Morphology of the coffee root system using polyethylene film[1]

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ABSTRACT

In the initial phase of the coffee crop, the control of weeds and water availability for the establishment of the plants is a concern. The polyethylene cover can positively influence the chemical and biological characteristics of the soil and, consequently, the root system. The objective of this work was to evaluate the morphology of the root system of coffee plants using polyethylene mulching of different widths and colors. Coffee was planted in December 2016 using the cultivar Topázio MG-1190. A randomized repetitions design was used, with four blocks and five treatments, as follows: 1.20-m wide white/black mulching, 1.40-m white/black mulching, 1.20-m silver/black mulching, 1.40-m silver /black mulching, and no mulching. Total root dry matter per soil volume, total root length per soil volume, total root volume per soil volume, total root area per soil volume, specific root surface, specific root length, and mean root diameter were all evaluated. Roots with smaller diameters were concentrated in the 0-0.20 m depth layer, while in the 0.20-0.40 m depth layer, roots with larger diameters were found. Plants grown in 1.20-m silver/black mulching showed a greater surface area and a specific length of the roots.

Keywords: *Coffea arabica*; polyethylene mulching; root growth.

INTRODUCTION

Coffee growth and yield are related to the balance between the aerial part and root system (Gómez-González *et al.*, 2018). In several coffee-producing countries, water deficit is the major environmental stress responsible for reducing plant production and development (Covre *et al.*, 2015). The main physiological mechanisms of plant tolerance for water deficit are the efficiency of soil water uptake and stomatal control (Marraccini *et al.*, 2012; Silva *et al.*, 2013).

The development of the coffee root system is related to several factors, including water availability, soil fertility, resistance to soil penetration, and physical and chemical properties of the soil. In this context, as mulching influences soil properties, it may provide a better spatial distribution of coffee roots, providing better conditions for water and nutrient absorption, which may reflect increases in crop productivity.

The traffic of machines and implements in the last decades has resulted in the modification of the physical attributes of the soil, such as a reduction in the availability of water and air and an increment in soil resistance, impairing the exploration by the roots of plants in depth (Silva *et al.*, 2017). In addition, rainwater infiltration is reduced, increasing surface runoff and limiting the development of the root system of the plant, causing a reduction in growth and productivity (Sartor *et al.*, 2020).

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Mulching is commonly used in the implantation of crops such as strawberries, tomatoes, and lettuce, among others. It rises soil temperature, maintains moisture, and controls weeds. The use of this technology will result in the reduction of soil temperature fluctuation at a 0.20-0.30 m depth, promoting better root development and also reducing fertilizer leaching and soil compaction (Jayalalitha *et al.*, 2020), in addition to increasing the availability of nutrients and providing protection against injuries caused by frost (Pandey *et al*., 2015).

For the coffee crop, experiments conducted in the Cerrado Mineiro region show a 96% increase in productivity in the first harvest with the use of mulching compared to the absence of plastic cover. There was also an increase of 8.7% in height, 9.7% in stem diameter, and 15.6% in crown diameter, in non-irrigated cultivation (Nascimento *et al.*, 2020).

A wide variety of soil cover can be found in the Brazilian market. The black/black film is recommended for regions with a mild climate as it provides a rise by 3 °C in soil temperature; the white/black double-faced polyethylene is indicated for tropical climate regions, as it has good reflectivity, therefore it reduces the temperature at the soil surface (Yuri *et al.*, 2012). The silver/black double-faced polyethylene is indicated for hot regions, as it reflects most of the sun's rays, conveying little energy to the ground (Yuri *et al.*, 2014).

One of the major obstacles in coffee growing, especially in the crop formation phase, is the control of weeds and the availability of water, responsible for providing the establishment of seedlings and the entire initial development of the plant. In order to promote adequate root development, the use of polyethylene mulching can be an alternative to improve the chemical and biological properties of the soil.

MATERIAL AND METHODS

The experiment was conducted at the Federal University of Uberlândia, Monte Carmelo campus (south latitude 18º43'28", west longitude 47º31'27", and altitude of 907 m). The study site belongs to the Alto Paranaíba region in the state of Minas Gerais. The soil in the experimental area is classified as a dystrophic Red Latosol, with a clayey texture.

The crop was planted using the cultivar Topázio MG-1190 in December 2016, using a spacing of 3.5 m between rows and 0.6 m between plants. The experimental design used was in randomized repetitions, with four repetitions and five treatments, as follows: 1: 1.20-m wide double-sided white/black mulching; 2: 1.40-m wide white/black mulching; 3: 1.20-m wide silver/black mulching; 4: 1.40-m wide silver/black mulching and 5: no mulching. Each plot consisted of 10 plants, considering the eight plants as useful. The experimental area had 250 plants.

Over the entire evaluation period of the experiment, soil samples were collected at a 0-0.20 m depth for chemical analysis and subsequent fertilization recommendation. The analyses were carried out in November 2016, corresponding to the implementation of the crop, in September 2017 corresponding to the first year after planting, September 2018 corresponding to the second year after planting, and in September 2019 referring to the third year after planting is found in Table 1.

Fertilization was performed according to the chemical analysis of the soil sampled in the 0-0.20 m layer, following the recommendations of Guimarães *et al.* (1999). At the implantation, applications of 371 g pit^{-1} of phosphate fertilizer containing 17.5% P_2O_5 were made. In addition, 805 g was used per linear meter of fertilizer containing 8% K_2O and 25% Si and 5 L linear m^{-1} of organic compost of bovine origin. For nitrogen, an application of 30 g of controlled-release fertilizer containing 37% of N was applied in topdressing, 30 days after seedling planting.

In the first year after planting, the recommendations for nitrogen and potassium fertilization were 34 g $plant^{-1}$ of the 30-00-11 ($N-P_2O_5-K_2O$) + 0.27% of B formulated, in which four applications were carried out from November 2017 to February 2018. Phosphate fertilization was not used because of the high content of this nutrient in the soil. Concerning micronutrients, the recommendation was 3 kg ha^{-1} of B due to its low content in the soil, being supplied with the formulated described above and the remainder with boric acid (17% of B). Liming was not necessary as the pH of the soil was 6.0 and base saturation was 70%, fitting into levels considered satisfactory for the coffee crop.

In the second year after planting, the recommendations for nitrogen and potassium fertilization were 50 g $plant^{-1}$ of the formulated 30-00-11 ($N-P_2O_5-K_2O$) + 0.27% of B and 16 g $plant^{-1}$ of 39-00-00 ($N-P_2O_5-K_2O$), with three applications being carried out from November 2018 to January 2019, and 19 g $plant^{-1}$ of KCl (60% K2O), carried out in November and December 2018. The recommendation for phosphate fertilization was 24 g $plant^{-1}$ of simple superphosphate (18% of P_2O_5) being carried out in a single application in November 2018. Regarding micronutrients,

Table 1: Soil chemical characterization in the 0-0.20 m depth layer in the experimental area in the 2016-2019 period

Characteristic	2016	2017	2018	2019
pH (H_2O)	5.5	6.0	5.8	5.2
Phosphorus (P) – mg dm^{-3}	18.6	29.9	12.4	12.6
Potassium (K) – mg dm^{-3}	134.0	149.0	91.0	165.0
Calcium (Ca^{2+}) – $cmol_c$ dm^{-3}	3.8	4.0	2.7	3.2
Magnesium (Mg^{2+}) – $cmol_c$ dm^{-3}	1.5	1.6	1.0	0.8
Aluminum (Al^{3+}) – $cmol_c$ dm^{-3}	0.0	0.0	0.0	0.1
H+Al (SMP extractor) – $cmol_c$ dm^{-3}	2.2	2.6	3.8	3.3
Exchangeable base sum (SB) – $cmol_c$ dm^{-3}	5.6	6.1	3.9	4.4
CEC (t) - $cmol_c$ dm^{-3}	5.6	6.1	3.9	4.5
CEC at pH 7.0 (T) - $cmol_c$ dm^{-3}	7.8	8.7	7.7	7.7
Base saturation index (V) - %	72.0	70.0	51.0	57.0
Aluminum saturation index (m) - %	0.0	0.0	0.0	2.0
Organic matter (MO) - dag kg^{-1}	2.6	2.4	2.6	2.5
Zinc (Zn) – mg dm^{-3}	4.7	5.9	2.5	2.8
Iron (Fe) – mg dm^{-3}	21.0	30.0	22.0	20.0
Manganese (Mn) – mg dm^{-3}	3.1	5.3	1.7	4.2
Copper (Cu) – mg dm^{-3}	2.0	4.2	2.7	3.5
Boron (B) – mg dm^{-3}	0.4	0.2	0.3	0.4

Soil Analysis Methods Guidelines - Embrapa, 2017.
t: effective CEC; T: potential CEC.
Extraction methods: P, K, Na = Mehlich^{-1}; S-SO_4^{2-} = [Calcium phosphate monobasic 0.01 mol L^{-1}]; Ca, Mg, Al = [KCl 1 mol L^{-1}]; H+Al = [SMP buffer solutions pH 7.5]; B = [$BaCl_2$. $2H_2O$ 0.125% hot water]; Cu, Fe, Mn, Zn = DTPA.

the recommendation was 2 kg ha^{-1} of B due to its low content in the soil, being supplied with the formulated 30-00-11 (N-P_2O_5-K_2O) + 0.27% of B. 20 mL of a fertilizer containing 11% of Cu in 20 L of water were applied via foliar fertilization, with two applications from December 2018 to January 2019. Liming was performed in a single application of 90 g $plant^{-1}$ of dolomitic limestone (CaO 40.20%; MgO 14% and PRNT of 80%).

In the third year after planting, the nitrogen recommendation was 19 g $plant^{-1}$ of urea (45% of N) and 7 g $plant^{-1}$ of KCl (60% of K_2O), with three applications within the period from January to March 2020. Phosphate fertilization was not carried out because the levels were within the satisfactory levels for the coffee crop. Regarding micronutrients, the recommendation was 2 kg ha^{-1} of B via foliar application of boric acid (17% B), and 5 kg ha-1 of Mn supplied via foliar with manganese sulfate (31% Mn and 17% S). Liming was performed in a single application of 8 g $plant^{-1}$ of dolomitic limestone (CaO 40.20%; MgO 14% and PRNT of 80%).

Weeds between the rows were controlled using a brushcutter and herbicides, whose active principles were glyphosate and oxyfluorfen, used at doses of 4.5 L ha^{-1} and 2 L ha^{-1}, respectively. The control of pests and diseases was carried out with the use of phytosanitary products licensed for the crop. The experiment was conducted without irrigation.

The experimental field located in Monte Carmelo-MG has constant monthly temperature variations throughout the year, with a hot spring and summer with average temperatures close to 25 °C, and cold autumn and winter with average temperatures below 20°C (Figure 1). In 2016, the annual precipitation approached 2,500 mm, concentrated from January to March and from October to December. From 2017 to 2019, rainfall was close to 1,500 mm.

Root sampling was carried out in two periods: the first, in April 2019, after mulching removal and the second in

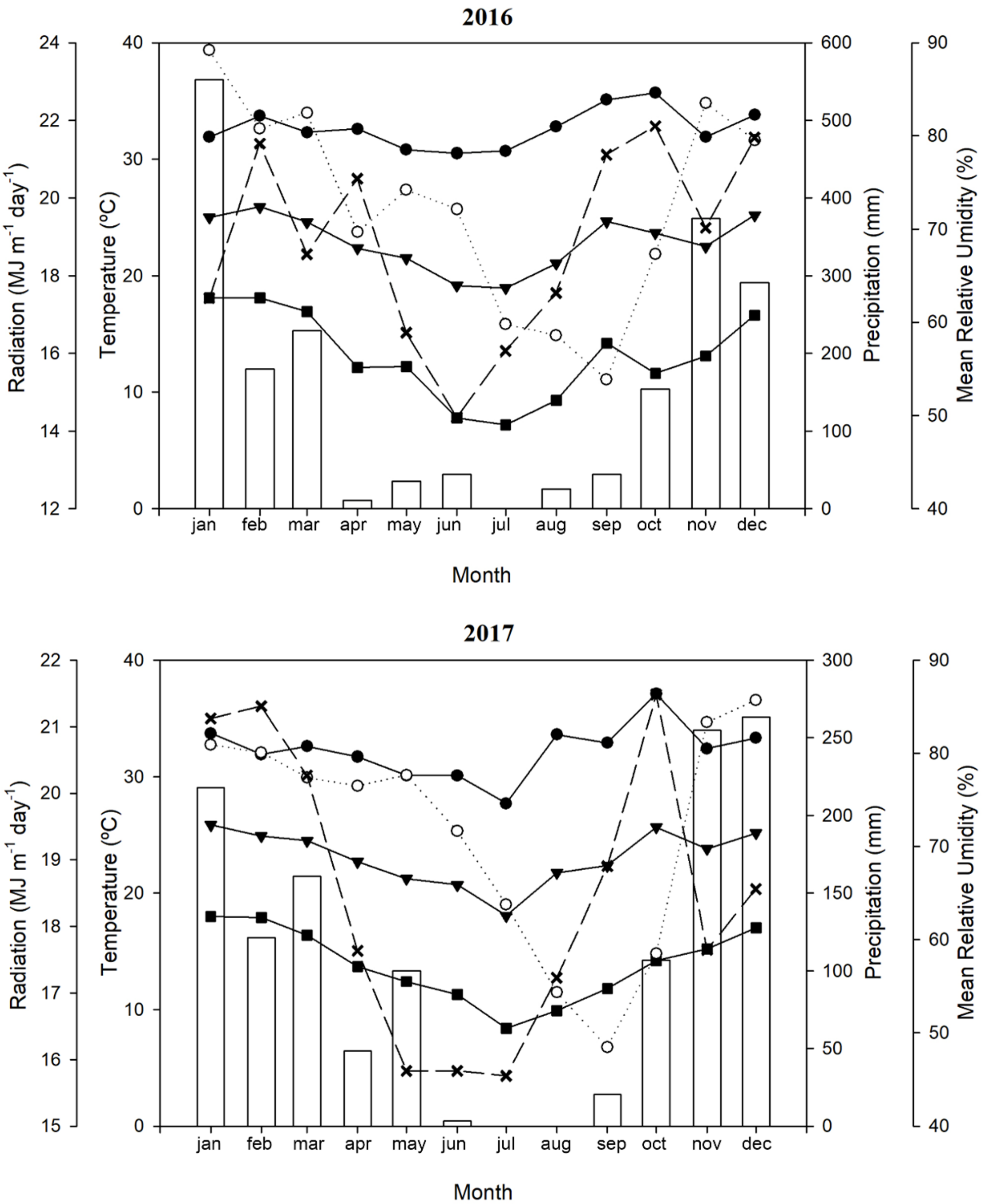

Figure 1: Precipitation, mean relative umidity, radiation and minimum, mean and maximum monthly air temperatures in Monte Carmelo, State of Minas Gerais in the period 2016-2017.

July, three months after mulching was removed with the aid of a two-inch auger (with a volume of 400 cm^3) (Figure 2). At all times, three points were collected, namely: point 1 (P1), between the adjacent plant on the right side in the same planting line, which was in the middle of the spacing between plants; points 2 (P2) and 3 (P3) away from the previous point in the line spacing at a distance of 0.15 and 0.30 m, respectively.

At point 1, samples were collected at two depths: 0-0.2 and 0.2-0.4 m, and at points 2 and 3, the samples were collected at a depth of 0-0.2 m. The samples were placed in transparent plastic bags and taken to the refrigerator until analyses. In the laboratory, each sample was placed in a bucket with water to break it up and then sieved through 4,2 and 1 mm mesh sieves. Subsequently, the roots were separated with the aid of tweezers.

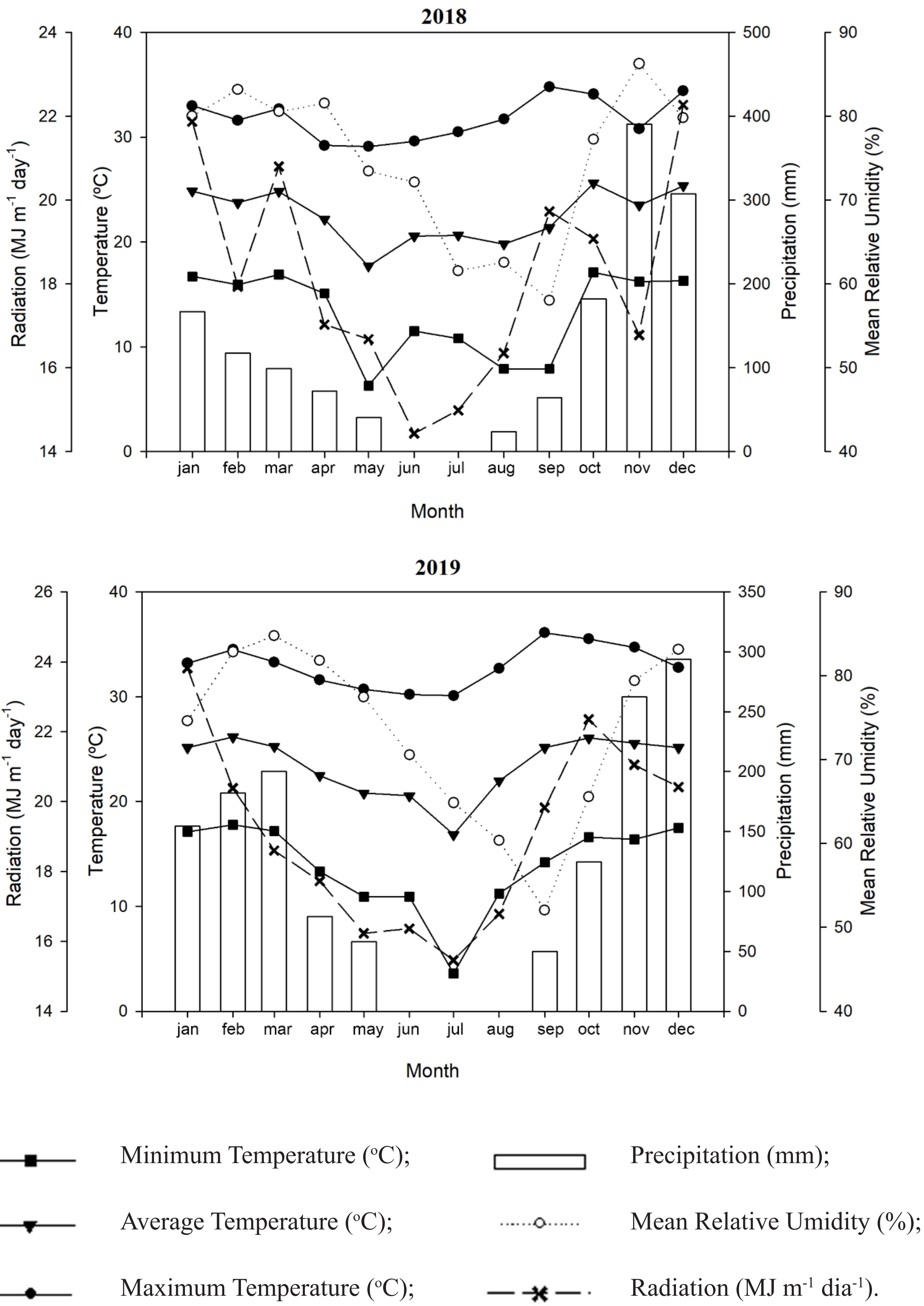

Figure 2: Precipitation, mean relative umidity, radiation and minimum, mean and maximum monthly air temperatures in Monte Carmelo, State of Minas Gerais in the period 2018-2019.

Then the roots were stained with gentian violet (1%) for five minutes and placed on paper towels to remove the excess dye. The roots were arranged on a transparent sheet of paper (transparent polystyrene film), without overlapping and scanned later.The root samples were dried until constant mass for dry matter quantification in a forced air circulation oven at 70 ºC. The scanned images were individually processed using the Safira program by Embrapa (Jorge & Rodrigues, 2008), with a threshold set at 150 (a parameter inherent to the program). From the results obtained by the program, the following morphological parameters associated with root morphology were estimated: total root dry matter mass per soil volume (TDM), in mg cm^{-3}; total length of roots per volume of soil (TL), in cm cm^{-3}; total volume of roots per volume of soil (TV), in mm^3 cm^{-3}; the total area of roots per volume of soil (TA), in mm^2 cm^{-3}; the specific surface of roots (SS), obtained by the ratio between TA and TDM, in m^2 kg^{-1}; specific length of roots (SL), obtained by the ratio between TL and TDM, in m g^{-1}; and mean root diameter (MD), in millimeters. The entire methodology was based on the work done by Ronchi *et al.* (2015).

The data were fitted to a Mixed Generalized Linear Model with normal distribution and identity link function using the Restricted Maximum Likelihood (REML) method. The mulching treatments, the assessed depths, and the interaction of these factors were considered fixed effects. As random effects, the collection dates and the effect of the subdivided plot for the depths were considered. The effects were tested using Analysis of Deviance (ANODEV) using the Chi-Square test. When significant, the means were compared using the test of Tukey, considering the significance of 0.05 for the tests. All data obtained were analyzed using the software R (R Development Core Team, 2011).

RESULTS AND DISCUSSION

The Deviance Analysis (Table 2) showed a significant effect among treatments for diameter, specific surface, and specific length. As for depth, a significant difference was observed only for diameter. The interaction between treatment and depth was not significant by the F test at a 5% probability for any response variable.

Root volume, total area, length, and root dry matter did not differ between treatments and between the collection points. Aranguren *et al*. (1982), Schaller *et al*. (2003), Cardoso *et al.* (2003), van Katen *et al*. (2005), Padovan *et al*. (2015) and Gárces (2018), report that coffee grown in an environment that provides less evaporation of soil water and better temperature balance as occurred in a coffee intercropping system with arboreal plants, induces the plant to produce fine roots (diameter smaller than 2 mm) in the topsoil, preferably in the 0-0.30-m depth layer.

The treatment without the use of mulching provided the development of roots with larger diameters in relation to plants grown without mulching (Table 3). In the absence of cover, the plants showed the superiority of 12.7% and 4.78%, respectively, in the root diameter in relation to the coffee plants implanted with 1.20-m width silver mulching and white mulching, regardless of width. It can be seen that at the 0.20-0.40 m depth, the presence of roots with a larger diameter (0.456 mm) was observed in relation to the topsoil. The greater development in root diameter in the absence of mulching was caused by the need for the coffee tree to expand the root system to greater depths in search of water in the dry season as the experiment was conducted without irrigation.

The points at the 0-0.20 m depth further from the orthotropic branch did not show differences in root diameter. Partelli *et al.* (2020) report that the fine coffee roots are more concentrated from 10 to 50 cm away from the orthotropic branch of the plant, and according to Ronchi *et al.* (2015), 75% of the fine roots of the coffee tree are located in the crown projection, which is the region where fertilization is carried out. Mulching minimizes the changes in soil temperature by reflecting most of the radiation to the plant canopy (Helaly *et al.*, 2017), decreasing evaporation and consequently maintaining soil moisture and water availability (Liu *et al.*, 2015).

The specific surface area and specific length of the roots were greater in the treatment that used a 1.20 m wide silver mulching, followed by the treatment that used a 1.40 m wide silver mulching, corroborated by results obtained in the research of Sarkar *et al.* (2019). The possible cause is related to the higher amount of available water in the topsoil, caused by low water evaporation, resulting in a concetration of roots in the shallower soil depths, thus forming several fine roots (Jayalalitha *et al.*, 2020).

Table 2: *Deviance* analysis for total volume (m^3 cm^{-3}), total area (mm^2 cm^{-3}), diameter (mm), total length (cm cm^{-3}), dry matter (mg cm^{-3}), specific surface (m^2 kg^{-1}), and specific length (m g^{-1}) of coffee roots according to the use of polyethylene film with different colors and widths

SV	DF	Total volume		Total area	
		Deviance	***Valor-p***	***Deviance***	***Valor-p***
Treatment	4	0.42	0.98^{ns}	0.81	0.94^{ns}
Depth	3	1.71	0.64^{ns}	3.6	0.31^{ns}
Block	3	3.42	0.33^{ns}	3.76	0.29^{ns}
Treatment X Depth	12	8.9	0.71^{ns}	7.48	0.82^{ns}
SV	**DF**	**Diameter**		**Total length**	
		Deviance	***Valor-p***	***Deviance***	***Valor-p***
Treatment	4	12.48	0.014*	2.12	0.71^{ns}
Depth	3	9.74	0.021*	5.83	0.12^{ns}
Block	3	3.22	0.36^{ns}	5.15	0.16^{ns}
Treatment X Depth	12	12.95	0.37^{ns}	8.43	0.75^{ns}
SV	**DF**	**Dry matter**		**Specific surface**	
		Deviance	***Valor-p***	***Deviance***	***Valor-p***
Treatment	4	8.79	0.066^{ns}	11.57	0.021*
Depth	3	0.33	0.95^{ns}	0.13	0.99^{ns}
Block	3	2.71	0.44^{ns}	1.48	0.69^{ns}
Treatment X Depth	12	9.89	0.63^{ns}	8.33	0.76^{ns}
SV	**DF**	**Specific length**			
		Deviance	***Valor-p***		
Treatment	4	15.07	0.004*		
Depth	3	0.11	0.989^{ns}		
Block	3	1.77	0.622^{ns}		
Treatment X Depth	12	8.52	0.743^{ns}		

**Significant at 0.01 of significance; *Significant at 0.05 of significance; Ns Not significant, by the Chi-Square at 0.05 of probability. FV: Source of variation; GL: degrees of freedom.

Silver mulching provides more favorable conditions for root development, creating a warmer and more humid microclimate in the surface layers of the soil. The greater the presence of fine roots in the soil surface layer l, the greater the distribution of the root system of the absorbent roots and the contact of the plant with the soil particles, promoting better use of water and nutrients.

The plastic cover on the soil is related to the production of hormones in the plant, particularly abscisic acid (ABA) and ethylene. The plant established in an environment that provides moisture in the root zone will be stimulated to produce ABA (Liu *et al.*, 2015), which is responsible for the elongation and differentiation of coffee roots (D'arêde *et al.*, 2017). The characteristics of the root system are influenced by a number of factors, including plant species, genotype, age, season, climate, planting density, biotic stress, soil texture, and structure (Partelli *et al.*, 2020).

Nascimento *et al.* (2020) found in the same experimental area, that the highest yields of coffee occurred in the treatments grown with the polyethylene plastic cover, besides having promoted better uniformity of fruit maturation and lower production of medium mocha beans. The increase in productivity with the use of polyethylene film was also observed in other research on annual and short-cycle crops, such as vegetables (Gao *et al.*, 2019; Lamont Jr, 2017; Jia *et al.*, 2020).

Table 3: Means of the total volume (m^3 cm^{-3}), total area (mm^2 cm^{-3}), average diameter (mm), total length (cm cm^{-3}), dry matter mass (mg cm^{-3}), specific surface (m^2 kg^{-1}), and specific length (m g^{-1}) of coffee roots according to the use of polyethylene film with different colors and widths

Mulching	TV^{ns}	TA^{ns}	MD^{*}	TL^{ns}	TDM^{ns}	SS^{*}	SL^{**}
MB 1.2 m	4.20	15.00	0.44 b	7.74	0.74	26.14 c	12.65 c
MB 1.4 m	3.56	13.30	0.44 b	6.93	0.75	21.75 d	11.28 d
MP 1.2 m	3.81	14.00	0.41 c	7.50	0.56	45.05 a	22.29 a
MP 1.4 m	3.87	14.30	0.43 b	7.47	0.79	30.04 b	15.16 b
SM	2.96	10.90	0.46 a	5.54	0.77	21.33 d	10.29 e
Depth	TV^{ns}	TA^{ns}	MD*	TL^{ns}	TDM^{ns}	SS^{ns}	SL^{ns}
0-20 point 1	3.87	14.50	0.43 b	7.77	0.88	32.23	15.99
0-20 point 2	4.23	15.20	0.43 b	7.75	0.71	30.54	15.21
0-20 point 3	3.82	14.20	0.43 b	7.42	0.65	29.13	14.39
20-40 point 4	2.79	10.10	0.46 a	5.21	0.65	23.55	11.72

TV: Total volume; TA: Total area; MD: Average diameter; TL: Total length; TDM: Total dry matter mass matter; SS: specific surface; SL: Specific length. *Significant at 0.05 of probability; **Significant at 0.01 of probability; ns not significant by the test of Tukey at 0.05 of probability.

The use of mulching has shown positive results in non-irrigated areas or that the plants are experiencing water stress. In irrigated area, Deschamps & Agehara (2019), Zou *et al.* (2017) report that it has not obtained the expected production system improvement results.

CONCLUSIONS

Roots with smaller diameters are more concentrated in the 0-0.20 depth layer, while roots with larger diameters are found in the 0.20-0.40 m layer.

Coffee trees grown under 1.20-m width silver/black mulching have a greater surface area and a specific length of the roots.

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