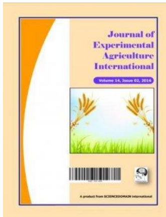

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Water Deficit as a Limiting Factor to the Initial Growth of Coffee Conilon Variety Diamante

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Authors' contributions

This work was carried out in collaboration between all authors. Authors WRR, AAP, DSF and MSG developed the experiment, performed the statistical analysis of the data and wrote the first draft of the manuscript. Authors and university professors CASM and EFR actively participated in the design of the project, orientation of the execution stages and elaboration of the data, being also responsible for the correction of the manuscript, contributing significantly to the improvement of the work. All authors read and approved the final manuscript.

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ABSTRACT

The water deficit is considered one of the main limiting factors of agricultural production, studies that aim to understand it become essential for improving productivity and rational use of water resources. Thus, the objective of this work was to evaluate the influence of the reduction of the fraction of transpirable soil water (FTSW) under the growth variables of the nine clones that compose the variety "Diamante Incaper ES8112" of the coffee Conilon and to estimate the critical FTSW (when the growth potential is reduced by the limitation of the transpiration process). The nine experiments were conducted in a greenhouse, located in the Center of Agrarian Sciences and Engineering of the Federal University of Espírito Santo, in the city of Alegre-ES, (20º45' S, 41º32' W and altitude of 269.0 m). The present study was carried out in the greenhouse, located in the Center

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of Agrarian and Engineering Sciences of the Federal University of Espírito Santo, in the city of Alegre-ES, Brazil. The experiment was carried out in a 9x2 factorial scheme, being clones of the variety Jequitibá Incaper ES 8122 in 9 levels and 2 levels of water regime (T_0 - irrigated during the whole experiment, not suffering water deficit; T_d - induced water deficit until the plants reached 10% of the relative transpiration of the T_0 treatment), in a completely randomized design with 8 replications. The variables evaluated were: relative transpiration (RT), plant height (PH) and leaf area (LA). At the end of the experiments it was verified that the clones are affected at different times, showing that they have different water needs, being clone 104 characterized as the most resistant to the water deficit in the soil, for keeping the TR to a lower value of FTSW (0.47) and clone 108 was characterized as the most sensitive to soil moisture variation, with critical FTSW value of 0.82.

Keywords: Water resources; Coffea canephora; FTSW; irrigation management.

1. INTRODUCTION

Coffee production is a highlight in the Brazilian agricultural scenario, and according to the National Supply Company [1], the coffee production for this year is estimated between 54.4 and 58.5 million bags benefited. The total area, in formation and production, amounts to 2,202.6 thousand hectares, of which 286.5 are in formation and 1,916.1 thousand hectares in production. The coffee conilon accounts for approximately 24% of the country's total coffee production, estimated at between 12.7 and 13.96 million bags [1], with the state of Espírito Santo is the largest national producer, with around 7.7 and 8.7 million bags estimated, corresponding to a growth between 29.5 and 46.3% over the previous year.

In Brazil and in other regions of the world, drought is considered the main climatic aggravating factor affecting coffee production [2, 3]. The water deficit besides affecting the water relations in the plants, altering the metabolism, is a phenomenon that occurs to a great extent of the cultivable areas [4], being responsible for most of the variability of the final production [5].

CONAB [6] affirms that the occurrence of a severe drought in the State of Espírito Santo accompanied by high temperatures and sunshine between December 2014 and February 2015, directly impacted productivity (a decrease of 22% in relation to the previous year). The prolonged period of drought in the State generated a serious water crisis that served as a warning for studies related to the water aspect.

Faced with the problem of water deficit, irrigation becomes a practice constantly employed in regions with water deficit, because it plays a major role in production, since investments in the sector result in a substantial increase in productivity and production value, which causes pressure reduction by the incorporation of new areas for cultivation [7]. However, for the adequate use of this technique, knowledge about the water requirement of crops is essential in order to guarantee satisfactory results and the rational use of available water resources.

One of the factors that can be used to express the content of water in the soil is the fraction of transpirable soil water (FTSW), widely used for the evaluation of plant responses to water deficit. It is assumed in this concept that the water content in the soil used by the plant for transpiration oscillates between the soil water content in the field capacity when the transpiration is maximum; and the water content in the soil, when the transpiration of the plant is equal to 10% of the maximum [8]. This seems to be the concept that most closely approximates as an indicator of the actual amount of water in the soil that can be extracted from the plants for transpiration [9].

For the determination of FTSW, two stages [8, 10,11] are considered: the stage I is when water is freely available in the soil, the plant has no water deficiency and its stomatal conductance and transpiration are maximal, that is, the content of transpirable water in the soil does not limit stomatal conductance and transpiration; and the stage II when the available water in the soil decreases and the plant reduces its stomatal conductance and transpiration to maintain its water balance and cellular turgescence.

Lago et al. [12] affirm that several studies have been conducted to verify critical FTSW values ranging from 0.30 to 0.71 in annual agricultural species and from 0.70 to 0.90 in forest species. But, the knowledge of the influence of these values on the growth of colon coffee is still limited.

Therefore, the objective of this study was to quantify the influence of the soil water deficit, represented by FTSW, on the transpiration, plant height and leaf area of conilon coffee (Coffea canephora) and to determine critical FTSW, that is, the moment in that the fraction of transpirable soil water begins to limit the growth variables

2. MATERIALS AND METHODS

The experiment was conducted in a greenhouse located at the Center of Agrarian Sciences and Engineering of the Federal University of Espírito Santo (CCAE-UFES), located in the city of Alegre-ES (20°45' S, 41°32' W and altitude of 269.0 m), Brazil. The climate of the region is of type "Aw" with the dry season in winter, according to the classification of Köeppen, with an average annual temperature of 23°C and annual precipitation around 1,200 mm.

The experiment was carried out in a 9x2 factorial scheme, being clones of the variety Jequitibá Incaper ES 8122 in 9 levels and 2 levels of water regime (T_0 - irrigated during the whole experiment, not suffering water deficit; T_d - induced water deficit until the plants reached 10% of the relative transpiration of the T_0 treatment), in a completely randomized design with 8 replications.

The seedlings of the conilon coffee were obtained in a suitable nursery, certified, theses are available in tubes with a commercial substrate, free of pathogens and presenting a pattern of three pairs of leaves. During the experiment, the monitoring and management of pests and diseases were carried out.

Each experimental plot consisted of a 12-litre pot filled with soil characteristic of the region, containing one plant per plastic pot. The eight T0 replicates were used as controls, where the plants grew without water deficit, and the other 8 Td replicates, the water deficit was imposed until reaching the pre-established limit.

The soil used as substrate was classified as a Red-Yellow Latosol, with a medium texture, according to the textural triangle of EMBRAPA, being collected in the depth of 0.00 to 0.30 m, disturbed, passed in a sieve of 4 millimetre and homogenized. The soil samples were sent to the laboratory for chemical and physical analysis, according to the methodology proposed by Almeida et al. [13]. The chemical and physical attributes of the Latosol used as substrate are presented in Table 1.

With the results obtained, the soil water retention curve was determined. Then, the soil acidity was corrected according to the methodology described by Prezotti et al. [14] and fertilization as recommended by Novais, Neves and Barros [15].

The pots were coated with white paper to reduce the absorption of solar radiation to minimize the heating of the soil. Subsequently, the pots were placed on a metal bench (3.0 x 0.80 meter) with 1-meter height and weekly the standardization procedure was carried out between the pots of the same treatment.

The was performance of the plants submitted to the water deficit verified by the method of the fraction of transpirable soil water (FTSW) in two stages of water deficit [8]: in stage I, water is freely available in the soil, with no water deficit for the plants, and 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.

For the beginning of the experiment, it was necessary to determine the initial weight of each plot (Wi), which corresponds to its weight with the soil moisture near the field capacity. In order to do so, all pots with already established seedlings were saturated with water and left in free drainage for 48 hours in order to determine the weight of the experimental units with the soil moisture corresponding to the field capacity. The soil surface of each pot was covered with white polystyrene to ensure that all lost water was from the transpiration process.

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

pH	P	K	Ca	Mg	BS	CEC	V	Sand	Silt	Clay
	mg dm^{-3}			$cmol_c\ dm^{-3}$ %					%	
5.25	2.28	82	0.79	0.43	1.46	4.84	30.09	73	3.0	24

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 applications of the water regimes began 30 days after planting of the seedlings, applying the water deficit in the pots referring to the Td, which were not irrigated until the end of the experiment, that is, until the relative transpiration (RT) of the plants of the Td to reach 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. on an electronic scale with a capacity of 25 kilograms, and a variation of 0.5 g. Subsequently, each T0 treatment pot represented the response to the amount of water the plant 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. [16]:

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

Where:

RT_0 – Relative transpiration;
W_d – the weight of each pot on the day of weighing; and
W_i – the 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;
W_d – the weight of each pot on the day of weighing; and
W_{da} – the 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 Wi. The Td plants did not have 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 3 [8]. The 10% limit of relative transpiration was adopted because it is assumed that below this transpiration rate the stomas 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;
D – Daily transpiration of treatments that suffer deficit;
ADT_0 – 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 determined and it was identified as final weight (Wf).

In order to evaluate coffee responses to water deficit, used the concept of the fraction of transpirable soil water (FTSW) [8,10,11,16]. The fraction of transpirable soil water was calculated by equation 4 [8].

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

Where:

FTSW – Fraction of transpirable soil water;
W_{daily} – Weight of the experimental plot in each day;
W_i – the Initial weight of each experimental plot; and
W_f – Final weight of each experimental plot.

The growth variables evaluated were: plant height (PH, cm - is the length of the main stem at ground level up to the apical bud) and leaf area (LA, cm²), calculated by the sum of the LA of all individual leaves of the plant. The growth analyzes were performed every 3 days, biometrically with the aid of a graduated ruler.

Based on total daily LA data, the daily leaf area (LA) and daily height (PH) increment for each clone were calculated, considering the first normalization with the aim of normalizing the data in the range of 0 and 1, performed by Equation 5 [16].

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

Where:

V – Variable in the 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 performed with the aim of reducing the variations among plants, caused by the environmental conditions of the greenhouse, according to equation 6 [17]:

$$Nv = \frac{value\ RT10\% - value(n)}{value\ RT10\% - v_{initial}} \quad (6)$$

Where:

Nv – Normalized variable;
Value RT 10% – final value of the variable (when RT was 10%);
Value (n) – the value of the variable on a specific day; and
$V_{initial}$ – the 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 independent FTSW variable in a non-linear sigmoidal model (Equation 7) [11].

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

Where:

Y - Dependent variable (Height and leaf area of plants);
X - Fraction of transpiration soil water; e
a and b - coefficients estimated using non-linear regression procedures.

Adjusted curves were used to determine the critical FTSW value at which relative transpiration reduction was initiated.

At the end of the experiment, critical analysis and data tabulation were performed. Regression analysis of the variables was used as a function of the quantitative factor. 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

The value of the fraction of transpirable soil water, in which the relative transpiration reduction (RT) begins, occurs when the curve estimated by the logistic equation moves away from 1 and starts the linear decrease (critical point) [8].

Thus, it is observed in the cultivar Diamante that the critical FATS values for the RT variable were concentrated between a range of values of 0.47 and 0.82, confirming the hypothesis that the clones have different water needs. Souza [18] affirms that it is possible to occur variation among clones in different cultures since tolerance to water deficit is a genotype-dependent character.

Lago et al. [12] verified variation among clones of the same species in the potato crop, which presented a critical FTSW variation between 0.28 and 0.49, which indicates the existence of genetic variability for tolerance to water deficit. Kelling et al. [16] found variation between different cultivars in chrysanthemum, with oscillation from 0.48 to 0.65. Rodrigues et al. [19] found FTSW variation between species identical, but with different ages and that converged from 0.40 to 0.61.

The critical FTSW determination is a character of interest since it represents the ability of the genotype to respond to soil water deficit to maintain foliar turgescence [12]. The indication of the exact moment when the growth variables were affected is a fundamental factor to inhibit the effect of the water deficit, avoiding changes in the plant behaviour whose irreversibility will depend on the genotype, duration, severity and stage of development of the plant [9].

The clones that obtained the lowest values were clones 104 and 103 presenting critical FTSW of 0.47 and 0.56, respectively. These results are considered inferior to the results obtained by Rodrigues et al. [19], in the tropical Robusta species with critical FATS of 0.71. But, close to the results obtained for arabica coffee, variety Catucaí Vermelho 785-15 (0.52) [20].

It is possible to indicate that clones 104 and 103 have more efficient stomatal control mechanisms than the other clones that compose the variety because they can reduce the water consumption, probably due to the less stomatal opening, delaying the effect of reduction in leaf growth [12]. Probably, a form of adaptation to water deficit conditions [11,17].

The clones 107, 108 had the highest critical FATS values 0.79 and 0.82, respectively. The FTSW value at which the start of the stomas closure occurred is considered high when compared to other annual crops, as soybean (0.40) [8]; for maize (0.36 to 0.60) [21]; for

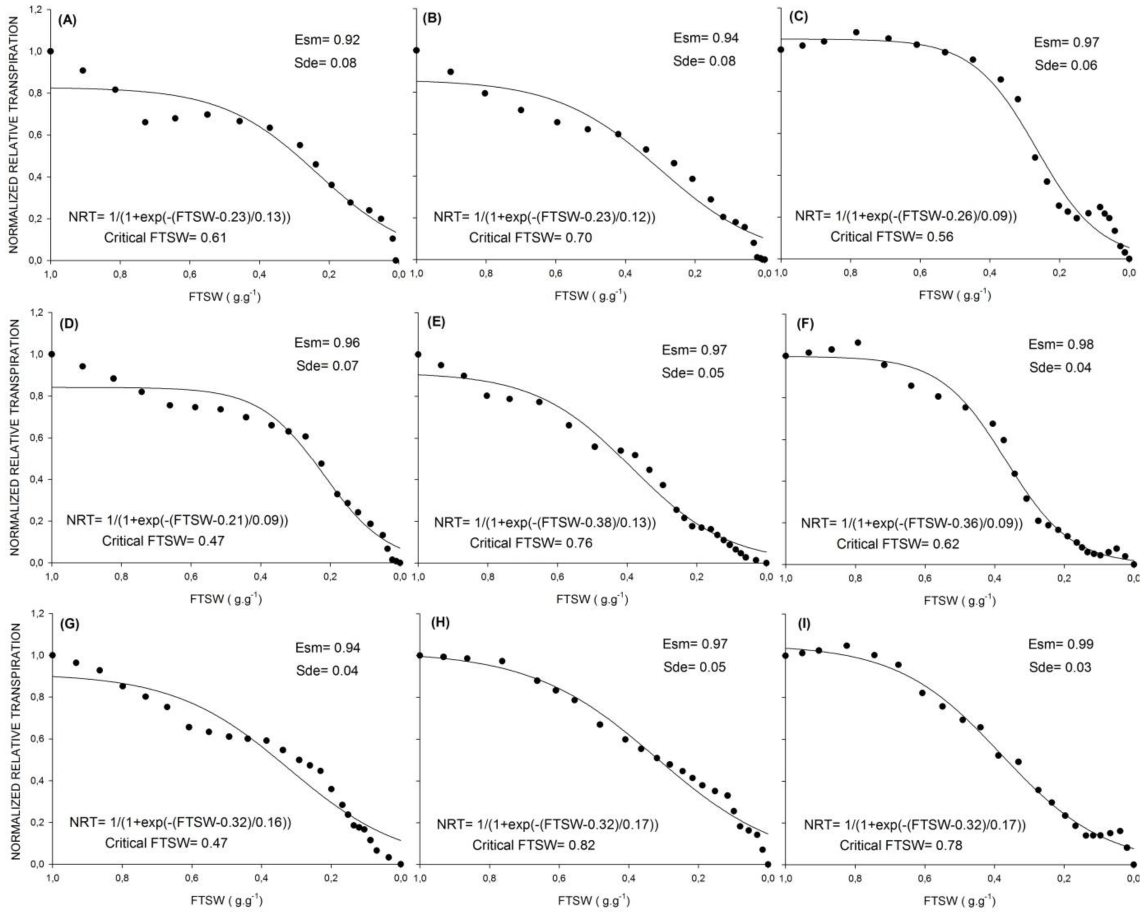

Fig. 1. Normalized relative transpiration (NRT) in function of the decrease of the fraction of transpirable soil water (FTSW), in the nine clones of conilon coffee Diamante Incaper ES8112 (''A''- Clone 101; ''B''- Clone 102; ''C''- Clone 103; ''D''- Clone 104; ''E''- Clone 105; ''F''- Clone 106; ''G''- Clone 107; ''H''- Clone 108; ''I''- Clone 109). Esm is the efficiency of the statistical model and Sde is the standard error

grapevine (0.35) [11]; but close to those obtained for Robusta Tropical of 0.61 [19] and of 0.80 [22].

The productive point of view, the reduction of RT caused by the premature closure of stomas causes impacts because during a cycle of short-term deficit there will be a loss of productivity [21]. However, from the biological point of view, the species that closes the stomas in higher FTSW will save water, since stomatal closure in a higher soil moisture condition results in water conservation in the soil and constitutes an adaptation of the species, a characteristic that contributes possibly to better withstand prolonged water deficit [10].

The relationships between RT and FTSW and stages I and II of transpiration observed in this species, in which the plants dehydrated under the same conditions of temperature and water demand, reinforces the theory that stomatal closure, to prevent or reduce water loss is determined by soil water content [8].

The behaviour of the plant height variable is shown in Fig. 2.

As a response to the water deficit applied to the coil coffee Diamante, we obtained for the relative height variable an FTSW range that oscillated from 0.48 to 0.84. The clones 104 and 108 may be characterized as the two most resistant (0.48 and 0.51), followed by clone 105 (0.52). Clones that performed poorly, with growth paralyzing at higher levels were clones 107 and 102, obtaining a critical FTSW of 0.84 and 0.85, respectively.

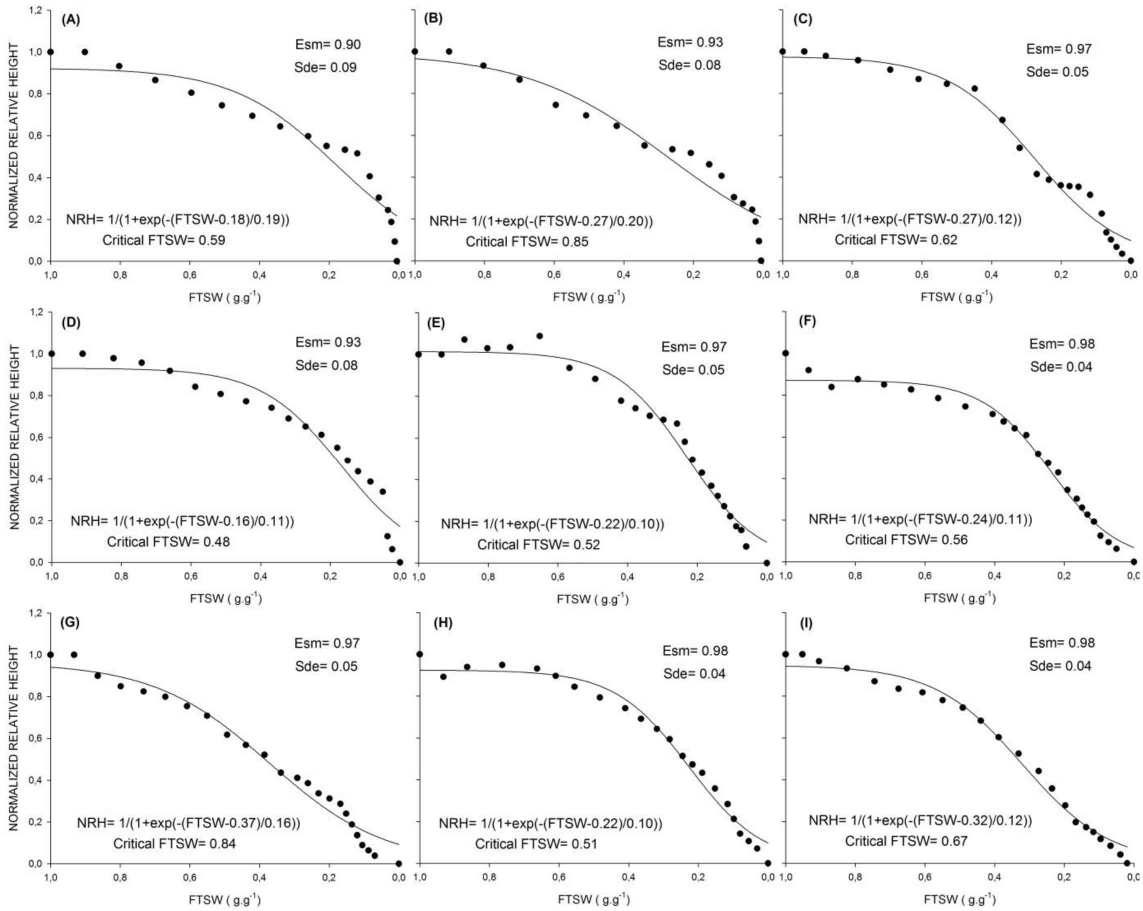

Fig. 2. Normalized relative height (NRH) in function of the decrease of the fraction of transpirable soil water (FTSW), in the nine clones of conilon coffee Diamante Incaper ES 8112 (''A''- Clone 101; ''B''- Clone 102; ''C''- Clone 103; ''D''- Clone 104; ''E''- Clone 105; ''F''- Clone 106; ''G''- Clone 107; ''H''- Clone 108; ''I''- Clone 109). Esm is the efficiency of the statistical model and Sde is the standard error

In some clones it is observed that the critical FTSW values for height variable were larger than the variable RT, that is, the height variable was more sensitive to the water variation, being the first variable affected. This is a statement by Larcher [23], where he reports that the first and most sensitive response to the water deficit is the reduction of turgescence and, associated to this event, is the decrease of the plant growth and extension process.

The results differ from that verified by Araújo [22] who found a critical FTSW value of 0.95 for the coffee plant but resembles the results of Rodrigues et. al [19] who applied water deficit at 30 days after planting in Robusta Tropical coffee plants where they observed a critical FTSW of 0.67.

Dardengo et al. [24] verified the negative influence of the water deficit on the height of the coil coffee, the plants that were submitted to the water deficit presented smaller height. Busato et al. [25] when evaluating the initial development of the conilon coffee plant under different irrigation layers found higher values of coffee height for greater water availability in the soil.

Fig. 3 shows the behaviour of the relative leaf area variable in function of FATS decrease.

The clones 101, 103 and 104 (critical FTSW 0.37, 0.41 and 0.42) behaved as resistant to the induced water deficit because they did not paralyze leaf area growth, however, the clones 102, 107 and 109 were those with the highest critical FTSW values, 0.68, 0.74 and 0.68,

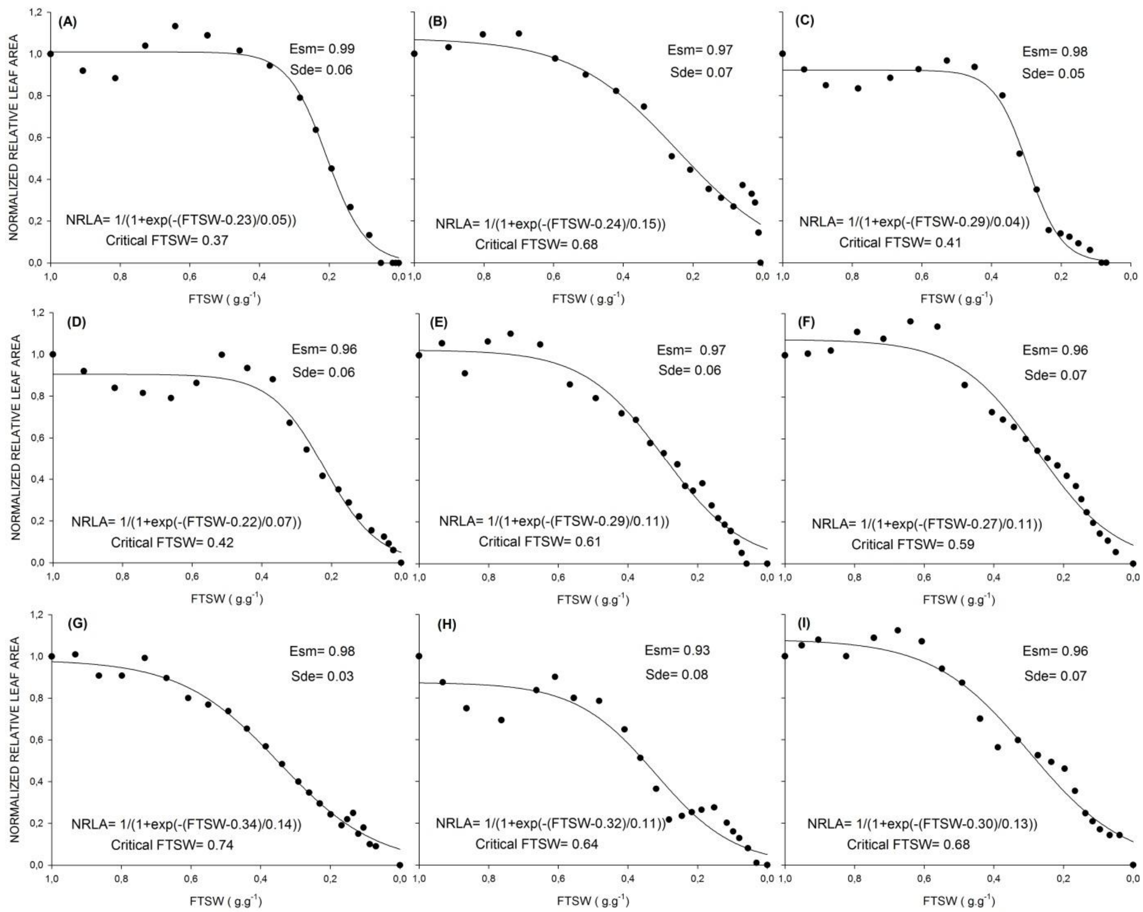

Fig. 3. Normalized relative leaf area (NRLA) in function of the decrease of the fraction of transpirable soil water (FTSW), in the nine clones of conilon coffee Diamante Incaper ES 8112 (''A''- Clone 101; ''B''- Clone 102; ''C''- Clone 103; ''D''- Clone 104; ''E''- Clone 105; ''F''- Clone 106; ''G''- Clone 107; ''H''- Clone 108; ''I''- Clone 109). Esm is the efficiency of the statistical model and Sde is the standard error

respectively. Thus, they ceased their leaf area growth prematurely in a condition of water stress.

These results indicate that under conditions of low soil water availability, stomatal closure occurs earlier in clones 102, 107 and 109. And this response is an adaptive criterion of clones to withstand prolonged water deficit, conserving for longer the water in the soil [10]. Kelling et al. [16] presents this inhibition of cell expansion as a defense strategy of the plant, because the plants respond to the water deficit according to the intensity of soil water stress, the genotype, the stage of development and the type of organ and cell considered, and may present responses at the morphological, physiological, cellular and metabolic level [26].

However, this plant's strategy to inhibit leaf growth due to the reduction of soil water availability affects metabolism, transport, solutes translocation, cell turgor, cell expansion, and stomas opening and closing [27], which induces the reduction of the growth and yield losses of the culture, since the stomatal closure decreases the CO2 entry, and consequently reduces the photosynthetic process [28].

In this study, critical FTSW values in which leaf growth begins to decrease ranged from 0.37 to 0.74 and are within the range of values found by Araujo et al. [29] (critical FTSW ranging from 1.0 to 0.40) and Rodrigues et al. [19] (critical FTSW ranging from 0.71 to 0.47) in which they worked with three times of water deficit in coffee.

The data of the present work are also in the range of values of foliar growth described by other works with other cultures, such as 0.55 in peas [30], 0.35 in grapevine [11], 0.44 in rice

[31], 0.70 and 0.90 in eucalyptus seedlings [32] and 0.48 to 0.71 in chrysanthemum cultivars [16].

It is observed that the RLA variable presented lower values of critical FTSW in all nine clones worked in relation to RT. This fact indicates that the realization of the foliar growth occurred after the stomatal closure mechanism that caused the RT limitation, since there was no decrease of the cellular turgescence, thus leading to cell expansion and consequent to the foliar growth [33, 27]. According to Lago et al. [12], this result indicates that the plants may have an efficient stomatal control mechanism, since they can reduce water consumption, probably due to the reduced stomatal opening, delaying the reduction effect on leaf growth.

Although most of the results converge to a single range of critical values of the fraction of transpirable soil water, there are some variations between the different studies. These variations in the critical values of the fraction of transpirable soil water could be attributed to differences in the size of the pots used in each study, soil type or variations in air evaporative demand conditions [34].

Studies of tolerance to crop water deficit should continue to be carried out, to characterize more tolerant genotypes [18] and adaptations to the climatic conditions of each region, to minimize the risks in agricultural production.

4. CONCLUSION

The clones have different water needs with this growth was limited at different times.

The relative transpiration was the first variable to be affected by FTSW reduction, followed by plant height and leaf area.

It is concluded that clones 104 and 103 were the most tolerant to the induced water deficit, being more recommended for environments with water restrictions. Clones 107 and 108 were found to be more susceptible soil moisture variation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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