SOIL WATER POTENTIAL DURING DIFFERENT PHENOLOGICAL PHASES OF COFFEE IRRIGATED BY CENTER PIVOT

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ABSTRACT: Irrigation management can be established, considering the soil water potential, as the limiting factor for plant growth, assuming the soil water content between the field capacity and the permanent wilting point as available water for crops. Thus, the aim of this study was to establish the soil water potential interval during four different phenological phases of coffee irrigated by center pivot. The experiment was set at the experimental area of the Engineering Department at the Federal University of Lavras, in Brazil. The coffee variety planted is designated as Rubi, planted 0.8 meters apart, with rows spaced 3.5 meters apart. The treatments corresponded to the water depths applied based on different percentages of Kc and reference evapotranspiration (ET_0) values. Sensors were used to measure the soil water potential interval, installed 25 centimeters depth. In order to compare the results, it was considered as the best matric potential the one that was balanced with the soil water content that resulted in the largest coffee productivity. Based on the obtained results, we verified that in the phases of fruit expansion and ripening, the best results were obtained, before the irrigations, when the soil water potential values reached -35 and -38 kPa, respectively. And in the flowering, small green and fruit expansion phases, when the values reached -31 and -32 kPa, respectively.

KEY WORDS: irrigated coffee, available water, *Coffea arabica* L.

POTENCIAL DE ÁGUA NO SOLO EM DIFERENTES ESTÁDIOS FENOLÓGICOS DO CAFEEIRO IRRIGADO POR PIVÔ CENTRAL

RESUMO: O manejo de irrigação pode ser estabelecido considerando-se o potencial de água no solo, como fator limitante para o crescimento das plantas, assumindo o teor de água no solo entre a capacidade de campo e o ponto de murcha permanente, como água disponível para as culturas. Assim, o objetivo deste trabalho foi estabelecer o intervalo de potencial matricial de água no solo para o manejo de irrigação, em quatro estádios fenológicos do cafeeiro irrigado por pivô central. O experimento foi desenvolvido na área experimental do Departamento de Engenharia, na Universidade Federal de Lavras. A variedade de cafeeiro cultivado foi a "Rubi", plantada no espaçamento de 3,5 x 0,80 m. Os tratamentos corresponderam a lâminas de água aplicadas em função de percentagens de valores de Kc e da evapotranspiração de referência (ET_0). Para a obtenção do intervalo de potencial matricial de água no solo, foram instalados sensores de umidade tipo watermark, na profundidade de 0,25 m. Para a comparação dos resultados, considerou-se como melhor intervalo de potencial matricial, aquele em equilíbrio com o teor de água no solo, que resultou em maior produtividade da cultura. Com base nos resultados, verificou-se que, nas fases de granação e maturação dos frutos, os melhores resultados foram registrados quando, em geral, antes das irrigações, os valores de potencial matricial de água no solo alcançados foram de -35 a -38 kPa, e nas fases de dormência e florada, chumbinho e expansão dos frutos, os valores de potencial matricial alcançaram de -31 a -32 kPa, respectivamente.

PALAVRAS-CHAVE: cafeicultura irrigada, água disponível, *Coffea arabica* L.

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INTRODUCTION

Much of the success of irrigated agriculture depends on proper management of soil-water that, interacting with the atmosphere, determine the conditions of maximum potential productivity of a culture that is at full health conditions and nutrition. Studies on irrigation in coffee regions considered suitable for cultivation demonstrated that the use of this technique is justified, once irrigation ensures greater vigor to plants and eliminates risks arising from occasional droughts, increasing productivity (CUSTÓDIO et al., 2007; GOMES et al., 2007; SATO et al., 2007; SILVA et al., 2008a; SILVA et al., 2008b).

According to CAMARGO & CAMARGO (2001) the Arabica coffee has four distinct phases of development during the year: dormancy and bud formation, flowering, small green and fruit expansion, and ripening; the authors also report that for the conditions in the central-south region, the water deficit during the expansion phase (October-December) delays the fruit growth, resulting in its lower size and reduced productivity. During maturation and bud formation (April-June), the water deficit does not affect maturation of fruits already formed or productivity for the same year; however, it can reduce blossom and fruiting at the following year; at the stage of dormancy (July-September), the water deficit may be even beneficial because it might bring abundant flowering after rain or watering in the late phase, resulting in uniform fruiting and maturation for the following crop.

In irrigated agriculture, water management requires determination of water needs, application forms and observation of moisture at the root zone of plants. Continuous monitoring of soil moisture in irrigated areas is important to assess whether the water applied by irrigation is readily stored into the soil explored by the roots or is moving by percolation to deeper layers (SOUSA et al., 2006).

Irrigation management of a culture must be based on criteria that enable the application of water in the soil, in order to promote optimum production, from economical perspective. Irrigation should provide the amount of water withdrawn by the culture. The irrigation time is identified when the availability of water in the soil takes minimum value below that at which the plant begins to feel the effects of water restriction. The definition of when irrigation must be provided can be done with threshold values provided by methods based on soil or plant (MARTINS et al., 2007).

A quantitative approach seeks to establish, for design purposes and irrigation management, a percentage of the total available water in the soil that could be used by the culture. This concept is useful for defining the moment to irrigate with by the water balance method, being important to monitor the soil moisture. Several methods can be used to define the moment irrigation and the easier to use is through the control of the matric potential of soil water (TAYLOR, 1965; CAMPBELL, 1988; HENDRICKX & WIERENGA, 1988). Tensiometers and moisture sensors such as the Watermark can be used for this purpose to indicate when plants should be irrigated based on soil water potential as limiting factor for plant growth.

One of the few studies that related the matric potential to critical soil moisture for coffee crop was developed by FARIA & SIQUEIRA (2005) who found the threshold -40 kPa, as the one associated with the best response in crop yield. However, FARIA et al. (2009) observed tensions values that varied among treatments from -11 to -33 kPa indicating differences occurred in water absorption among the treatments between irrigations.

Given the above, the aim of this study was to establish the interval of potential soil water for irrigation management in four phenological stages of the coffee irrigated by center pivot in the southern region of the state of Minas Gerais, in Brazil.

MATERIAL AND METHODS

The experiment was conducted at experimental area of the Department of Engineering at the Federal University of Lavras (Departamento de Engenharia - Universidade Federal de Lavras DEG-UFLA), located at Lavras city - Minas Gerais (MG) state, in Brazil, in a coffee plantation irrigated by center pivot. The crop studied is located in the southern region of the state of Minas Gerais, at 21º13' south latitude and 44º58' west longitude with average altitude of 918.8 m. The average annual air temperature in Lavras - MG is 19.40 ºC and total annual rainfall 1,530 mm (DANTAS et al., 2007). The variety of coffee grown in the area is referred as "Rubi", planted in March 1999 at a spacing of 3.5 m between rows and 0.80 m between plants. The total area of the experiment is approximately 1.6 ha, divided into 18 plots of about 888 m^2 each, aiming to distribute the treatments. The soil is classified as Purple Eutrophic Latosol.

The experimental delineation was of randomized blocks with six treatments and three replications. To establish the interval of matric potential of soil water, the treatments consisted of water depths applied according to percentages of Kc values currently used by irrigators in Lavras-MG and reference evapotranspiration (ET_0), i.e.: Tr 01 = 0; Tr 02 = 60%$KcET_0$; Tr 03 = 80%K_cET_0; Tr 04 = 100% K_cET_0; Tr 05 = 120% K_cET_0; and TR 06 = 140%K_cET_0. In each experimental plot eight plants were considered for evaluations. Irrigation was performed always on Mondays, Wednesdays and Fridays.

The values of matric potential (h) were obtained by matric sensors connected to data-loggers where data were measured and stored each hour. The collection of data stored from data-loggers was performed using a notebook. Sensors were installed at depth of 0.25 m, being 0.40 m apart from the stem of the crop.

Results were compared during the coffee crop development and production. Behavior of matric potential data obtained throughout each phenological stage of the crop was investigated. For this purpose, simple linear regression of matric potential (h) data for each plot was analyzed and to obtain the best treatment, lowest angular coefficient was seek and expected to contribute to a greater crop productivity. To establish the interval of matric potential of soil water, average potential values, before and after each irrigation, throughout each stage of the crop, were measured.

The collection and tabulation of data were made along the years 2007 and 2008. The monitoring was divided into four periods, corresponding to the phenological phases of coffee, i.e., Period A - 01/01 to 03/31, Kc = 1.15 (fruit expansion); Periodo B - 04/01 to 07/31 (ripening), Kc = 1.10; Period C – 08/01 to 10/31 (dormancy), Kc = 0.90; and Period D – 11/01 to 12/31 (flowering, small green and expansion of fruits), Kc = 1.30. At period B, the data were collected between 04/01 and 05/18 for the years 2007 and 2008, because during the period 05/19 to 07/31/2007, the irrigation was not performed in the farming in order to standardize the flowering and to allow the harvest of the experimental plots.

To evaluate the effect of soil water tension on productivity of coffee, data for two harvests (2006/2007 and 2007/2008) were considered. The productivity averages were compared by Tukey test at 5% significance level.

RESULTS AND DISCUSSION

Coffee yield

The analysis of variance for coffee productivity observed in crops 2006/2007, 2007/2008 and the sum of the two crops revealed that there were significant differences between treatments in crops analyzed, at 5% level of significance.

Results for coffee yield are presented at table 1 for crops 2006/2007, 2007/2008 and the sum of both crops. Treatment 4 (100% KcET0) resulted in higher productivity for both harvests. In the 2006/2007 harvest, treatment 4 was considered statistically equal to treatment 5; however, in

2007/2008, the same treatment was considered equal to the treatments 5, 6 and 3, and equal to treatments 5 and 6 for the sum of both harvests.

Considering the sum of the two harvests, the productivity achieved by treatment 4 was 149.67 bags (60 Kg) per hectare, considered as an excellent average productivity, over 70.0 sc ha^{-1} per year. Given the importance of coffee productivity to economical return to the growers, it is important to notice that the productivity obtained with the best treatment (Tr 04) at 2006/2007 and 2007/2008 seasons, were 239 and 300% respectively higher to yield presented by the non-irrigated treatment (Tr 01).

TABLE 1. Table of averages detailing the irrigation effects on yield of crops 2006/2007 and 2007/2008 and the sum of both crops.

Treatments	Productivity (sc ha^{-1})		
	Crop 06/07	Crop 07/08	Sum of Crops
4	45.59 a	104.08 a	149.67 a
5	38.35 ab	89.27 ab	127.63 ab
6	26.57 bc	94.73 ab	121.30 ab
3	21.50 c	80.74 abc	102.25 bc
2	17.56 c	61.46 bc	79.02 cd
1	15.15 c	43.48 c	58.63 d

* Means followed by the same letter do not differ at the level of 5% probability by the Tukey test.

It can be noticed in Table 1 that the productivity rises as the water depth increases, reaching a maximum value (Tr 04) and thereafter tends to decrease with the increase of water applied. The reduction in productivity of plants irrigated with depths relatively high (Tr 5 and 6) is explained possibly by excess water in root zone resulting in lack of oxygen or probably by leaching of nutrients by excessive irrigation water to deeper layers. Thus, increasing the amount of water applied to coffee plants does not necessarily result in increased productivity.

In this study, the control treatment was the one where the average productivity was lower, indicating that the use of irrigation in coffee crops in Lavras-MG is an advantageous practice, even this area presenting annual rainfall above 1,500 mm (DANTAS et al., 2007). This superiority of the irrigated plants compared to non-irrigated was also found by ROTONDANO et al. (2005) in Uberlândia - Minas Gerais State, by BONOMO et al. (2008) in Jataí - Goiás State and by LIMA et al. (2008) in Lavras - MG, all in Brazil.

Matric potential of soil water

During the development of this research, it was noticed that the data of matric potential of soil water recorded in different growth stages were similar from one year to another, and therefore the results were discussed based on data registered in 2008.

The variation of values of matric potential of soil water (h) at 0 to 0.25 m layer, measured in non-irrigated and irrigated plots with the different treatments during the period A (fruit expansion), can be viewed in Figure 1. At this figure linear equations fitted to h values are presented.

It can be observed in Figure 1 that the angular coefficient of the line fitted to h values recorded in non-irrigated plots (Tr 1) was -0.266. The high positive value of the angular coefficient found when compared to the equations of the straight lines adjusted to the data observed in the irrigated portions, indicates reduction tendency in the values of h over the period and, consequently, reduced water availability for plants, which explains the lower productivity of coffee in the non-irrigated portion. It is noteworthy that a large proportion of the fruits harvested in this portion were deffective, probably because of the occurrence of water deficit, which, according to CAMARGO & CAMARGO (2001), in the fruit expansion internal fluids solidify, giving formation to coffee grains, so when water deficit occurs it can result in poor endosperm formation, or "void process" of the fruit.

Analyzing the h values recorded in the layer of soil irrigated with 2 and 3 treatments (60% and 80%Kc - Figure 1), it was found that the angular coefficients of the straight lines fitted (-0.034 and -0.048) were relatively low, however the matric potential values observed in some periods were also relatively low, reaching values lower than -50 kPa. It is noteworthy that the average productivity of coffee obtained through these treatments was reasonable (Table 1), but below that obtained with the treatment 4 (higher productivity).

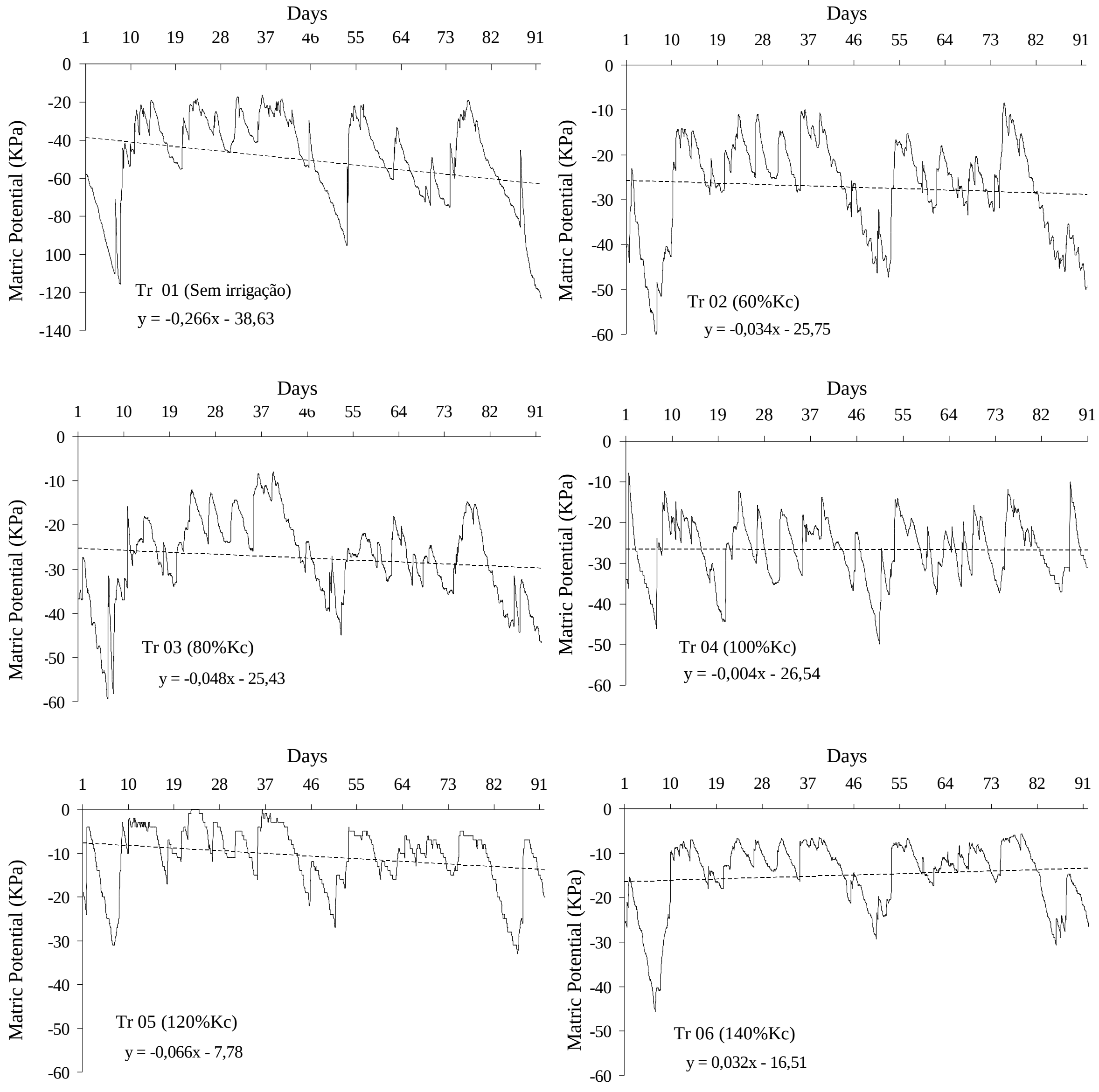

FIGURE 1. Variation of the average values of matric potential observed at the non-irrigated portions (Tr 01) and at the irrigated portions with the treatments 2 to 6, during the period A (germination of fruit), in Lavras - MG.

It can also be observed at Figure 1 that the treatment 4 (100%Kc) showed the best result, i.e., the one that maintained more regular values of matric potential throughout the crop cycle, indicating less variability in the soil water content, justified by the lower angular coefficient (-0.004) of the line. The values of matric potential (h) observed in irrigated plots with this treatment ranged from -10 to -35 kPa. When compared to results of productivity, this tension range seems to be satisfactory as it probably warranted, at this stage, the ideal soil moisture which contributed to a better vegetative growing without water restrictions.

At plots irrigated with treatments 5 (120%Kc) and 6 (140%Kc), even during the period A (Figure 1), values of h observed in some periods remained below -10 kPa, corresponding to field capacity of the cultivated soil. Therefore, the depth applied based on these treatments may have contributed to excess water in root zone and consequently in nutrient losses and water percolation to deeper layers, confirming reports of SOUSA et al. (2006). On the other hand, irrigating the plots with such treatment may result in increased costs of water and electricity.

During the stage of fruit maturation (Period B) we also found that the treatment 4 (100%Kc) was the one that presented the best results, as seen in Figure 2 (angular coefficient of -0.272), despite the descendent tendency of h values recorded over the period, reaching a value close to -40 kPa. We also noted at this stage that the treatments 2 and non-irrigated (TR 1) were those with the worst outcome (Figure 2). It is noteworthy that despite the productivity of plants irrigated with treatment 4 have surpassed those of plants irrigated with other treatments, the quality of the fruits harvested when the plants were irrigated with treatment 03 was relatively higher than those achieved with other treatments, where values of soil water potential were lower compared to those made when the plants were irrigated with the treatment 4. These results are in agreement with results reported by GUERRA et al. (2006) and CUSTÓDIO et al. (2007), who claim that the crop evapotranspiration (ETc) decreases significantly at this stage and the moderate water deficits may even benefit the quality of harvested coffee. The authors found that the suspension of irrigation from June 15th to end of August resulted in higher quality coffee. It is worth noting that at this stage, when plants were irrigated with treatments 5 and 6, the registered values of water potential in the soil were relatively high, therefore, with excess of water in the region of the radicular system of plants irrigated with these treatments.

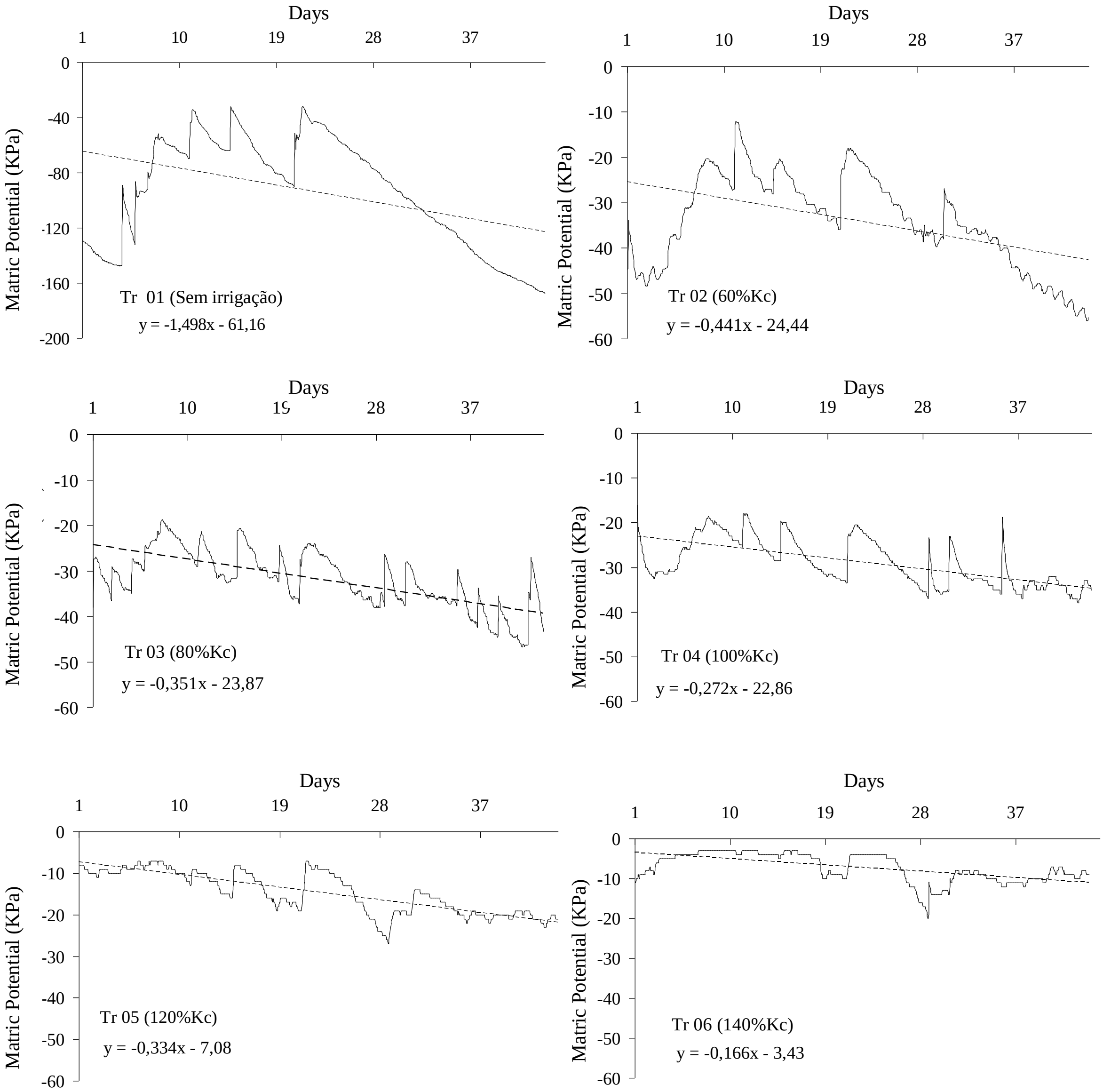

FIGURE 2. Variation of the average values of matric potential observed at the non-irrigated portions (Tr 01) and at the irrigated portions with the treatments 02 to 06, during the period B (maturation of fruits), in Lavras - MG.

Variations in average values of h are shown in Figure 3, in non-irrigated plots and also for irrigated ones with treatments 1 to 6, during period C (dormancy).

Observe that, unlike previous cases, the treatment 3 presented the best result (angular coefficient = 0.010), followed by treatment 2 (average angular coefficient = 0.072). We observed that in general the minimum values of matric potential recorded in soil irrigated by these treatments reached values of -31 and -34 kPa, respectively. Analyzing the Figure 3, we verify that the values of h recorded in plots irrigated with treatment 1 (without irrigation) reached the maximum value (-229 kPa) measured by the sensors used. We emphasize that in these plots, symptoms of water deficit such as wilting and defoliation of plants, were noticed justifying once again the importance of coffee irrigation at Lavras – MG region.

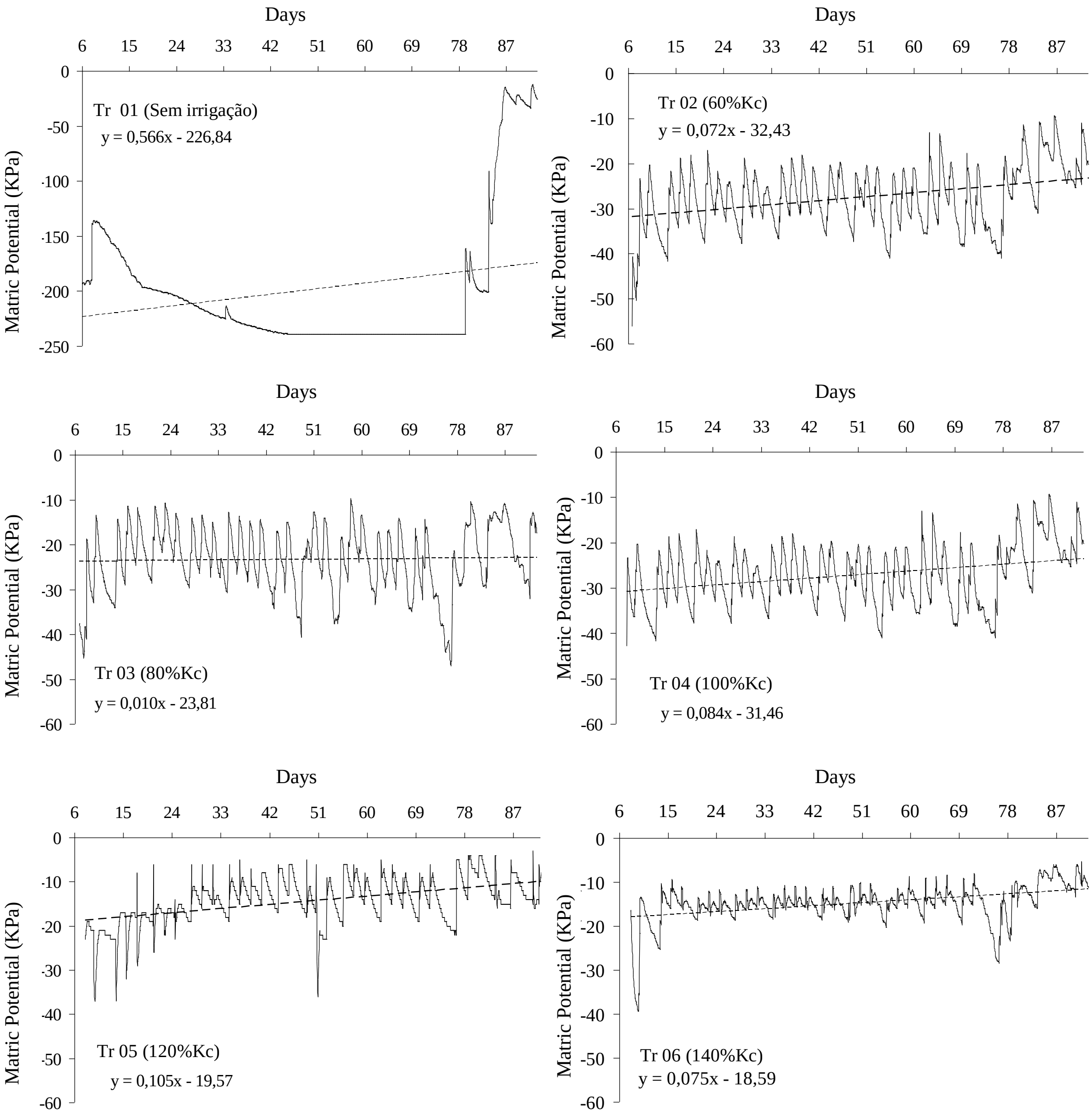

FIGURE 3. Variation of the average values of matric potential observed at the non-irrigated portions (Tr 01) and at the irrigated portions with the treatments 2 to 6, during the period C (dormancy), in Lavras - MG.

During period D (flowering, small green and expansion of fruits), values recorded in the matric potential registered in the soil irrigated with treatments 2 and 3 showed similar tendencies highlighting the treatment 3 (Figure 4) where the angular coefficient of fitted line was the lowest (-0.007) of all treatments, though it was observed that between the 17^{th} and 45^{th} days, the recorded values of h when irrigated with this treatment were relatively low, ranging between -27 to -42 kPa, which may have resulted in low levels of moisture in the soil during this short dry period. Although the angular coefficient of the fitted line determined at treatment 4 was higher when compared to the straight line adjusted to the values of h recorded with treatment 3, values of h after the irrigation maintained near -10 kPa, tension corresponding to field capacity at cultivated soil. In general, before completion of irrigation, values of h reached -32 kPa. It was also observed that non-irrigated plants presented abortion of coffee flowers and consequently, reduced yield. As seen in Figure 4, the high values of matric potential recorded in non-irrigated plots (Tr 1), demonstrated a considerable reduction in the water content at soil during this period, thus justifying the plant damages, which corroborates the reports of REZENDE et al. (2006) who found similar results. It is also noticed that the water depth calculated over treatments 5 and 6 probably also promoted excess water in the soil at this stage, justified by the low values of h recorded.

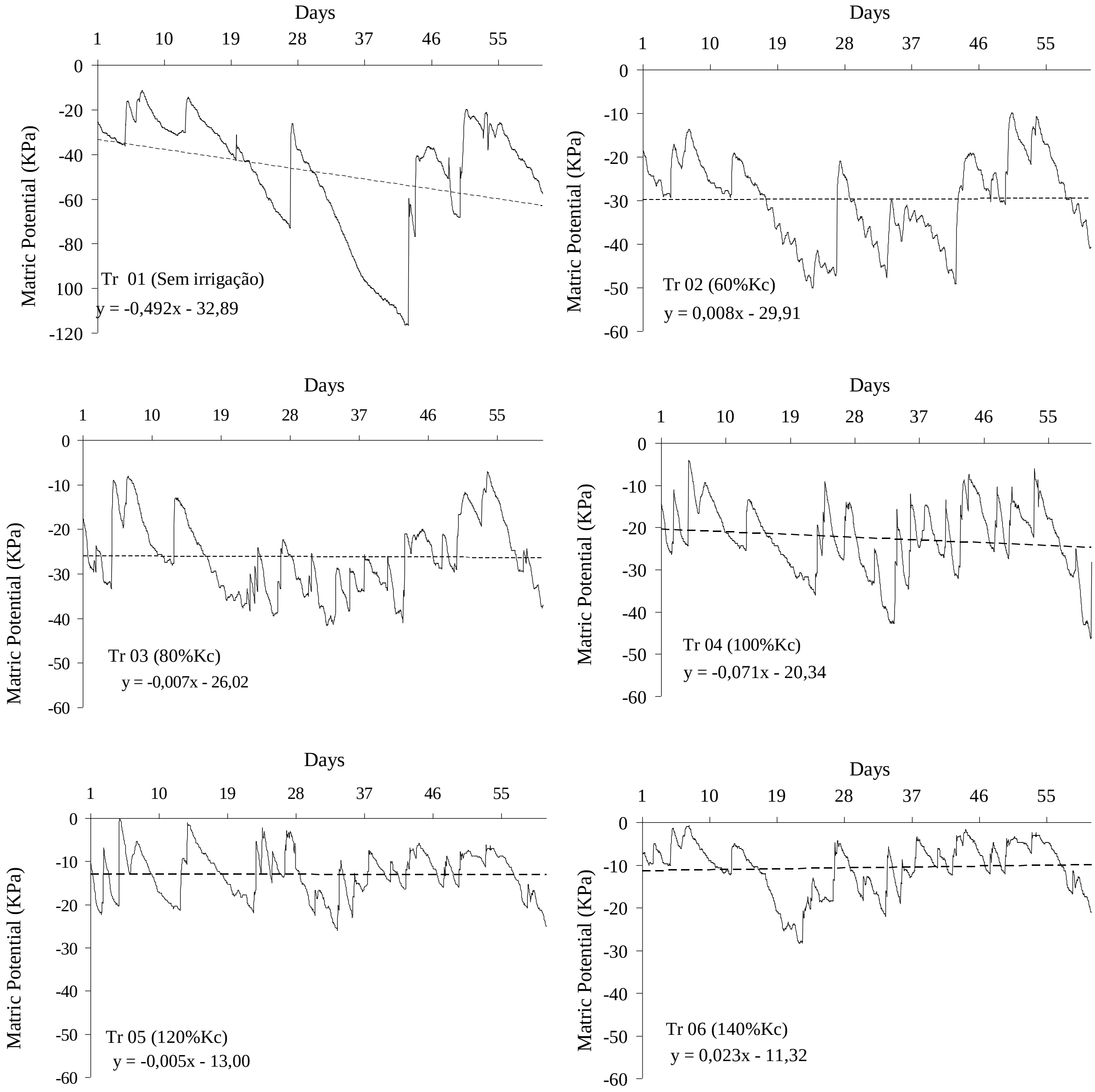

FIGURE 4. Variation of the average values of matric potential observed at the non-irrigated portions (Tr 1) and at the irrigated portions with the treatments 2 to 6, during the period D (flowering, small green and expansion of fruits), in Lavras - MG.

CONCLUSIONS

In the stages of growth and maturation of fruits, the best results were recorded when, before irrigations, the values of matric potential of soil water reached -35 and -38 kPa, respectively; and in the stages of flowering, small green and expansion of fruits, when the values of matric potential reached values of -31 and -32 kPa, respectively.

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