

Limitation of relative transpiration and growth of Arabic coffee in response to water deficit

ABSTRACT

The water has been the most limiting resource in the production of modern agriculture, and knowing its availability to plants is a crucial factor for the good performance of crops. The objective of this study was to evaluate the limitation of transpiration and growth of arabica coffee plants as a function of the reduction of water availability through the methodology of the fraction of transpirable soil water (FTSW). The study was conducted in a greenhouse of the Center of Agrarian Sciences and Engineering of the Federal University of Espírito Santo, located in the municipality of Alegre, Espírito Santo State, Brazil, with coordinates 20°45' S, 41°32' W and altitude of 269.0 m, in a factorial scheme 3x2, being the period of induction of the water deficit in three levels (P1= at 45 days after planting, P2= at 75 days after planting and P3= at 105 days after planting) and replenishment of water in the soil on two levels (T0-without water deficit and Td- water deficit induced until the plants reach 10% of the relative transpiration of the T0 treatment), in a completely randomized design with eight repetitions. The following variables were evaluated: relative transpiration (RT), mean leaf area (MLA) and mean plant height (MPH). It was concluded that the younger the plants are subjected to water deficit, the more sensitive they are to the effects of the phenomenon, and the first variable to be affected by the deficit is MPH. With the plants maturation there was gradual gain of resistance, which in some cases resulted in responses between treatments statistically equal.

Keywords: FTSW, *Coffea arabica*, water resources, irrigation management.

1. INTRODUCTION

The coffee is one of the most valuable commodities marketed, leaving behind only petroleum [1]. According to the National Supply Company - CONAB (2018), Brazil remains the world's largest producer and exporter of coffee. Estimate for the 2018 harvest a volume of 58.5 million bags benefited, in a total area of 2,202.6 million hectares [2].

The area planted to arabica coffee corresponds to 81% of the existent area with coffee plantations and represents approximately 76% of the country's total production, estimated from 41.74 to 44.55 million bags for the 2018 harvest [2]. The State of Minas Gerais stands out as the largest national producer of this species with an area of 1.23 million hectares and an estimated production between 29.1 and 30.6 million bags [2].

According to Arruda [3], expected an increase in the frequency and intensity of drought periods in the near future as a consequence of climate change, causing substantial losses in agricultural areas. Drought is the problem that has most affected the Brazilian coffee-growing, putting at risk the predictions of future crops [4], and it is essential to improve techniques that aim to minimize the effect of this phenomenon.

The water deficit occurs frequently during the coffee cycle, and may have a considerable negative impact on crop growth [5]. During these periods, several physiological processes occur [6,7], such as the reduction of the turgescence of the cells causing a decrease in the water potential and the decrease of the stomatal conductance, blocking the influx of CO₂ affecting the accumulation of photoassimilates, both lead to inhibition of cell growth, photosynthesis and productivity [8,9].

To minimize the effects of drought the irrigation technique becomes fundamental. In the Brazilian Cerrado, the irrigation during the flowering period guaranteed the ripening of the fruits, providing an

estimated 1.8 million bags benefited [2]. However, knowing the water requirement of the crops becomes a key factor for the correct application of the technique, in order allow to supply the demand of each species in its respective phenological phases and making the rational use of water resources. The fraction of transpirable soil water (FTSW) is an index used to evaluate the water requirement of each crop and consequently the effect of soil water deficit on transpiration and growth variables, allowing the detection of critical FTSW, when it occurs [10,11]. It is the concept that most closely approximates as an indicator of the actual amount of water in the soil that can be extracted by plants for transpiration [12].

Several authors report the use of the methodology as Araujo et al. [13,14] for the coffee Arabica and Conilon, Lago et al. [11] for potato, Pinheiro et al. [15] for cassava, Ramos and MartínezCasasnovas [16] in grapevine, Kelling et al. [17] for chrysanthemum and Ribeiro et al. [18] of coffee conilon variety diamante. However, in the literature different critical FTSW values are found, a consequence of soil, climate and crop variations [19]. Thus, the objective of this study was to quantify the influence of soil water deficit on transpiration and on the growth variables for arabica coffee plants, variety IAC 144.

2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY

The study was carried out in a greenhouse at the Center of Agrarian Sciences and Engineering of the Federal University of Espírito Santo (CCAUE/UFES), located in the municipality of Alegre, Espírito Santo State, Brazil (20°45' S, 41°32' W and altitude of 269.0 m). Three experiments were conducted on the cultivation of arabica coffee (*Coffea arabica*), variety IAC-144.

The experiment was set up in a 3x2 factorial scheme, the periods of induction of the water deficit being three levels (P1 = at 45 days after planting, P2 = at 75 days after planting and P3 = at 105 days after planting) and the replacement of water at two levels (T0 = control, irrigated throughout all period of the experiment and Td = water deficit induced until the plants reached 10% of the relative transpiration of the T0 treatment), with 8 replications.

Each experimental pot portion, with 12 liters, was coated with white paper to reduce the absorption of solar radiation minimizing the heating of the soil. The soil used as substrate was classified as a Red-Yellow Latosol, of medium texture, being collected in the depth of 0.00 to 0.30 m, disruptioned, passed in a sieve of 4 millimeter and homogenized. Soil samples were sent to the CCAUE/UFES Soil Laboratory for chemical and physical characterization (Table 1), according to the methodology proposed by EMBRAPA [20].

Table 1. Chemical and physical attributes of the Red-Yellow Latosol used as substrate.

pH	P	K	Ca	Mg	BS	CEC	V	Sand	Silt	Clay
mg dm ⁻³			cmol _c dm ⁻³ %				%			
4.51	2.50	30.0	0.41	0.26	0.80	4.60	17.23	66.0	6.0	29.0

Extraction and determination: pH in water (1:2.5); P, K, Na: Mehlich 1; Ca, Mg, Al: KCl (1M); H+Al: calcium acetate (0.5M), CTC a pH 7.0. For physical analysis slow stirring at 50 rotations per minute for 16 hours, with wagner type stirrer; chemical dispersant: NaOH 0.1 mol L⁻¹ and determination of the silt and clay fractions by the pipette method [13].

The soil acidity correction was according to the methodology proposed by Prezotti et al. [21], the nutritional fertilization as recommended by Novais, Neves and Barros [22] and the making of the soil water retention curve according to Van Genuchten [23].

The seedlings of arabica coffee plants were obtained in a suitable and certified nursery, available in tubes with comercial substrate, free of pathogens, and presented a pattern of three pairs of leaves. During the experiment was carried out the monitoring and management of pests and diseases.

The performance of the plants submitted to the water deficit was verified by the method of the fraction of transpirable soil water (FTSW) in two stages of water deficit, as described by Sinclair & Ludlow [10]; in stage I, water is freely available in the soil, with no water deficit, where stomatal conductance and transpiration are potential; in stage II, the available water in the soil decreases, and the stomatal conductance and the transpiration decrease, to maintain the water balance and the cellular turgescence.

The initial weight of each plot (Wi) was determined, which corresponds to its weight with the soil moisture near the field capacity, through the weighing of the pots already with the seedlings

established after being saturated and remain for 48 hours in free drainage. The soil surface of each pot was covered with white styrofoam to ensure that all lost water was obtained from the transpiration process.

The applications of the water regimes were initiated according to the age of the plants (P1 = 45, P2 = 75 and P3 = 105 days after planting), applying the water deficit in the Td pots, which were no longer irrigated until end of the experiment, that is until the relative transpiration (RT) of the Td plants reached 10% of the transpiration of the T0 plants, which occurred before the plants reached the permanent wilting point.

All experimental plots were weighed daily at 5:00 p.m. in an electronic weighing-machine with a capacity of 25 kg, and variation 0.5 g, thus, knowing the amount of water that the T0 treatment plants transpired from the previous day. The daily loss of water by the T0 plants was determined according to equation 1 and for Td according to equation 2, as demonstrated by Kelling et al. [17]:

$$RT_0 = W_d - W_i \quad (1)$$

where: RT₀ – relative transpiration T0 plants; W_d – weight of each pot on the day of weighing; and W_i – weight of the same pot on the day of the start of the experiment.

$$RT_d = W_d - W_{da} \quad (2)$$

where: RT_d – relative transpiration Td plants; W_d – weight of each pot on the day of weighing; and W_{da} – weight of the same pot on the day of the start of the experiment.

Then, the average daily loss of water in the 8 plants constituting the T0 treatment in each experiment was calculated. With the obtained value the water lost by sweating on the day was returned, each plot returning to its value of W_i. The Td plants did not undergo water replacement in order to reach the pre-established limit.

With these variables, it was possible to monitor the decrease of RT by the equation described by Sinclair & Ludlow [10]. The 10% limit of relative transpiration was adopted because it is assumed that below this transpiration rate the stomata are closed and the loss of water is due only to epidermal conductance.

$$RT = \frac{DTT_d}{ADT_0} * 100 \quad (3)$$

where: RT – relative transpiration; DTT_d – daily transpiration of treatments that suffer deficit; and ADT₀ – average daily transpiration of treatment T0.

The end of the water deficit period was determined when the Td treatment plots reached 10% of the relative transpiration of the T0 treatment, at which time the weight of each plot was calculated and it was determined as final weight (W_f).

In order to evaluate coffee responses to water deficit was used the concept of fraction of transpirable soil water (FTSW), used by several authors such as Sinclair and Ludlow [10], Muchow and Sinclair [24], Bindi et al. [25], Lago, et al. [26], Rodrigues et al. [18] Kelling et al. [17] and Pizetta et al. [27]. The fraction of transpirable soil water was calculated by equation 4 [10].

$$FTSW = \frac{(W_{daily} - W_f)}{(W_i - W_f)} \quad (4)$$

where: FTSW – fraction of transpirable soil water; W_{daily} – weight of the experimental plot in each day; W_i – initial weight of each experimental plot; and W_f – Final weight of each experimental plot.

The growth variables evaluated were: plant height (PH, in centimeter, length of main stem at ground level to apical bud) and leaf area (LA, centimeter squared), calculated by the sum of the leaf area of all individual leaves of the plant. The growth analyzes were performed every 3 days, biometrically with the help of a graduated ruler.

Based on daily total LA and daily PH data, daily leaf area (LA) and daily height (PH) were calculated for each clone, considering the first normalization with the objective of normalizing the data in the range of 0 and 1, according to Equation 5 [17].

$$V = Vd_{total} - V0_{total} \quad (5)$$

where: V – variable in study (LA; PH); Vd_{total} – increase of the total variable in each Td plant; and $V0_{total}$ – Increase of the total variable in each T0 plant.

The second normalization was carried out with the intention of reducing the variations between plants, caused by the environmental conditions of the greenhouse, according to equation 6 [28]:

$$Nv = \frac{\text{value RT 10\%} - \text{value}(n)}{\text{value RT 10\%} - v_{initial}} \quad (6)$$

where: Nv – normalized variable; Value RT 10 % – final value of the variable (when RT was 10%); Value (n) – value of the variable on the specific day; and $V_{initial}$ – value of the variable on the first day of the experiment.

The growth data of the dependent variables obtained from the second normalization were adjusted to a logistic function of the FTSW independent variable in a non-linear sigmoidal model (Equation 7) [25].

$$y = \frac{1}{(1 + \exp(a \cdot (X - b)))} \quad (7)$$

where: y – dependent variable (height and leaf area of plants); X – fraction of transpirable soil water; and a and b – coefficients estimated using non-linear regression procedures.

The adjusted curves were used to determine the critical FTSW value at which relative transpiration reduction was initiated. After the Td plots reached the pre-established limit, the pots were saturated with water in order to return the soil moisture to the field capacity. During a period of 30 days periodic irrigations were carried out in order to provide adequate conditions to be able to quantify the effect of the water deficit between plants and their potential recovery capacity.

The data were submitted to analysis of variance ($P=0.05$), when the F test was significant, the Tukey test ($P=0.05$) was used for the qualitative factor and regression analysis for the factors quantitative. The models were chosen based on the significance of the regression coefficients, using the student's t test, at the 5% probability level and by the determination coefficient, using SAEG Software, version 9.1.

3. RESULTS AND DISCUSSION

All the logistic equations, in the three epochs of water deficit, presented good precision, with high values of efficiency of the statistical model (Esm) and low values of standard error of the estimate (Sde), corroborating with work of Araujo [13,14], Lago et al. [26,11], Martins et al. [29] and Rodrigues et al. [18].

The critical FTSW value in all variables decreased as a function of the greater age of the plants. The Arabica coffee tree presented a superior response to short-term water deficit in P3 and P2, with P1 being more sensitive to short-term water deficit, with early stomatal closure and loss of turgescence [27]. This fact was already expected, since the younger plants have a less developed root system [18], making soil exploration difficult, as well as less efficiency in stomatal regulation.

The RT variable (Figure 1) in P1 obtained a critical FTSW mean value of 0.76, in P2 of 0.67 and in P3 of 0.47. The values diverge from Pizetta et al. [27] who verified critical FTSW value of 0.52 and 0.44 for arabica coffee Catucaí Vermelho 785-15 variety water deficit applied at 30 and 90 days after planting respectively. Santos & Carlesso [12] argue that this result is common, since the effects of water deficiency may vary according to genotype, duration, severity and stage of development of the plant.

The high value of FTSW represents the precocity of stomatal closure, leading to reduced plant growth in a short cycle of deficit [9]. However, Ray and Sinclair [30] state that in cultivation systems, species that reduce the degree of stomates opening in higher FTSW will save water and increase their chances of survival in prolonged drought periods.

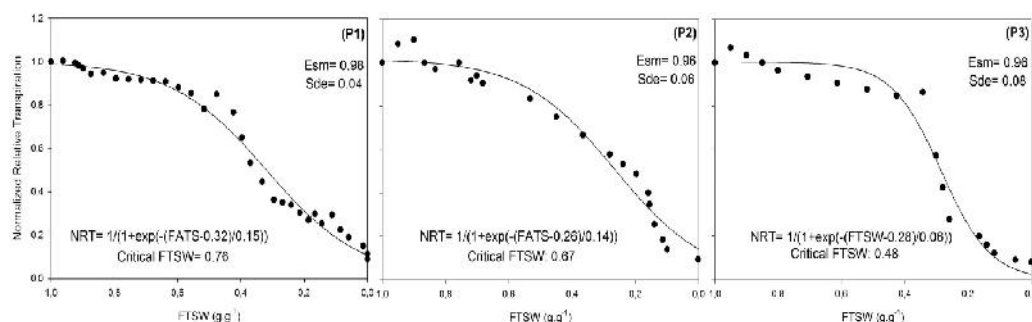


Figure 1 – Behavior of the normalized relative transpiration variable (NRT) of arabica coffee in function of the fraction of transpirable soil water (FTSW), in the three seasons "P1", "P2" and "P3" (45, 75 and 105 days after planting). In that T0 = irrigated plots throughout the experiment and Td = water deficit induced until the plants reach 10% of the relative transpiration of T0.

For the plant height variable (Figure 2) it is observed a greater resistance to the deficit again as a function of the higher age of the plants, finding critical FTSW values of 0.52; 0.70 and 0.81 in P3, P2 and P1 respectively. In the work of Rodrigues et al. [18] critical FATS value with the advancement of the evaluation times for PH were 0.67; 0.55; 0.36 at 30, 60 and 90 days after planting. The variable PH obtained higher values of FTSW in relation to RT, indicating the greater sensitivity of this the water variation, and also, being the first variable to be affected. Corroborating with Larcher [6], where PH is the first and most sensitive variable to respond to the water deficit, causing a decrease in turgor pressure and consequently paralysis in the process of growth and extension of the plant.

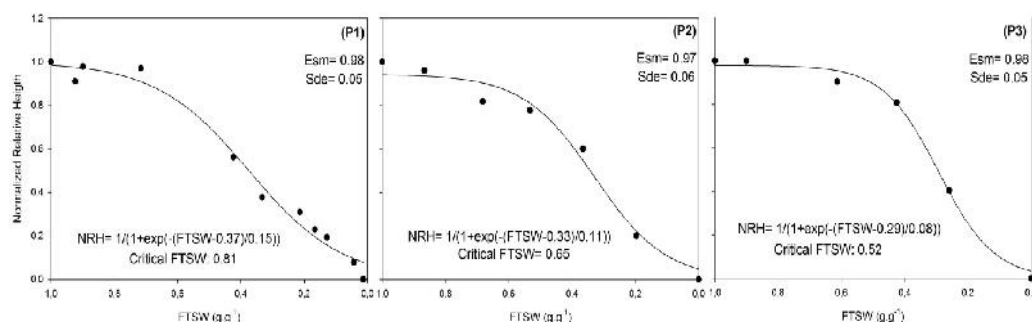


Figure 2 – Behavior of the normalized relative height (NRH) of arabica coffee in function of the fraction of transpirable soil water (FTSW), in the three seasons "P1", "P2" and "P3" (45, 75 and 105 days after planting). In that T0 = irrigated plots throughout the experiment and Td = water deficit induced until the plants reach 10% of the relative transpiration of T0.

For the variable LA, critical FTSW values of 0.69, 0.5 and 0.43 were obtained for P1, P2 and P3 respectively. According to DaMatta; Ramalho, [31], the LA reduction is an adaptive strategy for plants to resist for longer in environments with water restriction, contributing to the reduction of transpiration, leading to lower growth, but providing water saving in the soil. Similar result was verified by Pizetta, et al. [27], where FTSW values for LA were 0.97 at 30 days after planting of arabica coffee plants and from 0.47 to 90 days. Martins et al. [29] claim that a decrease in the turgidity of the cells before stomatal closure is enough to affect the metabolism and cause a reduction in the growth and development of the seedlings. The critical FTSW values for LA are lower than the other variables. Indicating that the stoppage of leaf growth occurred after the stomatal closure mechanism, since there was no decrease in the cellular turgescence sufficient to reduce cell expansion and consequently the foliar growth [32, 33]. According

3	1672.4 Aa	1715.0 Aa	1693.7	2015.8 Aa	1942.5 Aa	1979.2	2406.1	2300.9	2353.4 a
2	1102.7 Ba	901.4 Bb	1002.1	1268.2 Ba	953.2 Bb	1110.8	1993.3	1827.1	1910.1 b
1	527.3 Ca	458.0 Ca	492.7	731.0 Ca	412.3 Cb	571.7	1150.2	715.0	932.6 c
$\bar{x}$	1100.8	1024.8		1338.4	1102.7		1849.8 a	1614.3 b	
CV	8.37(%)			6.96(%)			8.62(%)		

*The averages followed by the same lowercase letter in the row and upper case in the column do not differ from each other at the 5% probability level by the Tukey test. CV = coefficient of variation, $\bar{x}$ = average.

In the initial evaluation there was no significant interaction between the levels of the variables except for LA, due to the difficulty of standardization of this one, although in the selection the maximum of homogeneity between plants was sought, a circumstance also reported by Kelling et al. [17].

For RT, the averages of the isolated factors were statistically the same, indicating that at the beginning of the experiment all the plants had maximum potential of transpiration. For PH and LA there was a difference between the time factor and plant age, and for LA there was also a difference between water levels in P2.

The end of the experiment occurred when the T_d plants reached 10% of the RT of the T_0 plants, thus, the averages of the periods levels were statistically equal and significant between the water levels, as expected, varying the number of days that each season led to reach the pre-established limit. In P1 the plants were in water deficit for 33 days, in P2 21 days and in P3 18 days. During the water replenishment period, the most developed plants were able to restore their growth more easily, reaching a mean of 90.04% (P3), 82.09% (P2) and 71.40% (P1) equivalent to the RT of the T_0 treatment (Figure 4).

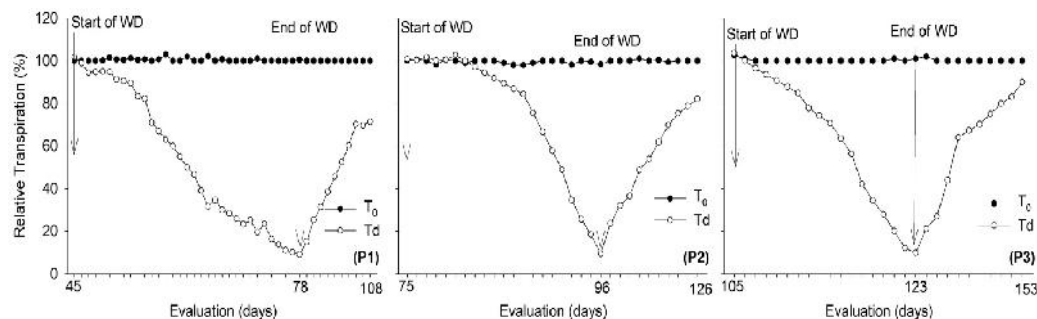


Figure 4 – Behavior of the relative transpiration variable (TR) of the arabica coffee, during the treatments, "P1," P2 "and" P3 "(45, 75 and 105 days after planting, respectively), and its recovery period. In that T_0 = irrigated plots throughout the experiment and T_d = water deficit induced to the plants reached 10% of the relative transpiration of T_0 .

The difference in the number of days is due to the stomatal closure [34], a common process in plants under water stress, providing a reduction in the RT, being a strategy developed by the plants as an attempt to avoid the loss of turgescence [35], and being the best way to deal with adversity. Costa et al. [36] working with deficit and recovery of mastic observed a rapid recovery in the transpiration rate of the plants after passing through period of water restriction.

However, the capacity of stomatal regulation varies according to the different stages of development of the plant, which allowed the better performance of P3, causing less developmental impairment and consequently greater recovery capacity, being statistically superior to the other seasons.

In the final evaluation for PH and LA there is a significant interaction between the factors. The PH variable obtained better performance in P3 (Figure 5), but statistically different among treatments (6.14% lower than T_0). This response directly affected the plots during the recovery period where P3 obtained the highest mean, reducing the difference to 5.75% (Figure 5).

The results corroborate with Peloso et al. [37] and Scalco et al. [38] who verified reduced plant height with prolonged water deficit time with plants in initial growth phase. Kramer & Boyer [40] explain that the reduction of the turgescence of the cells, caused by the water deficit in the soil, directly affects the process of cellular elongation, being necessary minimum levels of turgidity.

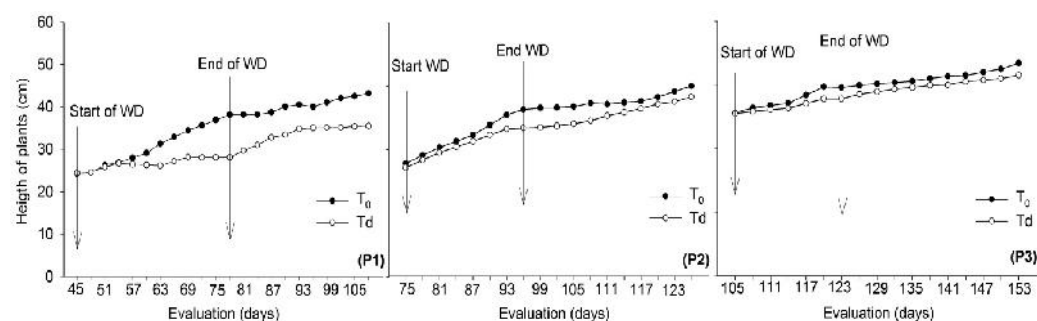


Figure 5 – Behavior of the plant height variable (PH) of the arabica coffee, during the treatments, "P1," P2 "and" P3 "(45, 75 and 105 days after planting, respectively), and its recovery period. In that T₀ = irrigated plots throughout the experiment and T_d = water deficit induced to the plants reached 10% of the relative transpiration of T₀.

For the variable LA at the end of the experiment there is significant interaction. The best results were obtained P3, which at the end of the water deficit period presented the smallest difference between treatments between the seasons (9.74%), being statistically the same. This allowed a better response to the recovery period, reducing the difference to 4.40% (Figure 6), statistically different from other periods. In P1 and P2 there was no difference between the averages of T₀ e T_d.

The reduction of LA was also verified in studies with other species, such as by Pinto et al. (2008), Busato et al. [41] and Silva et al.[42]. Peloso et al. [37] verified the negative influence of the water unavailability on the LA variable of the plants, decreasing this parameter with the decrease of the amount of water in the soil. Physiologically, the decrease of leaf area is the most effective response to water deficit, being a strategy of the plant to develop in environment with water restriction [43]. The reduction of leaf area contributes to the reduction of relative transpiration and photosynthesis, thus slower growth, resulting in higher soil water savings [32].

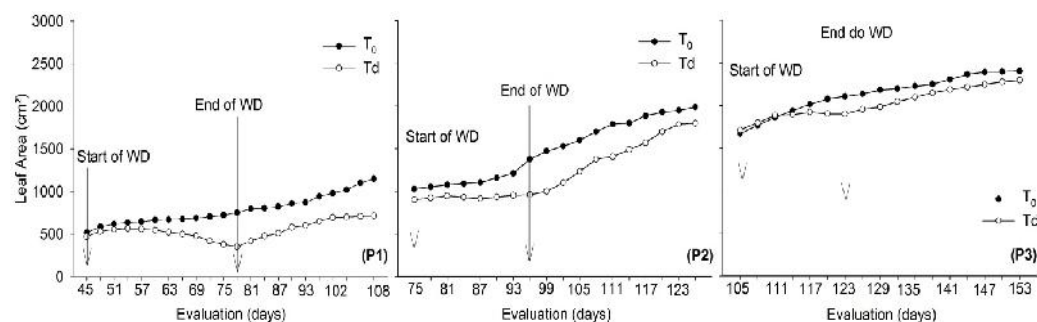


Figure 6 – Behavior of the leaf area variable (LA) of the arabica coffee, during the treatments, "P1," P2 "and" P3 "(45, 75 and 105 days after planting, respectively), and its recovery period. In that T₀ = irrigated plots throughout the experiment and T_d = water deficit induced to the plants reached 10% of the relative transpiration of T₀.

4. CONCLUSIONS

The plant height variable was the first and most sensitive to soil water variation. It is verified that the more developed plants (P3) were more efficient in the stomatal control, and consequently more resistant to the water deficit. The P3 plants presented better response of the variables during the period of 30 days of recovery imposed. The water deficit directly affected the growth and transpiration of the plants, with lower effects on P3 plants, allowing Td plants to have averages statistically equal to plants T0 for leaf area variable.

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