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REGULAR ARTICLE

Effect of different methods for estimation of evapotranspiration and water deficit in soil on the growth rates of conilon clonal coffee

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MGS: Conducted the experiment, analyzed the data and wrote the article; GBA: Contributed to the conduct and evaluation of the experiment; MECF: Contributed to the conduct and evaluation of the experiment; PHSdeO: Contributed to the conduct and evaluation of the experiment; EFdosReis: Idealized guides the research, contributes to the discussion and revision of the text.

Abstract

The water deficit is considered one of the main problems in coffee culture around the world. As a way to get around this problem, producers all over the world adopt the practice of irrigation. However, in the most cultivated areas, a rational irrigation management is not carried out, resulting in excessive or insufficient applications. Based on this, the present work aimed to evaluate the effect of different methods of evapotranspiration estimative and water deficit levels on the growth rates of the clonal conilon coffee. The experiment was conducted in a greenhouse, in a 2 x 3 factorial scheme with the factor evapotranspiration in 2 levels (Penman-Monteith (PM) and Hargreaves & Samani (HS), and the factor water deficit in 3 levels (80%, 50% and 30% of Evapotranspiration of Reference (ETo)) in a completely randomized design. From the results obtained, it was observed that the evapotranspiration estimation method and the water deficit levels had an effect on the growth rates and free assimilation rate of the clonal conilon coffee tree, with the highest growth values in plants irrigated with 80% of ETo by the HS method, and higher assimilation values in plants irrigated with 80% of ETo by the PM method.

Keywords

Irrigation management; Development; Coffea Canephora

Introduction

Coffee is one of the main commodities, being traded around the world and present on the main stock exchanges. Cultivated in over 80 countries, it is responsible for the livelihoods of about 25 million farmers, mainly smallholders, and it is estimated that about 100 million people are involved in this production chain (Martins et al., 2017; Ramalho et al., 2018).

One of the main problems in coffee culture around the world, is the water deficit, as it is capable of affecting the development and production of the coffee tree, especially in areas with long periods of drought (DaMatta and Ramalho, 2006; Tesfaye et al., 2015).

One of the ways to get around the water deficit is through the practice of irrigation, however this practice must be done in a judicious and adequate manner for the rational management of water. However, if handled improperly, it generates waste of water, which, in addition to increasing production costs, compromises the availability and quality of this resource (Mantovani et al., 2009; Silva et al., 2016). However, due to not approving management practices and low efficiency of irrigation systems, it ends up solving economic and environmental losses (Martins et al., 2007).

To carry out a rational management of water in irrigation, it must be determined how much to irrigate, according to the capacity of the soil surface and vegetation to lose water to the atmosphere (Silva et al., 2011). One way to determine how much water is being lost is by estimating the reference evapotranspiration.

There are several methods for estimating the reference evapotranspiration (ETo), one of the most direct and accurate ways, the use of the soil water balance with the use of lysimeters, however, this method has disadvantages, such as delay in responses, high costs and difficulty in routine field monitoring (Tabari et al., 2013; Ghahreman; Sameti, 2014; Silva, 2016).

Another way to estimate ETo is by using indirect methods, based on equations that use meteorological data. Among these methods, the Penman-Monteith method is recommended as

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the standard by the FAO due to its technical consistency (Allen, 1986; Allen et al., 1989). However, this method requires a large number of meteorological variables necessary for its application, as many meteorological stations do not have all the necessary sensors, which, even when present, often provide low quality data (Droogers & Allen, 2002).

Currently, there are more simplistic equations for accurately estimating evapotranspiration, and which require fewer variables, such as air temperature to estimate evapotranspiration, may be used to carry out irrigation management, among which the method stands out. Hargreaves and Samani (Carvalho et al., 2011; Pilau et al., 2012).

Based on the above, this study aimed to evaluate the relationship between different levels of water deficit using different empirical methods to estimate the reference evapotranspiration and its effect on the growth rates of the clonal conilon coffee tree.

Materials and methods

The present study was carried out in a greenhouse at the Center for Agricultural Sciences and Engineering of the Federal University of Espírito Santo, located in the municipality of Alegre-ES, at latitude 20º42'52" South, longitude 41º27'24" west and altitude 136, 82 m. The region's climate is characterized as being of the Aw type, with a dry season in winter. The average annual precipitation is around 1200 mm and the average annual temperature is around 23°C. The experiment was installed with clonal conilon coffee seedlings of the Diamond "INCAPER ES8112", Jequitibá "INCAPER ES8122" and Centenary "INCAPER ES8132" varieties, in a 2 x 3 factorial scheme, with the factor "reference evapotranspiration" (ETo) in 2 levels (Penman-Monteith (PM) and Hargreaves-Samani (HS)), and the water deficit factor (DH) of soil water in 3 levels (80%; 50% and 30% of ETo) in a fully design randomized with 4 repetitions.

Each experimental plot was established by a 12 liters pot filled with soil from the region. The soil used was collected at a depth of 0.00 –0.30 m, in which it was deflated, passed through a 4 mm sieve and homogenized. The soil used was collected for samples and these were sent to the soil analysis laboratory at UFES, to carry out physical and chemical analyses. Fertilization and liming practices, according to the methodology proposed by Novais, Neves and Barros (1991). Phytosanitary monitoring was carried out periodically, aiming to prevent interference of biotic factors in the results of the experiment.

After carrying out the soil preparation practices, the plants were kept under ideal growing conditions for a period of 25 days, promoting their total establishment in the soil. After this period, the treatments began. To carry out irrigation, climate management was adopted, using the methods of Penman-Monteith (Allen et al., 1998) (Equation 1) and Hargreaves-Samani (Hargreaves & Samani, 1985) (Equation 2). To perform the evapotranspiration calculations, meteorological data were obtained from an automatic station of the National Institute of Meteorology (INMET), located in the experimental area of the Center for Agricultural Sciences and Engineering (CCAE) of the Federal University of Espírito Santo (UFES), under OMM code 86828, latitude 20º44'32" South and longitude 41º29'20" West.

$$ETo = \frac{0.4808\ (Rn-G) + \gamma \left(\frac{900\ U_2}{t+273}\right) (e_s - e_a)}{\Delta + \gamma\ (1+0,34\ U_2)} \quad (1)$$

In which: ETo, estimate of the Penman-Monteith-Standard FAO evapotranspiration, (mm); Δ, declination of the water vapor saturation curve, (kPa/°C); Rn, radiation balance, (MJ/m^2d); G, soil heat flux density (MJ/m^2d); γ, psychometric factor (MJ/kg); U2, wind speed (daily average) at 2 m above the ground surface, (m/s); es, steam saturation pressure, (kPa); ea, actual steam pressure (kPa); and, Tmed, mean temperature, (°C).

$$ETo = 0.408 \times 0.0023 \times R_a\ (Tmax-Tmin)^{0,5}\ (Tmed+17,8) \quad (2)$$

In which: ETo, estimation of Hargreaves-Samani evapotranspiration; Ra, solar radiation at the top of the atmosphere, (MJ/m^2d); Tmax, maximum temperature of the day, (°C); Tmin, minimum temperature of the day (°C); and, Tmed, mean temperature of the day, (°C).

Each experimental unit had the water replacement performed manually with the aid of a graduated beaker and the amount of water needed will be determined according to Bernardo et al. (2019). The irrigation depth was calculated according to the following equation (Equation 3):

$$L = ETo_{AC} \times kc \times V \quad (3)$$

In which: L = irrigation depth (mm); ETo_{AC} = sum of reference evapotranspiration obtained accumulated over a period of 3 days; kc = crop coefficient, considering the percentage of deficit in relation to reference evapotranspiration (0.8; 0.5 and 0.3); V = volume of soil in the pot (0.012 m³).

The growth analyzes were carried out 15 days after transplanting the seedlings in the pots and at the end of the experiment (145 days). To obtain the total dry matter (MST), the plants were dried in an oven at 75 ºC until reaching constant dry weight. The leaf area was obtained according to the methodology proposed by Barros et al. (1973). Based on these data, the Absolute Growth Rate (ACT) (Equation 4), Relative Growth Rate (RCT) (Equation 5), Free Assimilatory Rate (FAR) (Equation 5) were determined, as proposed by Benincasa (2003).

$$ACT = \frac{(P_2 - P_1)}{(T_2 - T_1)} \quad (4)$$

$$RCT = \frac{(\ln P_2 - \ln P_1)}{(T_2 - T_1)} \quad (5)$$

$$FAR = \left[\left(\frac{P_2 - P_1}{T_2 - T_1}\right) \times \left(\frac{\ln A_2 - \ln A_1}{A_2 - A_1}\right)\right] \quad (6)$$

In which: P represents the total dry mass (shoot and root); T1 the time in the first collection, T2 the time in the last collection; A represents the leaf area.

The data collected in the experiment was entered into an electronic spreadsheet and submitted to analysis of variance

($p \leq 0.05$); when the F test is significant, the Tukey test ($p \leq 0.05$) was applied using the R software (R CORE TEAM, 2021).

Results and discussion

The figures below show the monthly values of ETo (Figure 1) and total water volume applied as a function of the method of estimating ETo and water deficit (Figure 2) during the period during which the experiment was carried out. It is extremely important to analyze the method to be used, since it will have an effect on the amount of water to be applied and, consequently, on the vegetative growth responses.

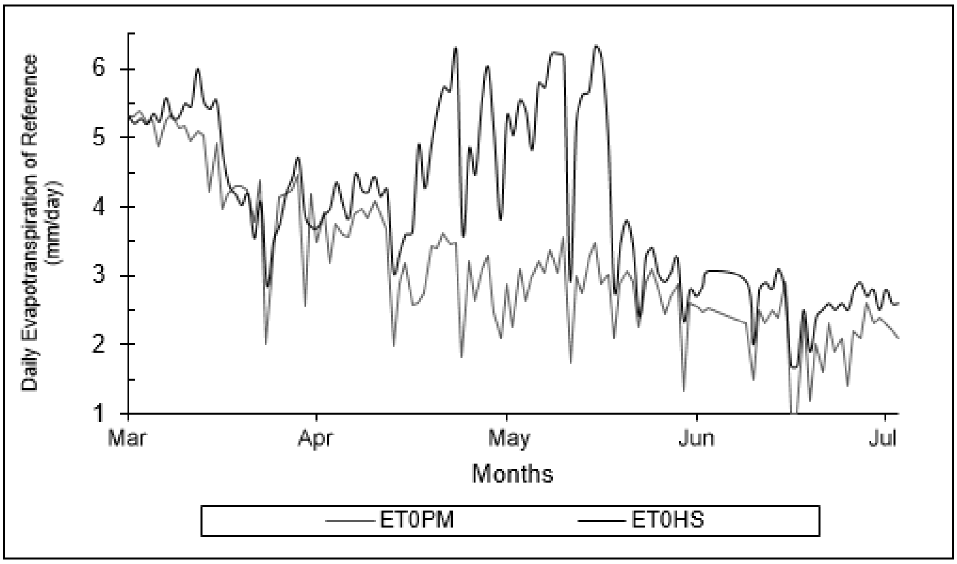

Figure 1: Daily values of ETo obtained by the PM and HS method during the period of the experiment.

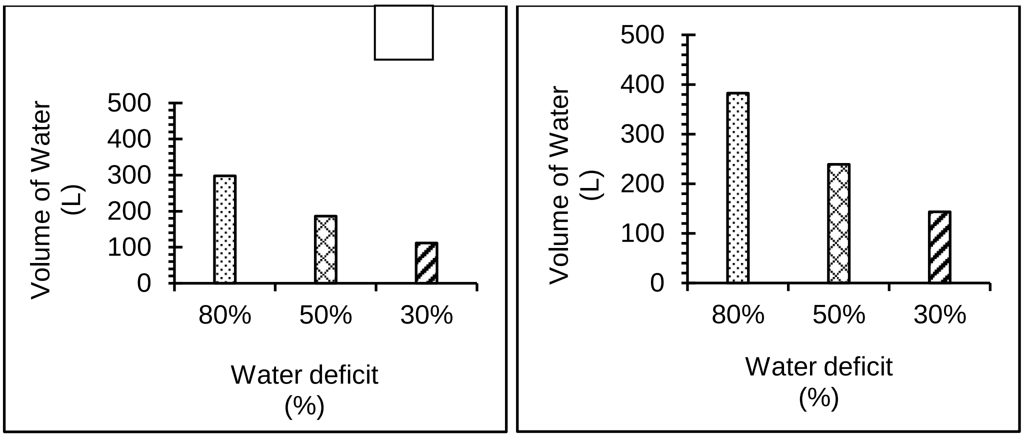

Figure 2: Total Water Volume applied as a function of the respective methods of estimating evapotranspiration and water deficit levels during the experimental period.

Analyzing the Figure 1, it can be seen that the highest ETo values obtained by the HS method were higher than those obtained by the PM method, with the period of higher demand, observed in May, ranging from 4.9 to 6.24 mm/day. For the PM method, the highest values were observed in the April period, ranging from 4.3 to 4.7 mm/day.

Analyzing the Figure 2, it can be observed that plants irrigated using the HS method obtained higher water applications compared to PM, during the experimental period at all levels of water deficit. In general, it can be observed that plants irrigated by the HS method presented an application of 22.12% more water at all levels of water deficit compared to plants irrigated by the PM method.

The highest values obtained by the HS method occur because of this method was developed for semi-arid climatic conditions, thus resulting in overestimated ETo values in humid climates, thus resulting in excessive water applications (SENTELHAS et al., 2010). Similar results to these, showing the overestimation of the HS method in relation to the PM method in southern Espírito Santo, were observed in studies such as the one by Bragança et al. (2010), Pinheiro (2019) and Felleti (2020).

The tables below show the Absolute Growth Rate (AGT), Relative Growth Rate (RGR), Free Assimilatory Rate (FAR) for each reference evapotranspiration estimate and soil water deficit level. It is possible to observe that there was a difference in plant growth rates in relation to each method of estimation of reference evapotranspiration and water deficit level.

Table 1: Absolute Growth Rate (AGT), Relative Growth Rate (RGR), Free Assimilatory Rate (FAR) as a function of the estimate of reference evapotranspiration for each level of water deficit.

	AGT (g day^{-1})			RGR (g day^{-1})			FAR (g cm^{-2} day^{-1})		
ETo	80%	50%	30%	80%	50%	30%	80%	50%	30%
PM	0,1767a	0,1035a	0,0635a	0,0137a	0,0104a	0,007a	0,0030a	0,0048b	0,0014a
HS	0,1791b	0,1178b	0,0744b	0,0140b	0,0114b	0,008b	0.0028b	0.0020b	0,0016b

Means followed by the same letter do not differ statistically from each other by Tukey's test at 5% probability.

Table 2.:Absolute Growth Rate (ACT), Relative Growth Rate (RCT), Free Assimilatory Rate (TAL) as a function of water deficit levels for each estimate of the reference evapotranspiration.

ETo	WD	AGT (g day^{-1})	RGR (g g^{-1} day^{-1})	FAR (g cm^{-2} day^{-1})
PM	80	0,1767a	0,0137a	0,0030a
	50	0,1035b	0,0104b	0,0048b
	30	0,0635c	0,0071c	0,0014c
HS	80	0,1791a	0,0140a	0,0028a
	50	0,1178b	0,0114b	0,0020b
	30	0,0744c	0,0084c	0,0016c

Means followed by the same letter do not differ statistically from each other by Tukey's test at 5% probability.

The Absolute Growth Rate (AGT) acts as an indicator of the amount of dry matter produced per unit of area or plant during a certain time, also serving as an indicator of the average growth rate (g day-1 or g week-1), throughout the period evaluated (Benincasa, 2003; Bragança, 2005). While the Relative Growth Rate (RGR) represents the amount of plant material produced by a given amount of existing material (g) over a period of time, this factor being dependent on the assimilatory capacity of its leaves, which will also directly depend on factors such as leaf area and number of leaves (Oliveira & Gomide, 1986).

Analyzing the AGT and RGR, it can be observed that the highest values were obtained in plants irrigated with 80% of ETo, for both methods, and that this index decreased as the deficit level increased. These results are in line with Dardengo et al., (2009) who observed that soils with lower water availability, present the lowest values of growth rates. Busato et al., (2007) studying the effect of different irrigation depths on the growth of the conilon coffee tree, observed that the depths based on the highest percentages of evapotranspiration, promoted the greatest growth of the coffee tree. It is noteworthy to observe that higher values of growth rates occurred in plants irrigated by the HS method at all levels of water deficit, this being due to the overestimation promoted by the HS method in relation to the PM method.

The Free Assimilatory Rate (FAR) represents the balance between the material produced by photosynthesis and losses due to respiration, that is, it represents the net photosynthesis rate, in terms of dry mass produced (Machado et al., 1982). Also according to Dardengo et al., (2009), the variations observed in plant growth can be explained by the FAR, as it expresses the performance of the assimilatory system of plants as a function of the conditions in which they were submitted.

Analyzing the FAR, it can be observed that the highest values were obtained for plants irrigated with 80% of ETo. However, it is possible to observe that plants irrigated by the PM method, the values were higher than those for plants irrigated by the HS method, with the highest value being obtained in plants irrigated with 50% of ETo by the PM method.

One of the reasons for the lower FAR values in plants irrigated by the HS method would be due to the excess of water present in these plants. Under conditions of excess water in the soil, there is a decrease in oxygen levels close to the roots, affecting the energy metabolism of plants. One of the ways that plants survive in this type of environment is the decrease in root respiration rates, resulting in a change from aerobic to anaerobic metabolism, causing less energy production to occur (Ailey-Serres et al., 2008).

Taking into account also that the FAR is also affected by the increase in leaf area, since, as the leaf area increases, self-shading is favored and the efficiency of the assimilator system is disadvantaged, compromising the photosynthetic activity (Conceição et al., 2005).

Conclusions

Based on the obtained results, can be concluded the evapotranspiration estimation method and the water deficit levels had an effect on the growth rates and free assimilation rate of the clonal conilon coffee tree, with the highest growth values in plants irrigated with 80 % of ETo by the HS method, and higher assimilation values in plants irrigated with 50% of ETo by the PM method.

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