese.
36. Covre AM, Partelli FL, Gontijo I, Zucoloto, M. Distribuição do sistema radicular de cafeeiro conilon irrigado e não irrigado. Pesquisa Agropecuária Brasileira. 2015;50(11):1006-1016. Portuguese.
37. Souza JM, Reis EF, Bonomo R, Garcia GO. Wet bulb and Conilon Coffee root distribution under drip irrigation. Ciência e Agrotecnologia. 2018;42(1):93-103.
38. Santinato R, Fernandes ALT, Fernandes DR. Irrigação na cultura do café. 2 ed Belo Horizonte: O Lutador 2008;476. Portuguese.
39. Guarçoni AM, Prezotti LC. Fertilização do café conilon. In: Zambolim, L. (ed). Tecnologias para produção do café Conilon. Viçosa: UFV. 2009;249-294. Portuguese.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/26980