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Full Length Research Paper

The influence of several irrigation water depths in the growth and productivity of coffee shrubs in the Muzambinho Region, Southern Minas Gerais, Brazil

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Coffee crop, highly important worldwide, is one of the main commodities in Brazilian exports. However, due to climate changes, its cultivation is currently demanding irrigation techniques. Current assay evaluates the effect of different irrigation water levels on the development and productivity of coffee shrubs in predominant soil and climate conditions of the town of Muzambinho, in the southern region of the state of Minas Gerais, Brazil. The experiment was performed in July 2013 on a coffee plantation, planted with coffee shrubs, cultivar Red Catuaí IAC/144, by drip irrigation. Experiment design consisted of randomized blocks with four replications and four treatments, or rather, different irrigation water depths: 0 (without irrigation), 50, 100 and 125% of ET_0. Productivity, vegetal growth and distribution of the radicular system were evaluated after 12 months. Treatments did not affect vegetal growth. Better quantity and distribution of the radicular system were detected at 100% irrigation level, with a productionof 55 sacks.ha^{-1} or a 45% gain when compared to that in non-irrigated areas.

Key words: Management, coffee, drip system.

INTRODUCTION

It is a well-known fact that the coffee shrub is greatly affected by water deficit which causes a subsequent fall in production. Required irrigation has been employed to stimulate the shrub's vegetal development, increase production and harvest better grains. Much research is needed to discover the best form to supply water demands in coffee plantations. In fact, there are no definite criteria for irrigation management with regard to two factors: when irrigation is required or irrigation schedule, fixed or variable, and the amount of irrigation or

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the water depth necessary to supply water to the shrub (Silva et al., 2011).

The pressurized irrigation system allows drip distribution in the region, though the water must be of good quality so that no clogging or damage to the system's efficiency occurs (Valipour, 2012a, b, c; Valipour, 2014a, b).

When compared to the aspersion irrigation system, the great advantage in the drip system lies in the fact that the water applied on the soil surface does not moisten the leaves or the stem. The method reduces the occurrence of fungus diseases in the cultivation. Another advantage is the water amount, or rather, the great efficiency in its application and in the application of fertilizers (Boas et al., 2011). According to Evangelista (2011), success in irrigated coffee culture depends on the proper management of the natural resources soil-water-plant which interacts with the air and determine the potential conditions of maximum productivity of a culture in full phytosanitary and nutrition conditions.

Oliveira et al. (2010) reported the effect of drip irrigation on the production of coffee plantation in the first six harvests and verified that the productivity of the irrigated coffee shrubs averaged 50% higher than that without any irrigation. Drip irrigation in coffee culture is economically viable since a 33.48% increase in productivity, caused by irrigation, provides better income. Irrigation-caused productivity rise is an asset in investing in coffee production, with a considerable rise in economic levels and a decrease in the time for stock return.

Silva et al. (2011) applied water depth levels according to pre-defined percentages of the coefficient rates of the culture (Kc), namely, 60, 80, 100, 120 and 140% of Kc rates, plus a treatment without any irrigation. In the 2007 and 2008 harvests, the yearly productivity was higher than that in non-irrigated parcels. Further, the highest productivity in both harvests occurred with treatment at 100% water depth of Kc.

Rezende (2006) evaluated irrigation water levels 0% (L0, without irrigation), 40% (L1), 80% (L2) and 120% (L3) of evaporation of Classe A Tank (ECA) of 2002/2003 and 2003/2004 coffee harvest (cv. Topazio MG-1190). Accumulated productivity was higher for irrigated treatments, with increase when compared to non-irrigated ones; varying between 23.68% (L1) and 68.23% (L2) when compared to non-irrigated coffee shrubs.

Bruno et al. (2007) researched 3 to 5-year-old coffee shrubs, cv. Catuaí, and reported that the climatological water balance based on evapotranspiration estimates by the Thornthwaite and Penman-Monteith method replaced adequately field measurements and made possible a more practical irrigation management. Reference evapotranspiration (ET_0) is the evapotranspiration on a reference surface, with no lack of water. ET_0 may be obtained by direct and precise techniques with specific equipments, such as lysimeters, or estimated by mathematical models, with satisfactory results (Alves Sobrinho, 2011).

Due to the difficulties in the management of coffee shrubs, current experiment verified the effect of different irrigation levels, calculated by reference evapotranspiration, with drip irrigation, on the growth and productivity of coffee culture.

MATERIALS AND METHODS

Features of the experimental area

The experiment was conducted on the coffee culture experimental area of the Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais – Campus Muzambinho (IFSULDEMINAS), in the municipality of Muzambinho, in the southern region of the state of Minas Gerais, Brazil. According to Koppen's classification, the region's predominant climate is Cwb, with mean annual temperature at 18°C and mean yearly rainfall 1605 mm. The central point lies at 21° 21' 01.07''S and 46° 31' 21.10''W, at a mean altitude 1100 m.

Planting of 360 six-month-old coffee seedlings (*Coffea arabica* L.) var. Red Catuaí (IAC/144), with excellent phytosanitary conditions, occurred on January 2012. There was 3.0 spacing between the rows and 1.00 between the holes, totally 3333 plants per hectare, in an area 64.5 m long and 21.5 m wide, approximately totaling 1344 m^2.

Irrigation

The plants were irrigated three times a week by a localized irrigation system, with auto-compensating drip emitters, at a discharge of 1.3 $L.h^{-1}$ at every 30 cm, with a single irrigation row under the surface of each coffee shrub row.

Conditions tested in current experiment did not allow the application of FAO Peaman-Monteith method. However, empirical methods comprising mass transference, temperature and evaporation-based methods have been applied to estimate ET0. In fact, several research works show the efficiency of such methods (Valipour, 2014c, d, e, f, g, h, i, j, k; Valipour, 2015a, b, c). Applied water levels were calculated by Equation (1) with 0.9 efficiency, following Montovani (2011). Water excess in the soil was not reported during the experiment. Reference Evapotranspiration (ET_0) was calculated by the Penman-Monteith. Depths were calculated according to rainfall and water balance of the soil (Allen et al., 1998) (Figure 3b). The sum of ET_0 was performed every three days subtracting rainfall amounts.

$$Li = \frac{ETo * Kc}{Ei}, \quad (1)$$

where Li is the irrigation water depth [mm]; ETo is the reference evapotranspiration (Penman-Monteith) [mm]; Ei is the efficiency of irrigation; Kc is the crop coefficient.

Experimental design and treatments

The experimental design comprised randomized blocks with four treatments and four replications. Treatments were water levels applied as percentages of reference evapotranspiration (ET_0), namely: Li01 = 0 (without any irrigation); Li02 = 50% ET_0; Li03 = 100% ET_0; Li04 = 125% ET_0, totaling 16 parcels. Each block was

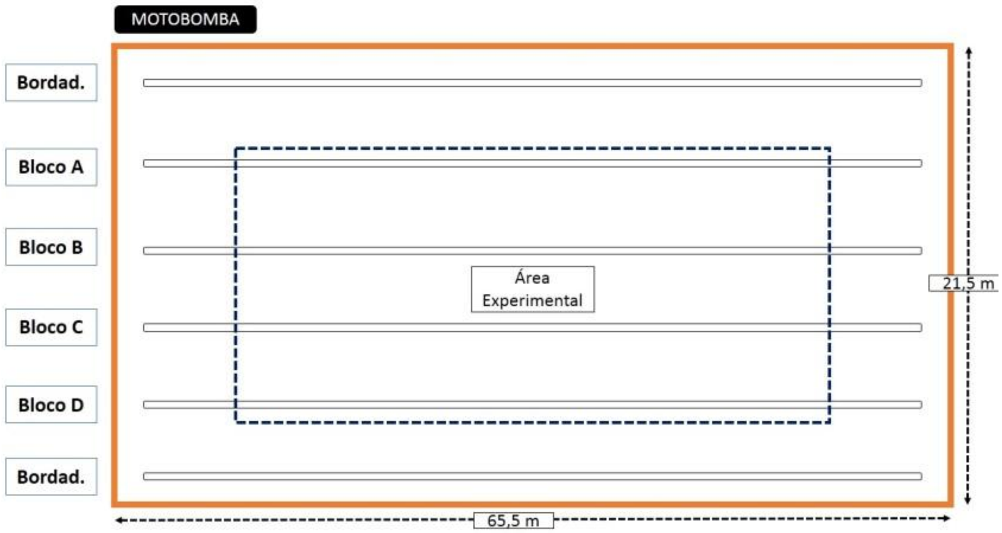

Figure 1. Experimental scheme.

composed of a row with 60 plants, totaling 240 plants. Each parcel comprised one row with 6 plants, but only the two central plants were evaluated; the other plants on the row were kept at the margins (Figure 1).

Estimates of reference evapotranspiration (ETo)

Reference evapotranspiration (ET_0) was estimated by the Penman-Monteith method, FAO 1998 standard, following Allen et al. (1998),

$$ET_0 = \frac{s}{(s+\gamma^*)}(R_n - G)\frac{1}{\lambda} + \frac{\gamma}{(s+\gamma^*)}\frac{900}{(T+273)}U_2(e_s - e_a) \quad (2)$$

where s is the curve declivity of vapor saturation pressure [kPa °C^{-1}]; R_n Rn is the radiation balance [MJ m^{-2} d^{-1}]; G is the heat flow in the soil [MJ m^{-2} d^{-1}]; λ is the evaporation latent heat [MJ kg^{-1}]; e_a is the partial pressure of the vapor [kPa]; e_s is the pressure of vapor saturation [kPa]; γ is the psychrometric coefficient [kPa ºC^{-1}], γ^* is modified psychrometric coefficient [kPa °C^{-1}]; T is mean air temperature [ºC]; U_2 is the mean speed of wind at a height of 2 m [m s^{-1}].

Climate variables for the estimation of ET_0 during the experiment were obtained from a Davis Vantage Pro 2 meteorological station, at 21°18'00"S and 46°30'00"W, mean altitude 1033 m.

Vegetal characteristics

After the start of treatment applications, the monthly evaluations on the vegetal growth of the plants were undertaken throughout the experiment, between July 2013 and July 2014, comprising height of plant (HP), measured by a graded bar from the soil surface to the tip of the plant, in cm; diameter of canopy (DC), measured by a graded bar at the height of the third middle of the plant and perpendicular to the row [cm]; number of primary plagiotropic branches (NPPB), measured all the plagiotropic branches in the plants. Radicular growth was measured by an auger drill at depths 20, 40 and 60 cm and at two distances from the trunk, at 20 and 50 cm, on July 2014.

Productivity and quality of the coffee plants

After the harvest of the experimental parcels, samples of coffee from cloth-sieve were retrieved and dried daily until moisture reached 11 to 12%. After drying, the samples were weighed, processed and weighed again. Data from all the process phases were used to calculate productivity, expressed in 60 kg of coffee per hectare.

Samples were removed from the processed volume for type and sieve classification. Grain size classification was undertaken in samples of 300 g and obtained by grain percentages in circular sieves (16 mm).

Statistical analyses

Evaluation results underwent analysis of variance (ANOVA) by F-test; when results were significant, means were compared by Scott & Knott test at 5% significance, with SISVAR (Ferreira, 2011).

RESULTS AND DISCUSSION

Vegetal growth was not affected by treatments, or rather, there were no significant effects on plant height, number of plagiotropic branches and crown diameter by F-test ($p<0.05$). The variables height of plant, the number of plagiotropic branches and crown diameter did not behave differently with different water regimes.

Figure 2 gives details on the equations of vegetal growth for treatment Li 3 = 100% ET_0, taking into consideration height of plants, crown diameter and number of plagiotropic branches versus time, coupled to the result of the regression test for this parameter with coefficient of determination at 97.7, 99.9 and 99.5%.

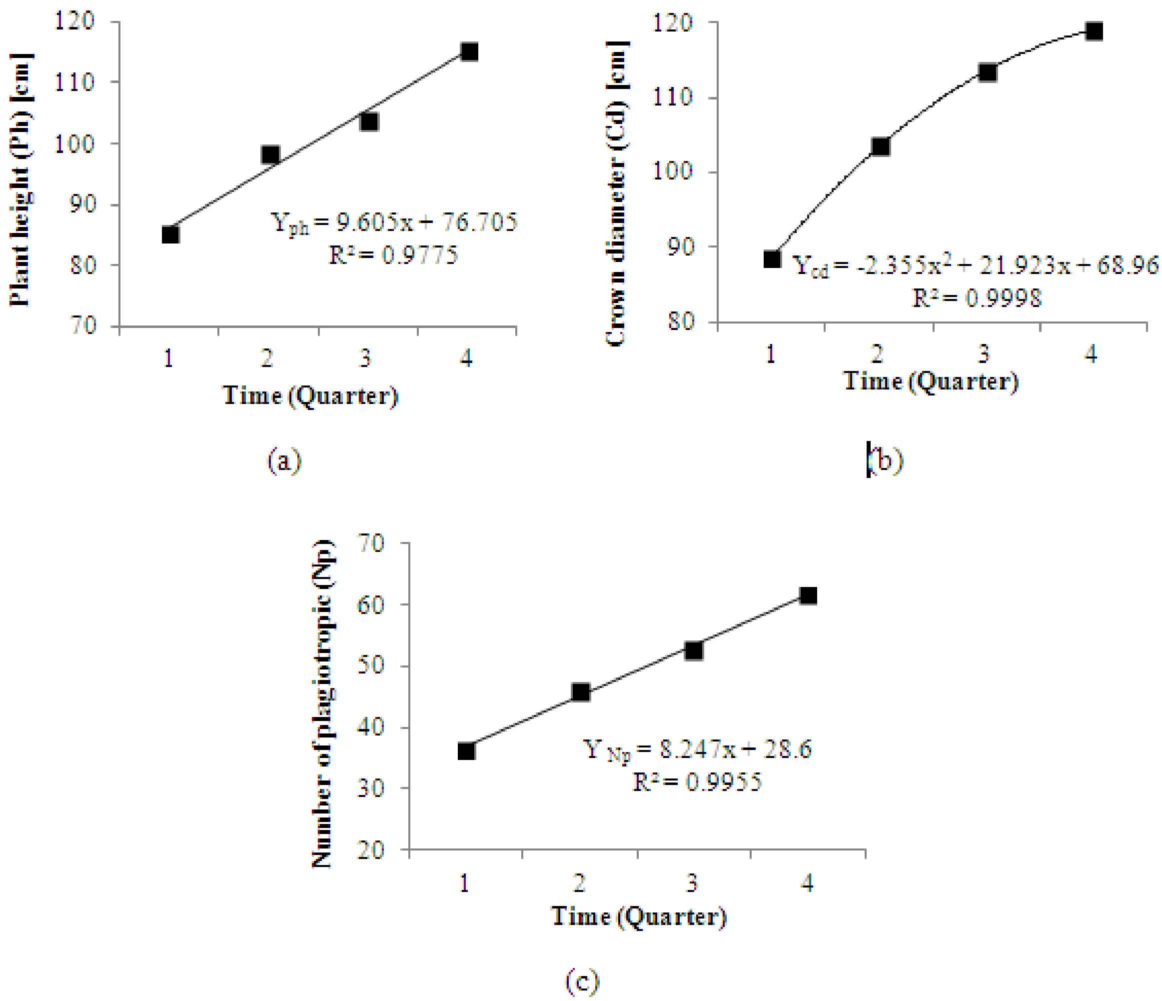

Figure 2. Vegetal growth of the coffee shrub between July 2013 and July 2014. Height of plants (A); diameter of crown (B); number of plagiotropic branches (C).

Linear behavior and higher growths were reported for the variable height and number of plagiotropic branches; a linear and quadratic adjustment was registered for the crown diameter.

Height of plant reached 115 cm, with a 35% growth during the year. The crown diameter reached 120 cm with 62 plagiotropic branches during the same period, featuring respectively a yearly growth of 35 and 70%. In their research on different cultivars of irrigated coffee shrubs in the savannah of Goiás, Brazil. Oliveira et al. (2004) reported heights between 111 and 120 cm and 47 to 50 plagiotropic branches per plant of the 24-month-old cultivar Red Catuai. Vegetal growth was similar to that in current analysis.

Rezende et al. (2010) reported a positive irrigation effect on plant growth with regard to height and crown diameter in 457-day-old Obatã-IAPAR-59 cultivar. Carvalho et al. (2006) also registered that the crown diameter of the coffee shrub cultivar Rubi MG-1192 was also affected by irrigation, underscoring its benefits in the development of coffee cultivation.

Figure 3 gives data on rainfall, evapotranspiration (ET), water storage and irrigation depth between July 2013 and June 2014. Irrigation depths did not influence the vegetal growth, probably due to the good water conditions of the soil assessed between July and mid-September 2013. On the other hand, the soil suffered a water deficit from October till the end of November. In December, the soil's water deficit decreased significantly due to rainfall increase, with good water conditions during approximately four months, from July to December 2013. This fact may have contributed towards the development of the plants within the crop´s vegetal growth phase.

Irrigation affected the distribution of the radicular system ($p<0.05$). As a rule, roots had a greater concentration at a distance of 20 cm from the trunk, or rather, practically for the projection of the coffee plants' crown (Figure 4). A decrease in the number of roots

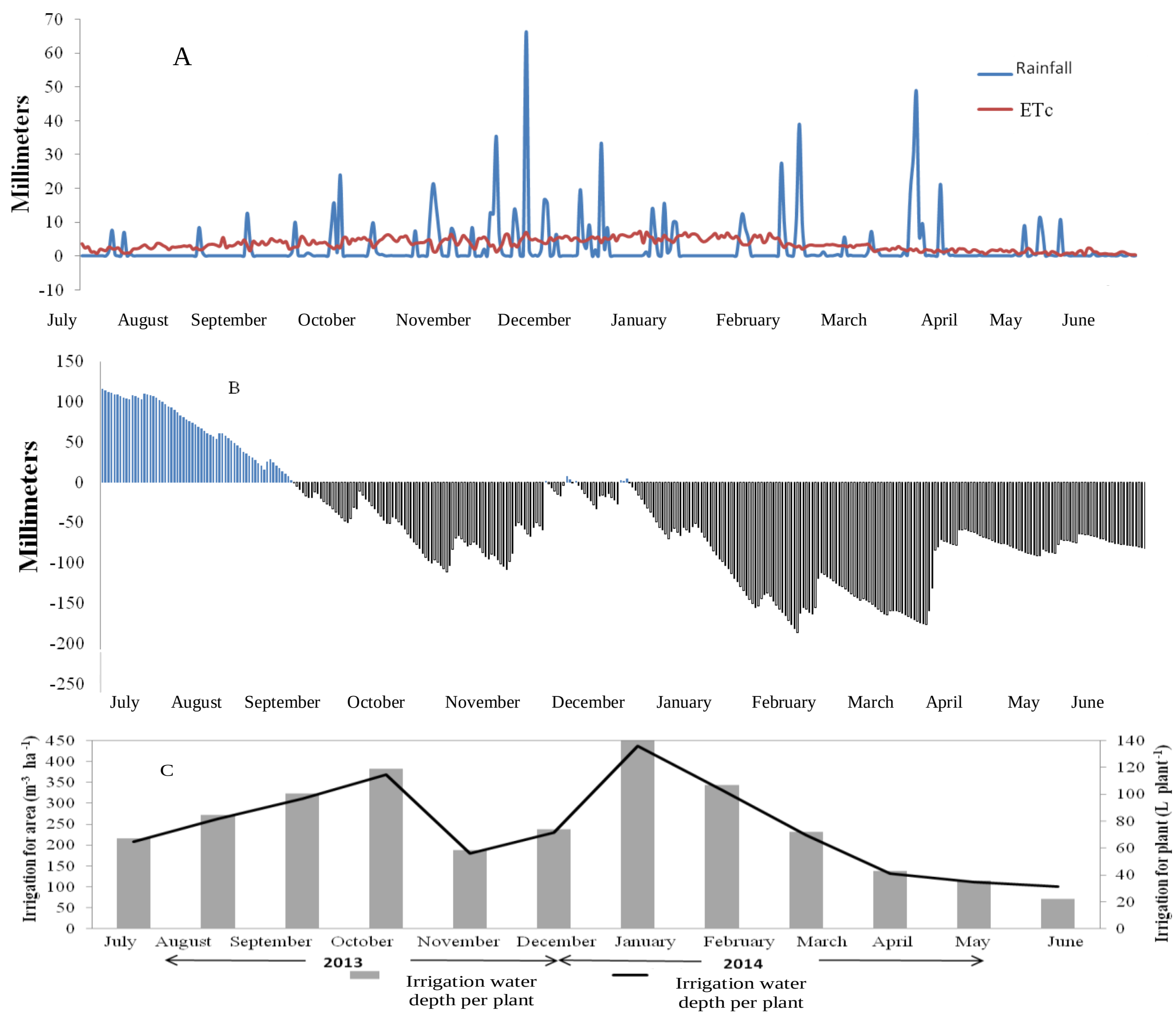

Figure 3. A) Rainfall and evapotranspiration (ET); B) water storage; C) Irrigation water depth between July 2013 and June 2014.

occurred in most treatments when distance increased to 50 cm from the trunk. At a depth up to 60 cm, there was a decreasing trend in the quantity of roots in the treatment with plants growing without any irrigation water.

According to Carducci et al. (2014), the greatest concentration of the coffee shrub's radicular system occurs with the crown projection band, predominantly at depths between 20 and 34 cm, corroborating results obtained in control as those with different irrigation water depths.

The treatment with 100% irrigation water depth

Table 1. Summary of the analysis of variance for productivity of the 2012 harvest of coffee plant (*Coffea arabica* L.) cv. Red Catuaí (IAC/144) and the test for the comparison of means of harvested and processed coffee, yield, sieve over 16, coffee productivity, according to different treatments.

Irrigation depth (%)	Harvested coffee (kg plant^{-1})	Processed coffee (kg plant^{-1})	Yield (%)	Sieve over 16 (%)	Productivity (sacks ha^{-1})
0	3.262^{B}	0.6317^{B}	23.12^{B}	61.21^{B}	39.39^{C}
50	3.536^{B}	1.0515^{A}	31.10^{A}	61.65^{B}	57.18^{A}
100	4.267^{A}	1.0117^{A}	24.29^{B}	74.23^{A}	55.36^{A}
125	3.238^{B}	0.8045^{B}	24.49^{B}	64.88^{B}	45.38^{B}
			Statistical parameters		
Treatment	22.431**	11.268**	5.242*	18.17*	67.02**
Block	0.260^{NS}	0.687^{NS}	1.275^{NS}	3.075^{NS}	0.121^{NS}
CV (%)	5.68	13.27	12.27	4.32	11.17

Means followed by the same capital letter on the vertical line do not differ by Scott-Knott test at 5% probability; ** - significant by F-test 1% probability level; ^{ns} – not significant by F-test at 5% probability level.

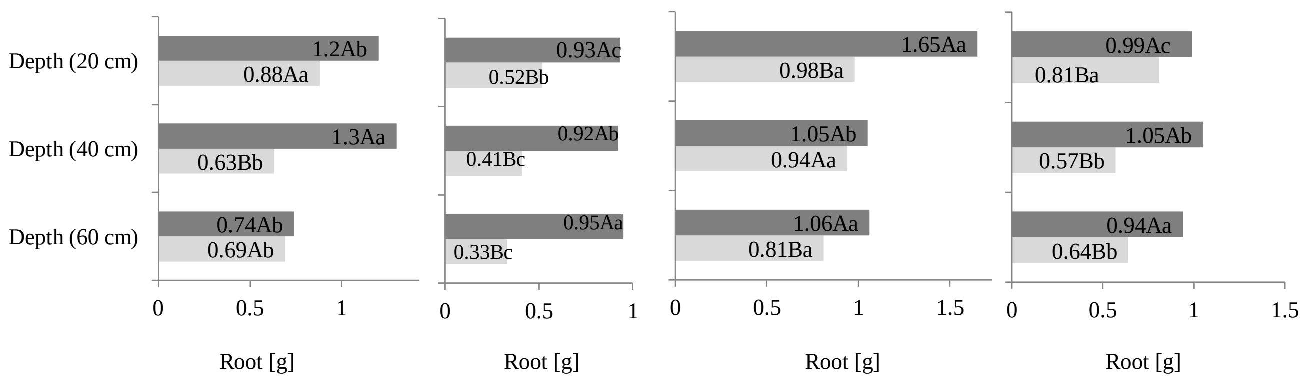

Figure 4. Distribution of radicular system according to different irrigation water depths, at different distances from the trunk and soil depths. Means followed by the same capital letter on the vertical line and by a small letter on the horizontal line did not differ by Scott-Knott test at 5% probability.

(Li 03) tended towards a greater number of roots distributed at a 20 to 50 cm distance from the trunk and at a 20 to 60 cm in depth. The treatment with the combination 50 cm distance and 40 to 60 cm depth was better than the others; similarly, at a distance of 20 cm from the trunk and at a depth of 20 cm.

There was a decrease in the radicular system in treatment with 50% irrigation water depth at a distance of 50 cm from the trunk for all soil depth evaluated and in all treatments studied. Growth decrease in the radicular system, even when compared to control treatment (without any irrigation water), may be related to the re-translocation process of photo-assimilates for the aerial section of the coffee shrub in this treatment, aiming to maintain the high productivity reported (57 sacks ha^{-1}), statistically equal to treatment with 100% of water irrigation depth (Table 1).

There was probably better water distribution in the treatment 100% irrigation water depth (Li 03) at a 20 cm distance from the trunk. This was due to the dripper which formed a moist bulb with an amount of water close to the ideal for the coffee shrub and which contributed towards a higher radicular growth with the sampled band. In the sample 50 cm from the trunk, there occurred a natural decrease in water availability, with a decrease in the radicular system. Similar results were verified by Barreto et al. (2006) in a drip irrigated coffee plantation. According to these authors, high water rate in the soil interferes in radicular aeration and respiration, besides making difficult the passage of ethylene produced by the radicular system, and by soil pores, jeopardizing root growth. The above may explain the behavior of radicular growth in treatment 125% of irrigation water depth (Li 04) in current analysis (Figure 4).

Characteristics of production

Table 1 shows a summary of the analysis of variance for the productivity of processed coffee for the 2012 harvest.

There was a significant effect ($p<0.05$) for all evaluated production attributes.

Table 1 reports the analysis of variance for granulometry and demonstrates that irrigation water depths applied according to ET_0 percentage affected significantly the granulometry of the coffee grains.

Irrigation at 100% water irrigation depth provided 74% of over 16-sieve coffee grains, registering the best result for the variable. It is actually about 8% more grain than that of other treatments, which is highly beneficial from the commercial point of view, since over 16-sieve grains are better classified on the market.

Processed coffee production derived from irrigation Li 03 (100% ET_0) was higher when compared to treatment without irrigation and to treatment 120% of ET_0. It was statistically equal to coffee with 50% ET_0, with rates between 1.01 and 1.05 kg plant^{-1}, with no difference by Scott-Knott test at 5% probability. In fact, irrigation enhanced an approximately 60% increase of processed coffee per plant when compared to plants without irrigation. The performance of the treatments 50 and 100% irrigation water depths for the variable processed coffee provided the highest productivity rates which varied between 55 and 57 sacks ha^{-1}, respectively between 16 and 18 surplus coffee sacks, or a 45% gain when compared to the productivity of plants without any irrigation water.

Harvest provided a mean productivity of 55.36 sacks per hectare (Li 03), which is excellent productivity, when the importance of coffee productivity for the coffee producer´s economic return is so relevant. It should also be verified whether the productivities obtained are the first produce of the coffee plantation.

Productivity decreases as the irrigation water depth increases, till it reaches 45.38 sacks per hectare with Li 04 (125% ET_0). Decrease in the productivity of irrigated plants at depth over 100% ET_0 may be due to the excessive water application at the region of the radicular system of the culture and, consequently, the leaching of nutrients with the irrigation water at the soil's deepest layers. Therefore, increase in water volume to the coffee plants does not necessarily mean an increase in productivity.

In current analysis, the non-irrigated treatment had the lowest productivity and showed that irrigation in coffee plants in the region of Muzambinho MG Brazil is advantageous, corroborating results by Oliveira et al. (2010) and Silva et al. (2011).

Conclusions

(i) Irrigation under soil and climate conditions of the experimental area does not affect the vegetal growth of plants;

(ii) 100% irrigation water depth provided a higher growth and distribution of the plants' radicular system.

(iii) Irrigation enhances a significant increase to the production of coffee plants (*Coffea arabica* L.) cv. Catuaí when compared to non-irrigated treatments.

Conflict of Interest

The authors have not declared any conflict of interest.

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