

Growth and Quality of Cacao Tree Seedlings Genotype TSH1188 Produced under Different Seasons and Irrigation Depths

ABSTRACT

The cacao tree (*Theobroma cacao* L.) is very sensitive to the lack of water in the soil. The low quality of seedlings can be caused by problems in the irrigation and / or nutrition of the seedlings in their early stage in the greenhouse, thus compromising the success of the implantation of the crop. The aim of this work was to determine the optimal irrigation depth for the good development of cacao tree seedlings genotype TSH1188, cultivated at different times of the year. To reach this goal, a study was developed, at the Federal Institute of Espírito Santo - Campus Itapina, about the effect of the application of six different daily irrigation depths (4, 6, 8, 10, 12 and 14 mm d⁻¹) on growth and quality of seedlings of the cacao tree genotype TSH1188, produced in tubes, evaluating the morphological characteristics of the seedlings and their relationship with the quality of the plant. The study experimental was conducted in a completely randomized design (CRD) at three different planting seasons: the first one, from 03/16/2017 to 05/12/2017 (Autumn), with 36 useful plants per treatment; the second, from 08/01/2017 to 10/06/2017 (Winter), with 20 useful plants per treatment and the third, from 10/20/2017 to 12/15/2017 (Spring), with 20 useful plants per treatment. The results evidenced, regardless of the production period of the seedlings, for all the variables studied, the quadratic effect with interference of the irrigation depths on the growth and quality of the cacao tree seedlings, being the depths 8 and 10mm d⁻¹ the ones that provided the best answers of all evaluated characteristics. The irrigation depth of 8 mm d⁻¹ was the one that presented, for all the evaluated periods, in the production of cacao tree seedlings genotype TSH1188, ideal Dickson quality index, stem diameter, plant height and number of leaves, these characteristics used to identify quality seedlings.

Keywords: *Theobroma cacao* L., vegetative development, water replenishment, phenology, Dickson index.

1. INTRODUCTION

The cacao tree (*Theobroma cacao* L.) is a perennial and arboreal plant, belonging to the family Malvaceae, typical of tropical climate and native to the rainforest region of America. It is a species that demands lots of heat and humidity and, for this reason, the main cacao tree producing regions in the world are located between latitudes 10° N and 20° S [1]. In Brazil, it found adequate climate and soils for a good adaptation, mainly in the south region of Bahia, bringing prosperity and being one of the main pillars for the development of the local producers [2].

Its main economic importance is as a basic raw material for the manufacture of chocolate. In production, Brazil is in 6th position, with 256,186 tons and, in harvested area, in the 5th position with 689,276 hectares [3], being Pará (113,150 t), Bahia (103,218 t) and Espírito Santo (6,936 t) the states with the highest production [4]. In Espírito Santo, the cities of Linhares, São Mateus, Colatina and João Neiva [5] are noteworthy in the practice of this activity.

Historically, Brazil had already been among the world's two largest cacao tree producers, however, its production was greatly reduced by the emergence of the Witches' Broom Disease in 1989, caused by the fungus *Moniliophthora perniciosa* [6]. One of the cultivars resistant to this infestation is TSH1188, originating from the island of Trinidad, because it presents adaptation to regions of humid tropical

climate, with self-incompatible pollination, red fruits when unripe, moderately wrinkled, with moderately deep grooves, with elongated shape and productivity average of 1.453 kg per plant [7].

Concerning to the moisture for plants, cacao tree has high water consumption, being very sensitive to lack of water in the soil. The quantity and distribution of the harvest in cacao tree crop are regulated more strongly by water availability than by any other factor. A minimum annual precipitation of 1,300 mm, well distributed, with a drought period of not more than two months, is considered as the minimum limit, however, rainfall above 5,000 mm is considered undesirable, once it contributes to the emergence of fungi harmful to the crop and it may still cause nutrients losses due to leaching and surface runoff [8].

In the formation of a perennial crop, such as cacao tree, the quality of the seedling used in orchard formation is one of the fundamental factors for success. The low quality seedlings can be caused by problems in irrigation and / or seedling nutrition in their early stage in the greenhouse.

In relation to irrigation, the problems may happen because of the poor distribution of water or its management, generating deficit or over irrigation, which, in the latter case, can leach nutrients [9]. The application of water to the plants is usually done by the producers without technical criteria, and, therefore, it cannot reach the genetic potential or it can even start a decrease in crop productivity due to inadequate use. In this way, the knowledge of the productive system of seedlings, in general, allows the elaboration of protocols that optimize the production of seedlings with better quality, reducing the waste of water resources, energy and nutrients [10].

However, the hydrological and agro climatic information for cacao tree cultivation described in the literature are for the cultivation of adult plants, with no citations for the seedlings production phase.

For all the information brought along the text about this subject, the purpose of this work was to determine the optimal irrigation depth for a good development of the cacao tree seedlings genotype TSH1188, conducted at different times of the year.

2. MATERIAL AND METHODS

The experiment took place in the horticultural sector of the Federal Institute of Espirito Santo - Campus Itapina, located in Colatina / ES, geographical coordinates of 19°29' South, 40°45' West and altitude of 62 meters. The region, according to the classification Köppen [11], presents Tropical Aw climate, characterized by irregular rains and elevated temperatures.

The study was carried out in plants of cacao tree (*Theobroma cacao* L.) of the genotype TSH1188, produced in three different planting seasons, according to the seasons of the year for the Southern Hemisphere: the first one, from 03/16/2017 to 05/12/2017 (Autumn), the second, in 08/01/2017 to 10/06/2017 (Winter) and the third, from 10/20/2017 to 12/15/2017 (Spring).

The plantations were conducted in an agricultural greenhouse with linear dimensions of 25 m x 5 m, 3 m high, covered by transparent plastic film and black polypropylene screen with 50% shading. In the interior of the greenhouse, the seedlings were conducted in six individualized environments, with transparent plastic film on the sides, 2.20 m long and 1.10 m wide, where six NaanDanJain® GREEN MIST anti-mist foggers were installed, located one meter above the plant in spacing of 0.8 mx 0.8 m, with an application efficiency of 85%. A 0.5 cv centrifugal pump, operating at a service pressure of 2.0 kgf cm⁻², was used for each individual study environment (treatment), operated by frequent pulses, driven by electronic controllers, distributed during 10 hours a day (from 7 a.m. to 5 p.m.).

The treatments consisted in the daily application of six irrigation depths for the production of cacao tree seedlings genotype TSH1188, corresponding to 4, 6, 8, 10, 12 and 14 mm d⁻¹ in a completely randomized design (CRD), with 36 plants useful for treatment in the first planting and 20, in the second and third plantings.

The seedlings were produced in tubes with a diameter of 53 mm, 190 mm in height and 280 ml of volumetric capacity. The containers were carried in carriers with capacity for 54 cells, however, they were distributed in alternating cells, for not to limit the arrival of light in the seedlings, according to the growth, which could lead them to a wading.

All tubes were pre-washed and sterilized with 2% sodium hypochlorite diluted in water and filled with Tropstrato HT Vegetable substrate plus Osmocote Plus 15-9-12 (3M), at the 3 g tube⁻¹ dosage, which shows the following chemical composition: N = 15%, (7% ammoniacal and 8% nitrate), P₂O₅ = 9%, K₂O = 12%, Mg = 1.3%, S = 5.9%, Cu = 0.05%, Fe = 0.46%, Mn = 0.06% and Mo = 0.02%, with no additional fertilization being performed.

The cacao tree seeds genotype TSH1188 (*Theobroma cacao* L.) used were obtained from the Experimental Station "Filgônio Peixoto" - belonging to CEPLAC, in the city of Linhares / ES. The ripe fruits were sectioned horizontally, the seeds removed and the mucilage removed by sawing powder rubbing. After extracting the mucilage, the seeds were planted at a depth of approximately 2 cm, leaving only one per tube.

During the seedling production period, variations in temperature and relative humidity within the greenhouse were monitored by a WatchDog® Model 200 Data Logger and externally by an ONSET® brand weather station installed near the greenhouse used in the experiment. Through the climatic variations registered by the station, the reference evapotranspiration (ET_o) was estimated using the Penman-Monteith method FAO-56 Standard [12], Equation 01.

$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (1)$$

where ET_o is the daily reference evapotranspiration (mm d⁻¹); Rn is the daily radiation balance (MJ m⁻² d⁻¹); G is the daily flow of heat in the soil (MJ m⁻² d⁻¹); T is the daily air temperature average (°C); u₂ is the daily average velocity of the wind at 2 m in height (m s⁻¹); e_s is the saturation pressure of the daily water vapor average (kPa); e_a is the daily water vapor pressure average (kPa); Δ is the slope of the vapor pressure curve at the point of T (kPa °C⁻¹) and γ is the psychrometric coefficient (kPa °C⁻¹).

Seedlings began to be evaluated when hypocotyl emerged on the substrate in the shape of a hook (emergence finding) in more than 80% of plants, thus recording the following dates as day after emergence (DAE). The characterization of the hypocotyl emergence of the 1st planting was registered on 03/22/2017, from the 2nd one, on 08/04/2017 and from the 3rd on 10/28/2017.

At the end of each planting, the seedlings were evaluated for the following morphological characteristics: a) Soil Plant Analysis Development index (SPAD), measured with SPAD 502 Plus equipment; b) shoot height (SH), measured in cm, using ruler graduated in millimeters, from the stem base until the apical gem; c) stem diameter (SD), measured at 2 cm above the edge of the tube, in mm, with a Metrotools digital model caliper, model MPD-150; d) root length (RL), measured in cm, with ruler graduated in millimeters, from the base of the stem to the largest root length; e) fresh mass of shoot system (FMSS) and the fresh mass of the root system (FMRS), expressed in grams, determined by weighing them after cutting at the base of the stem, through an electronic scale with an accuracy of 0.001 g; f) dry mass of the shoot system (DMSS), root system (DMRS) and total dry mass (TDM), obtained by the sum of DMSS and DMRS expressed in grams, by weighing them in an electronic scale with 0.001 g of precision after being separately packed in paper bags and subjected to a drying process in an oven with forced air circulation at 65 °C until constant weight; g) number of leaves (NF), determined by counting the total number of leaves in the plant; h) leaf area (AF), expressed in cm², estimated with LI-COR leaf area meter model LI-3100C.

With the data obtained, the quality of the seedlings was determined by analyzing: a) the relationship between shoot height and stem diameter (RSHSD); b) relationship between dry mass of the shoot system and dry mass root system (RDMSR); c) Dickson quality index (DQI), by the formula: DQI = [TDM / (RSHSD + RDMSR)] [13].

The results were submitted to analysis of variance of the regression by the test F, at 1% probability, and, when significant, adjusted regression models that best represented the effect of the treatments, higher coefficient of determination (R²) of the irrigation plates applied on the analyzed variables. The maximum points were determined by means of the first derivative of the regression equations. The open source program R [14] was used for data organization and manipulation.

3. RESULTS AND DISCUSSION

The productions of the cacao tree seedlings at the different planting times allowed for different developments and similar patterns of behavior depending on the irrigation depths applied. The maximum and minimum temperatures average within the greenhouse of all the epochs evaluated during the experiment were 37.67 °C and 19.82 °C, respectively. The average of the temperatures were 29.74 °C, 25.90 °C and 30.61 °C, respectively, in the 1st, 2nd and 3rd plantings (Table 1). The relative air humidity average in the greenhouse was 56.38%, 57.61% and 60.13% in the 1st, 2nd and 3rd plantings, respectively. The maximum and minimum relative humidity average recorded for the 1st planting was 86.74% and 26.01%, for the 2nd planting of 87.02% and 28.20% and for the 3rd planting of 85, 80% and 34.46%.

Table 1. Duration of cycle, in days after emergence (DAE), average temperature, maximum and minimum temperatures average (in °C), occurring within the greenhouse, during the production of cacao tree seedlings, in the three different seasons of planting, Colatina/ES, 2017

Season	DAE	Air temperature (°C)		
		Average	Average maximum	Average minimum
1 st Planting (Autumn – 03/16/2017 a 05/12/2017)	52	29,74	39,12	20,36
2 nd Planting (Winter – 08/01/2017 a 10/06/2017)	64	25,90	34,82	16,97
3 rd Planting (Spring – 10/20/2017 a 12/15/2017)	49	30,61	39,08	22,13

It is possible to observe that the second planting presented, compared to the others, lower average values of maximum and minimum temperatures during the production of the seedlings and, consequently, lower average temperatures (Fig. 1). The highest temperature recorded inside the greenhouse was 49.1 °C on 10/29/2017 (3rd planting) and the lowest 12.1 °C on 08/09/2017 (2nd planting). The thermal amplitude and the average values of the temperatures inside the greenhouse during the conduction of the experiment are within the ideal range of production and development of the cacao tree crop, according to Souza et al [15].

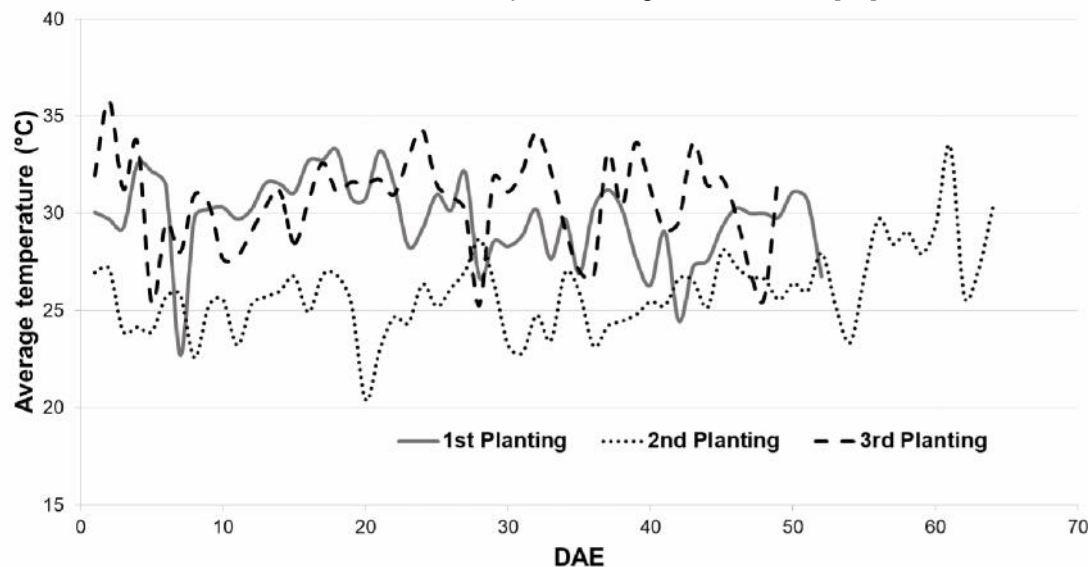


Fig. 1. Daily values of the average temperature (°C) occurred within the greenhouse, for each planting season, throughout the production period of the cacao tree seedlings genotype TSH1188 in Colatina / ES, 2017.

The average reference evapotranspiration (ET_o), registered in the environment outside the greenhouse, for the 1st, 2nd and 3rd plantings were 3.90 mm d⁻¹, 2.91 mm d⁻¹ and 3.37 mm d⁻¹, respectively. The maximum value of ET_o registered for the first planting was 5.85 mm d⁻¹ (03/26/2017);

5th DAE), in the second planting of 4.32 mm d⁻¹ (10/06/2017; 64th DAE) and in the 3rd planting of 6.63 mm d⁻¹ (11/28/2017; 32nd DAE) (Fig. 2). Among the climatic factors, the temperature has a great value in the physiological processes of the plants, not being different for the cacao tree, acting in the development cycle and harvest season, influencing the growth and the development, being directly related to the processes of evapotranspiration and metabolic reactions [16].

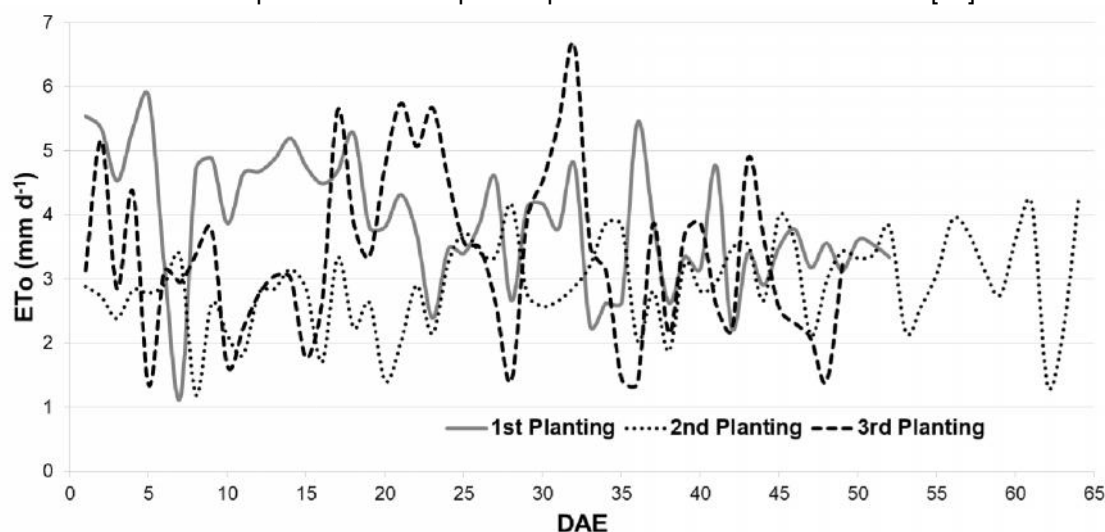


Fig. 2. Daily values of reference evapotranspiration (ETo), occurred in an external environment, for each planting season, during the whole production period of the cacao tree seedlings at Colatina / ES, 2017.

Once cacao tree is a typical tropical plant, in the spring, when the highest temperature averages occurred, the cycle duration of the plants was lower, and in winter, when the lowest temperature averages were registered, the plant cycle was larger, showing that the temperature has a direct effect on their development. This trend was also registered in studies of several crops such as triticale [17], canola [18] and olive tree [19].

Probably influenced by the climatic conditions that occurred in the production periods of the seedlings, the indexes and growth morphological characteristics presented by the seedlings in the first and third planting showed similar behavior and values, while the second planting ones, in several variables, showed a value lower, even though most of them had similar behavior to the other periods.

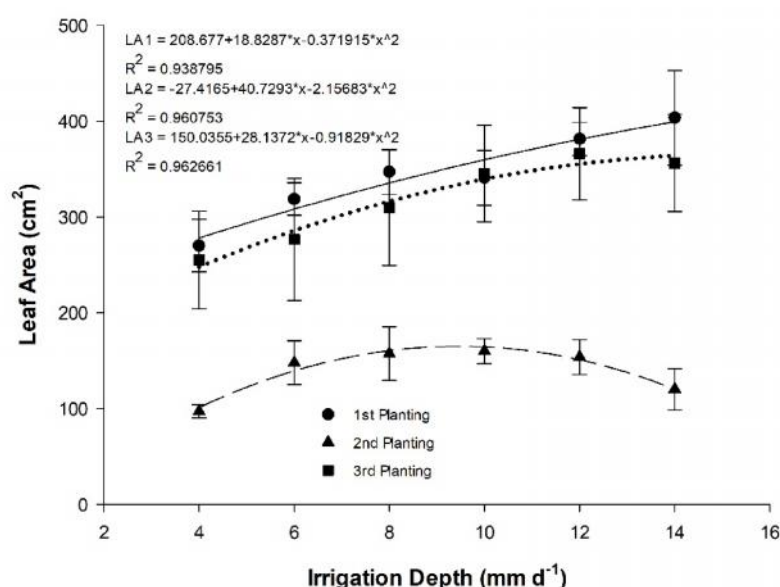
With similar patterns of behavior, the leaf areas, because of the applied irrigation depths in the three planting seasons, presented a quadratic effect with determination coefficients (R^2) varying from 0.93 to 0.96 (Fig. 3A). In spite of presenting the same quadratic behavior, the second planting was notable for presenting, even in the largest leaf area where the 9.44 mm d⁻¹ depth was applied, lower valuation than that recorded on the smallest depth of the 1st and 3rd plantings (4 mm d⁻¹). Such effect can be explained by the climatic conditions occurred in the second planting (cooler period) and not by the effect of the irrigation depths, since these presented the same quadratic behavior in the seedlings.

The leaf area of a plant is related to the number and size of its leaves, as well as the period of their permanence in the plant, providing an indication of the photosynthetic surface of the plant and its energy production capacity, destined to the growth and development of plants [20]. In addition, it is possible to understand their responses to environmental factors, thus being an important parameter in studies of morphology, anatomy and ecophysiology of the plants [21].

According to Mott et al. [22], the environment directly interferes with leaf size. The lower development of leaf area observed in cacao tree seedlings with smaller initial depths (depths of 4 and 6 mm d⁻¹) can be explained as a survival strategy adopted by the plants in order to reduce the available area of transpiration, considering the low water supply of the initial treatments (4 and 6 mm d⁻¹) in all planting periods [23]. A similar result was observed in the study of the effects of irrigation depths on the development of *Eucalyptus grandis* seedlings by Lopes et al. [24]. If, on the one hand, leaves with larger leaf area have a greater capacity of photosynthesis production, on the other hand, they evidence a higher rate of evaporation and excessive absorption of solar energy, which can cause, respectively, higher soil water consumption and damage to the leaf [25].

The number of leaves presented quadratic behavior in all the evaluated epochs, with R^2 varying from 0.85 to 0.98 (Fig. 3B). It is possible to note that the number of leaves tends to decay in depths superior to 8 and 10 mm d⁻¹. This increase in leaf area, recorded in the depths superior to these, evidences changes about larger leaves and not about number of leaves (quantity).

A



B

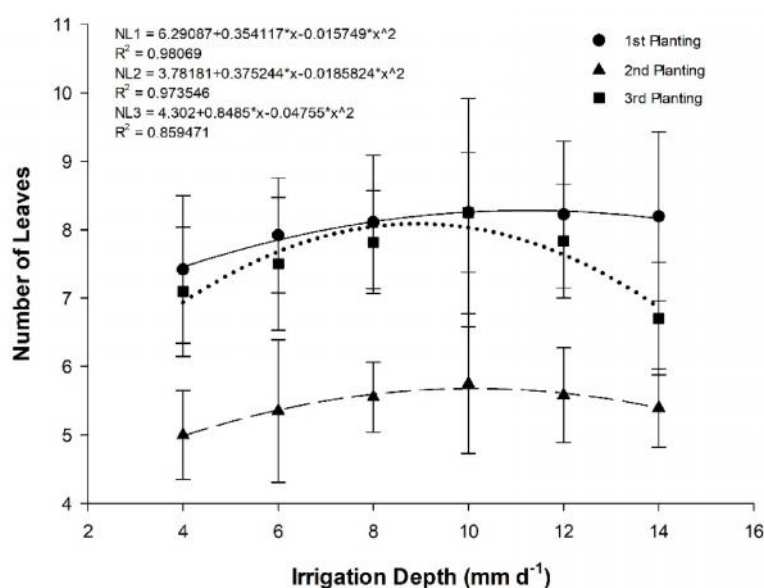


Fig. 3. Variation of leaf area (A) and number of leaves (B), in response to different

irrigation depths applied in the production of cacao tree seedlings genotype TSH1188, in the three different planting seasons in Colatina / ES, 2017.

Directly connected to the chlorophyll content present in the leaves, the SPAD readings determine the amount, the content of leaf nitrogen, considering that the chlorophyll of the plants has, in its composition, the nitrogen molecule. The treatments showed a tendency to reduce SPAD values in detriment to the enlargement of irrigation depths used (Fig. 4). Such fact may be related to the leaching of nutrients, especially of the nitrogen present in the substrate, as reported by Lopes et al. [24], as a result of the constant and excessive application of water in the production of seedlings in the larger depths of the treatments under study.

Another probable explanation for this behavior of reducing SPAD values in detriment of the enlargement of the irrigation depths may be the association of SPAD (Fig. 4) and the leaf area (Fig. 3A). There is a certain tendency to reduce SPAD values with increasing leaf area, especially in the first and third plantings, which could be explained by a better distribution of chlorophyll cells in the leaves with better leaf area development [25; 26].

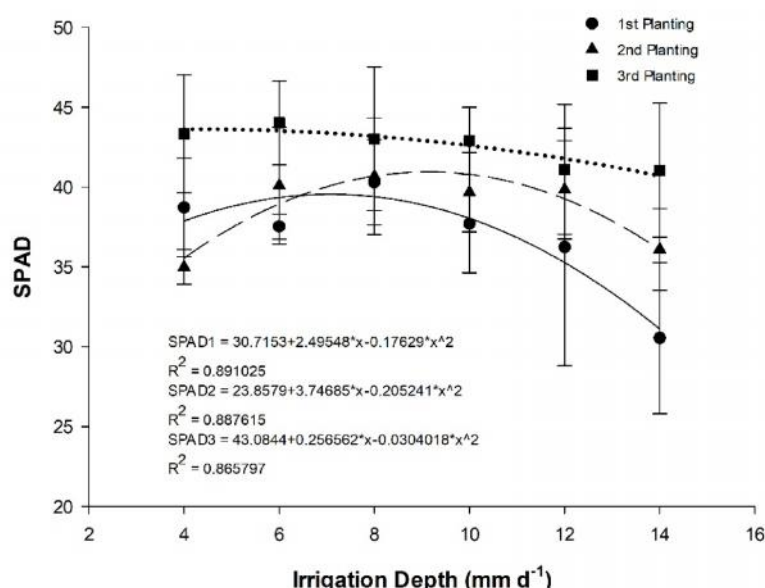


Fig. 4. Variation of chlorophyll content index (SPAD) in response to different irrigation depths, in cacao tree seedlings genotype TSH1188, at the three different planting seasons in Colatina / ES, 2017.

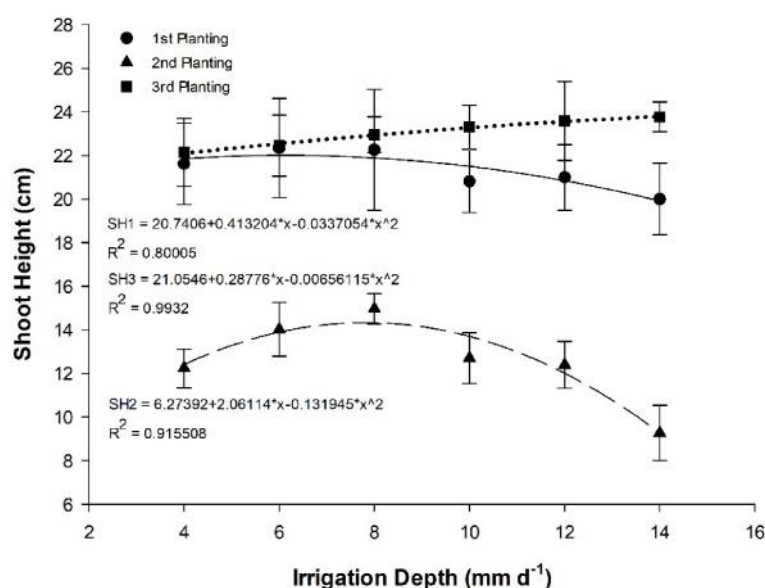
In all plantings, height (Fig. 5A) presented a regression with quadratic behavior and R^2 ranging from 0.80 to 0.99, in relation to the treatments adopted. The maximum height in the first planting was reached in depth the 8 mm d⁻¹ (22.2 cm), which was also responsible for providing the best results in the second (15.0 cm) and third plantings (22.9 cm).

The water deficit causes a reduction in seedling growth [27]. For Larcher [28], water deficiency changes the balance of growth regulators, as well as plant cell turgor, negatively influencing cell distension and thereby reducing plant growth.

The irrigation depths corresponding to 8 and 10 mm d⁻¹ were also the ones that presented the best results for the shoot diameter (SD) at all planting times. Such morphological characteristic demonstrated a quadratic regression model in all plantings, with R^2 ranging from 0.83 to 0.99 (Fig. 5B). In the first one, the best response was observed in the depth of 13.26 mm d⁻¹ (4.94 mm), but with an effective gain of only 0.11 mm if compared with that obtained by the depth of 10 mm d⁻¹ (4.83 mm).

The behavior of the shoot diameter (SD) because of the applied depths, at different times, shows that both the deficiency and the excess water applied to the substrate, limited the development of cacao tree seedlings TSH1188. In a study made by Ramos et al. [29], with cacao tree seedlings clone PH-16, the observed behavior was linear and positive of the collecting diameter according to irrigation depth applied. Melo et al. [30], studying the production of papaya seedlings in different substrates and phosphorus doses, observed that the increase of stem diameter of the seedlings is related to the higher production of photoassimilates, having a predictive correlation with another component of the photosynthetic system: number of leaves.

A



B

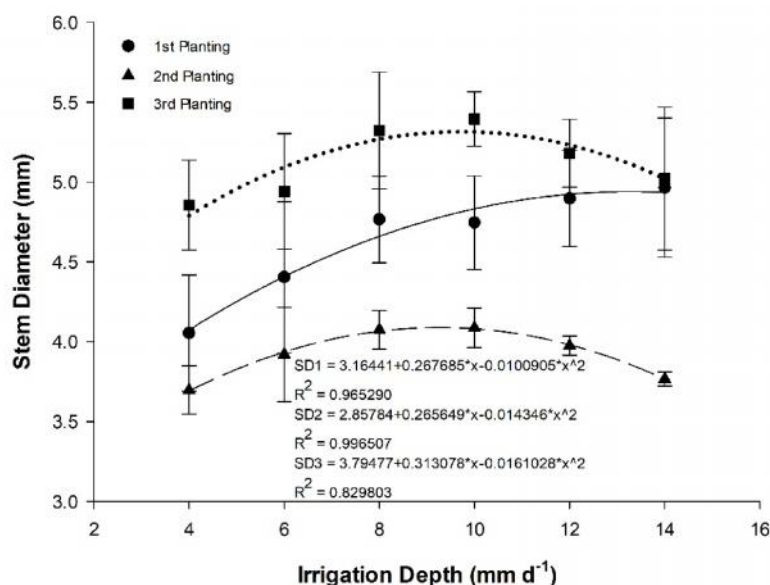
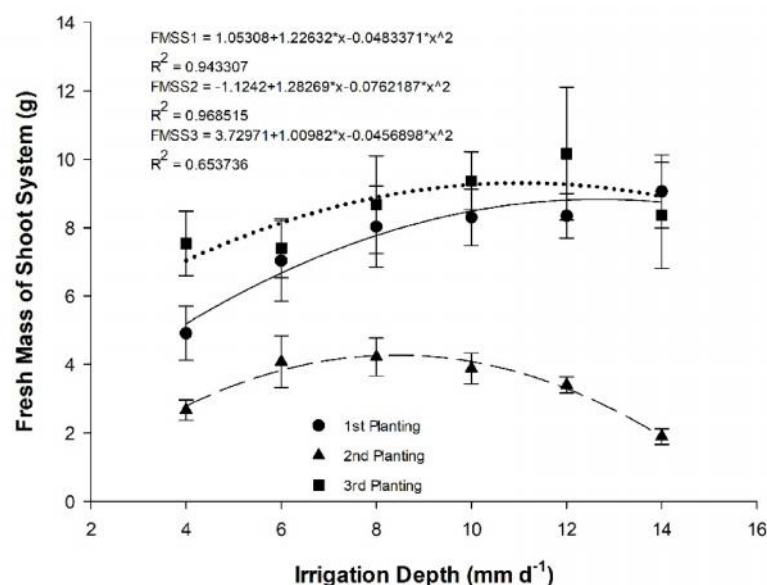


Fig. 5. Variation of shoot height (A) and shoot diameter (B), in response to different irrigation depths in the production of cacao tree seedlings genotype TSH1188 at three different planting times, Colatina / ES, 2017.

The regression in the values of the fresh mass of the shoot system (Fig. 6A), as a function of the irrigation depths applied in the three plantings, presented a quadratic tendency and varied R² from 0.65 to 0.97, with increasing predominance in the first and third plantations, till depths the 12.7 and 11 mm d⁻¹, respectively, and in the second planting till to depth the 8 mm d⁻¹. For the dry mass of the shoot system (Fig. 6B), it was also observed a quadratic behavior of the regressions and values of R² ranging from 0.83 to 0.99, with maximum yields of dry mass of the shoot system in the depths of 9 and 11.8 mm d⁻¹, in the first and third plantings, respectively, and 7.12 mm d⁻¹, in the second one.

A



B

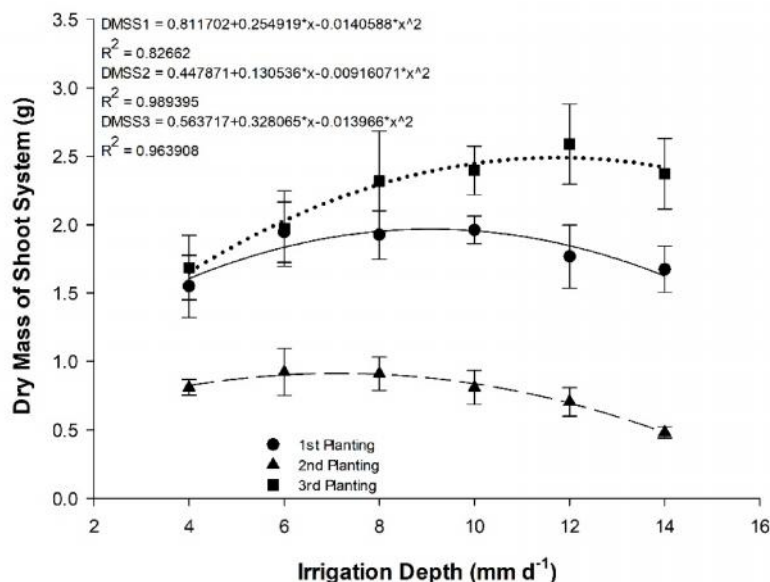


Fig. 6. Variation of the fresh mass of the shoot system (FMSS) (A) and dry matter of the shoot system (DMSS) (B), in response to the different irrigation depths in the production of cacao tree seedlings genotype TSH1188, in three different seasons of planting in Colatina / ES, 2017.

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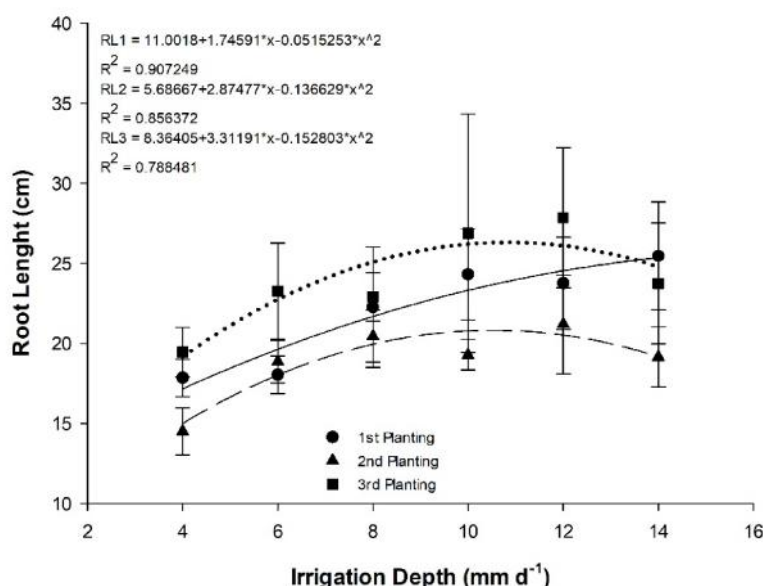
Regressions of the root length values (Fig. 7A) of the cacao tree seedlings, in the three planting seasons, with the exception of the irrigation depth of 4 mm d^{-1} , showed no significant difference. All of them demonstrated quadratic behavior and regressions with R^2 ranging from 0.79 to 0.91. The

maximum development estimated was observed in irrigation depths of 16 mm d⁻¹, 10.52 mm d⁻¹ and 10.83 mm d⁻¹ in the first, second and third plantings, respectively.

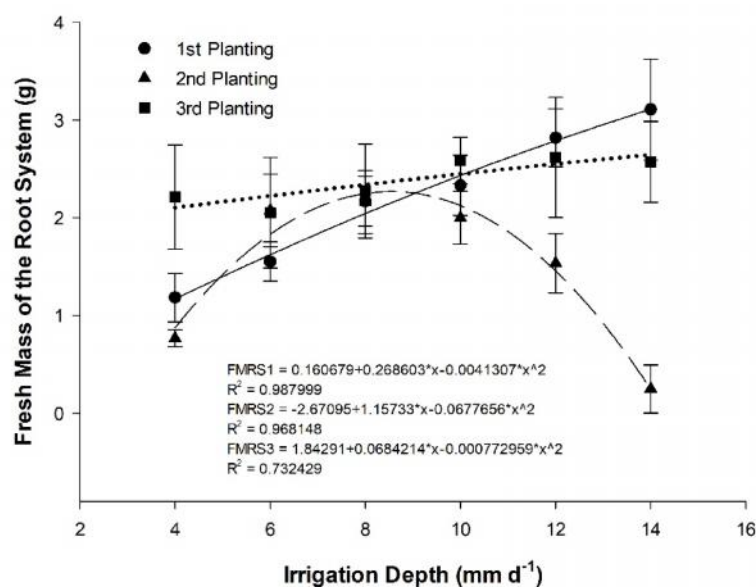
The lower values of root length in the smaller irrigation depths can be explained by the water deficit in the corresponding treatments. Morais et al. [31] working with seedlings of *Schinus terebinthifolius* (red Aroeira), found that the ones that received smaller irrigation depths also presented smaller root growth, while Scalon et al. [32] added that some species of plants, in such deficit condition, in which the water tends to concentrate only on the surface of the substrate, develop adaptations that optimize the water absorption by the plant. One of them is the higher formation and growth of the lateral roots induced by the action of the abscisic acid hormone, synthesized under conditions of water stress [25].

The fresh mass of the root system presented a quadratic regression in the three planting seasons, with R² between 0.73 and 0.99 (Fig. 7B). In the first and third plantations, there was a growth occurrence of the fresh mass in relation to the enlargement of the applied irrigation depths, but in the second, the development in mass is increasing only till irrigation depth of 8.5 mm d⁻¹. In relation to the dry mass (Fig. 7C), also with quadratic behavior and R² varying from 0.82 to 0.96, there was growth with the enlargement of the applied depths in the first and third plantings, while in the second, the growth of dry mass reaches its maximum on irrigation depth of 7.9 mm d⁻¹, decreasing thereafter.

A



B



C

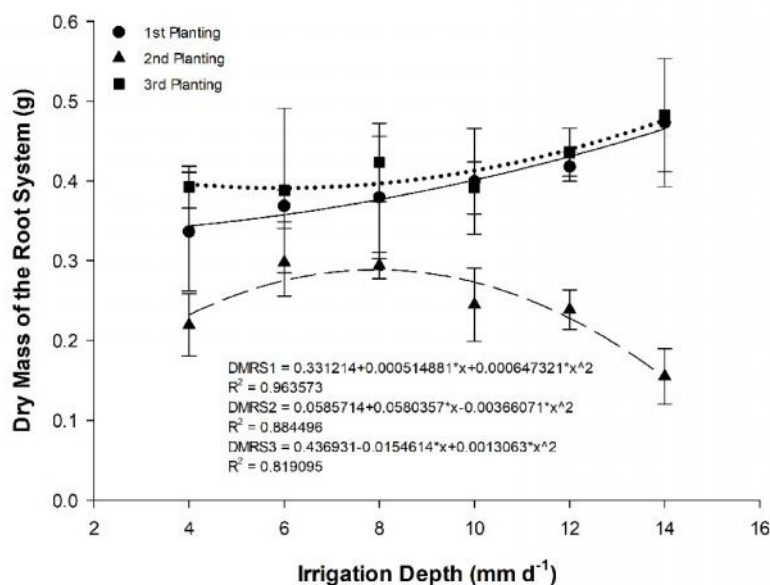


Fig. 7. Root length (A), fresh matter of the root system (B) and dry matter of the root system (C) of cacao tree seedlings genotype TSH1188, in response to different irrigation depths, in three different planting times in Colatina / ES, 2017.

Both the deficit and the excess of water present in the root system limit root development. High amounts of water reduce the concentration of oxygen in the rhizosphere, which causes lack of oxygenation for root respiration, reduction of the photosynthetic rate and transport of photoassimilates to the root system, culminating in the lower concentration of dry mass in the roots [33; 34]. Braga [35],

working with cacao tree seedlings of genotypes TSH1188 and SIAL-70 in nutrient solution and different concentrations of iron, found that, in the absence of oxygen in the root system, root growth decreased and, by aerating the root system, dry mass of the roots increased again.

The relationship between dry mass of the shoot system and dry mass of the root system (RSR) shows a quadratic behavior with R^2 0.97, 0.55 and 0.91, respectively, in the regression of the data obtained in the first, second and third plantings (Fig. 8). The data show the differential behavior between the seasons of highest temperatures - first (autumn) and third (spring) - with the second (winter), whose temperature averages were lower than the others.

The lower the value of RSR, the better balance is observed in the cacao tree seedling, which tends to present a better developed root system and more able to supply the needs of the seedling. The best dry mass of shoot system ratio, in the second planting, was estimated in irrigation depth of 10.2 mm d^{-1} , with a value of 3, which is very close to that found in irrigation depth of 8 mm d^{-1} .

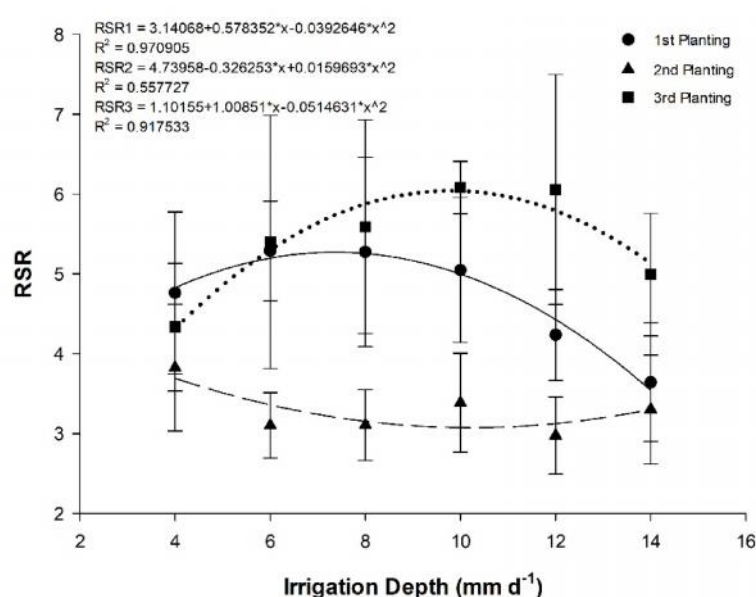


Fig. 8. Relationship between the dry mass of shoot system and the dry mass of the root system (RSR) of the cacao tree seedlings genotype TSH1188, in response to the different irrigation depths, in three different planting seasons in Colatina / ES, 2017.

In the first and third plantings, whose average air temperatures remained higher, there was a better improvement of the shoot system of the seedlings that could not be accompanied by the root development. Thus, the irrigation depths of 8 to 10 mm d^{-1} , which presented more vigorous growth and better morphological characteristics in the seedlings, ended up with one of the worst values of RSR (relationship between the dry mass of shoot system and the dry mass of the root system), whereas in the lower and upper depths, where the maximum potential of the evaluated characteristics was not reached, they presented the best relations. Thus, information about the value of RSR should not be used, in the case of the cacao tree, as isolated information to express quality of the seedlings.

In the relation between shoot height and shoot diameter (RHD) (Fig. 9), it was also observed a differential behavior between planting times that presented higher temperatures (first and third) with that in the second, when temperature was lower. For the first and third plantings, the best ratios were estimated, respectively, in irrigation depths of 11.4 and 8.48 mm d^{-1} . For the second planting, the best relationships between shoot height and shoot diameter occur on depths higher than 10 mm d^{-1} , but it should be noted that the values of this ratio (RHD), in this planting season, in all studied, were smaller than the minimum ratio reached in the other plantations.

For Dassi [et al.](#) [36], easily measured morphological characteristics, such as plant height and stem diameter, are the most used as basis for the evaluation of the transplanting point of the seedlings for the field, the highest values being desirable. The relation of these characteristics, height of the plant by the diameter of the stem, when it is very high, it is indicative of seedling shedding, which is not desirable [37].

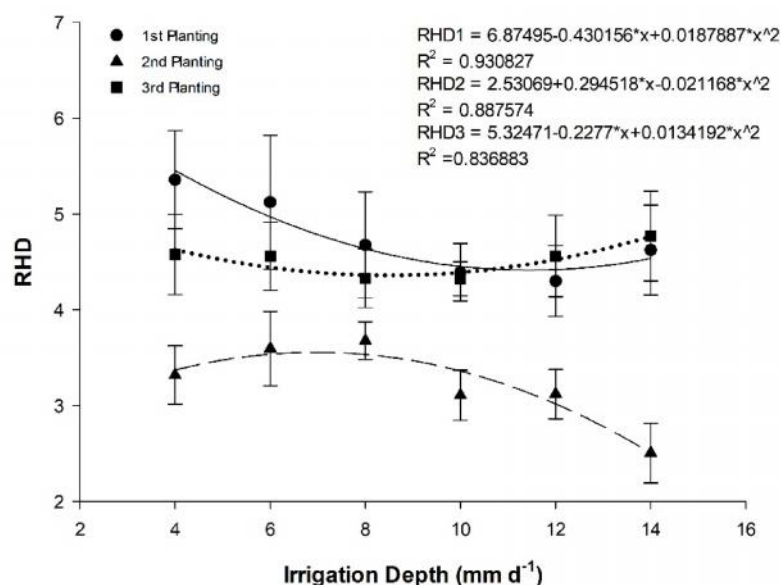


Fig. 9. Relationship between shoot height and stem diameter (RHD) of the cacao tree genotype TSH1188, in response to different irrigation depths, in three different planting seasons in Colatina / ES, 2017.

The Dickson quality index (DQI) presented quadratic function for the irrigation depths applied in the different production periods. The regression models presented coefficients of determination (R^2) of 0.98, 0.97 and 0.95, respectively, in the first, second and third evaluated plantings (Fig. 10).

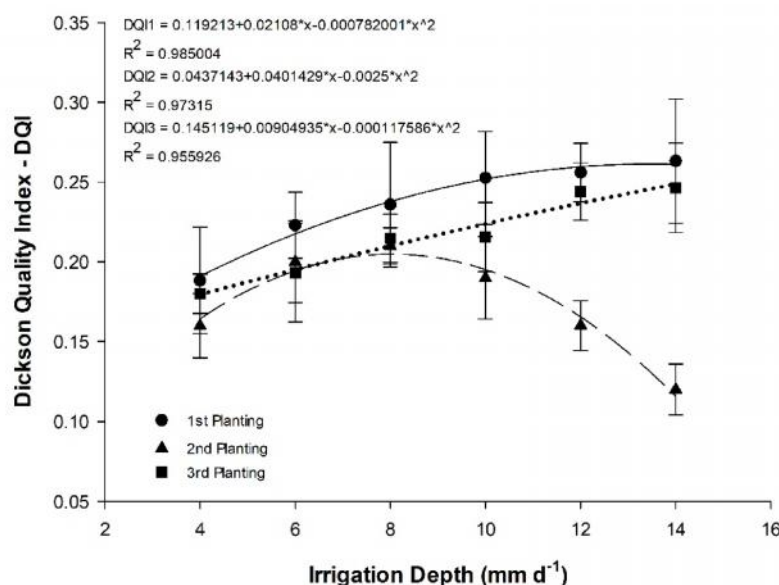


Fig. 10. Dickson quality index (DQI) of the cacao tree genotype TSH1188 in response to different irrigation depths, at three different planting times in Colatina / ES, 2017.

Dickson quality index (IQD) is considered as an integrated morphological measure [38] and balances several parameters: shoot height, shoot diameter, shoot dry matter and root system [39]. In this way, both the robustness and the equilibrium of the dry matter distribution are identified, thus identifying seedlings with greater capacity for adaptability and development when taken to the field [40; 41].

During the production of cacao tree seedlings when air temperatures remained higher, first and third plantings, the DQI values showed an increasing behavior in relation to the increase of the irrigation depths studied, differently from the second one, which had the lowest average values of air temperature, which allowed the index to grow until it reached its maximum response in irrigation depth of 8 mm d⁻¹ and, after that, showed a drop in quality.

Hunt [42], establishes 0.2 as the minimum value of QDI for the production of good quality seedlings. This value was found in the second planting only on irrigation depth of 8 mm d⁻¹, while for the first and third plantings, the index 0.2 was found in depths above 6 and 8 mm d⁻¹, respectively. In this way, the choice of irrigation depth of 8 mm d⁻¹ is clearly characterized as being the ideal for production of quality cacao tree seedlings, independent of the growing season, with the advantage of water, manpower and reduction of possible losses of nutrients by leaching. The quality index of Dickson (QDI) was shown to be a good quality indicator for the seedlings of the cacao tree genotype TSH1188.

Morais et al. [31], when studying red Aroeira seedlings, found that the ideal daily irrigation depth occurred between 10 and 12 mm d⁻¹, but that the use of the 10 mm d⁻¹ **one** promoted a satisfactory development of the seedling reconciled with rational use of water. Lopes et al. [24] found that, for the development of seedlings of the best quality, at 108 days after sowing, crude irrigation depths of 12 to 14 mm d⁻¹ were required. Posse et al. [43] verified that the irrigation depth of 8 mm d⁻¹ was the most suitable for the formation of yellow passion fruit seedlings, with higher water savings, obtaining growth and quality similar to irrigation depths of 10 and 12 mm d⁻¹, which maximized the characteristics evaluated.

Analyzing together all the growth and quality characteristics studied, through the different the different planting times and irrigation depths applied, depths of 8 to 10 mm d⁻¹ presented the best growth and

quality responses, even though it does not confer the maximum potential of development in all the analyzed planting times. Thus, to obtain quality seedlings, they must be produced with an irrigation depth of 8 mm d⁻¹ because it presents, independently of climatic conditions, ideal growth and quality responses in an associated way about the formation of cacao tree seedlings, with economic use of water and energy.

4. CONCLUSION

Independently of the production period of the seedlings, the irrigation depths interfered in the growth and quality of the cacao tree seedlings genotype TSH1188.

The irrigation depths of 8 and 10 mm d⁻¹ were the ones that provided the best growth and quality responses in the production of cacao tree seedlings genotype TSH1188.

The irrigation depth of 8 mm d⁻¹ was the one that presented for all the evaluated periods, in the production of the cacao tree seedlings TSH1188 genotype: ideal minimum quality index of Dickson, stem diameter, plant height and number of leaves, characteristics that are used to identify better quality seedlings.

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