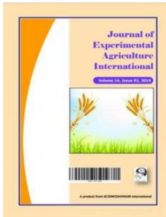

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Growth and Quality of Genotype TSH1188 Cacao Tree Seedlings Produced under Different Seasons and Irrigation Depths

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Authors' contributions

This work was carried out in collaboration between all authors. Author RPP designed the study, conducted the experiment in the field with authors FV, SSS, SMFS, RLP and IMT managed the writing of the manuscript. Authors RPP and CASS managed the analyses of study. Author RPP performed the statistical analysis. Authors GSC and RPP performed translation of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The low quality of seedlings can be caused by problems in the irrigation and nutrition of the seedlings in their early stage, thus compromising the success of the implantation of the crop. The aim of this work was to determine the optimal irrigation depth most suitable for the development of cacao tree seedlings genotype TSH1188, raised at different times of the year. To achieve 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) on the growth and quality of seedlings of the cacao genotype TSH1188, produced in tubes, by evaluating the morphological characteristics of the seedlings and their relationship with the quality of the plant.

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The study was conducted in a completely randomised design (CRD) at three different planting seasons notably in the Autumn with 36 plants per treatment, in the Winter with 20 plants per treatment and the spring using 20 plants per treatment. The results showed that regardless of the season, for all the variables studied, it was discovered that irrigation depths had impacts on the growth and quality of cacao seedlings, the best depths were 8 and 10mm d^{-1} as the seedlings proved to be the best in all characteristics evaluated. The irrigation depth of 8 mm d^{-1} was the one that presented the best results for all the three seasons, in the production of cacao tree seedlings genotype TSH1188, i.e. ideal Dickson quality index, stem diameter, plant height and a number of leaves, which are characteristics used to identify quality seedlings.

Keywords: Theobroma cacao L.; irrigation; seedlings; depths; characteristics.

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 10º N and 20º S [1]. In Brazil, the climate and soils provide the necessary requirements for the crop to thrive, especially in the South region of Bahia, creating agricultural wealth from the local producers [2].

Its main economic importance is as a basic raw material for the manufacture of chocolate. In World production, Brazil is in the 6th position with 256,186 tons in harvest and occupies the 5th position with 689,276 hectares of the cultivated area [3]. Pará, with 113,150 tons, Bahia with 103,218 tons, and Espírito Santo with 6,936 tons are the leading States in Cacao production [4]. In Espírito Santo, the cities of Linhares, São Mateus, Colatina and João Neiva [5] are popular producers of Cacao.

Historically, Brazil was one of the world's two largest cacao 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 pathogen 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].

Regarding moisture requirement, cacao tree has high water consumption, being very sensitive to water deficit in the soil. The quality and quantity cacao production is regulated more strongly by water availability to the cacao tree 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 cultivation of a perennial crop, such as cacao tree, the quality of the seedling used in orchard formation is one of the fundamental factors of success. The low-quality seedlings can be caused by problems in irrigation and seedling nutrition in their early stage in the greenhouse.

Concerning 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 decrease 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 optimise 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 is 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 genotype TSH1188 cacao tree seedlings, conducted at different times of the year.

2. MATERIALS AND METHODS

The experiment was conducted at the horticultural sector of the Federal Institute of Espirito Santo - Campus Itapina, located in Colatina / Espirito Santo, 19º29' South, 40º45' West and at 62 m of altitude. The region, according to the classification Köppen [11], presents Tropical Aw climate, characterised by irregular rains and elevated temperatures.

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

The nurseries 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 m x 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 six treatments consisted in the daily application of six irrigation depths for the production of genotype TSH1188 cacao tree seedlings, corresponding to 4, 6, 8, 10, 12 and 14 mm d^{-1} in a completely randomized design (CRD), with 36 useful plants per 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, so as not to hinder adequate illumination of the seedlings, in the seedlings, required for their growth which could make them to wither.

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), P_2O_5 = 9%, K_2O = 12%, Mg = 1.3%, S = 5.9%, Cu = 0.05%, Fe = 0.46%, Mn = 0.06% and Mo = 0.02%, with no additional nutrients supplied.

The genotype TSH1188 cacao seeds (*Theobroma cacao* L.) used were obtained from the Experimental Station "Filogônio Peixoto", in the city of Linhares / ES. The ripe pods were sectioned horizontally, the seeds removed and the mucilage removed by sawing powder rubbing. After removal of the mucilage, the seeds were sown at a depth of approximately 2 cm, leaving only one per tube.

During the seedling growth period, variations in temperature and relative humidity within the greenhouse were monitored by a WatchDog® Model 200 Data Logger (Spectrum Technologies, Aurora, Illinois) and externally by an ONSET® brand weather station (Onset Computer Corporation, Bourne, Massachusetts) installed near the greenhouse used. From the climatic variations registered by the station, the reference evapotranspiration (ETo) was estimated using the Penman-Monteith method FAO-56 Standard [12], Equation 01.

$$\mathrm{ETo} = \frac{0.408\Delta(\mathrm{Rn}-\mathrm{G}) + \gamma \frac{900}{\mathrm{T}+273} \mathrm{u}_2(\mathrm{e_s}-\mathrm{e_a})}{\Delta + \gamma(1+0.34\,\mathrm{u}_2)} \tag{1}$$

where ETo 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 (ºC); u_2 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 vapour average (kPa); e_a is the daily water vapour pressure average (kPa); Δ is the slope of the vapour pressure curve at the point of T (kPa $ºC^{-1}$), and γ is the psychrometric coefficient (kPa $ºC^{-1}$).

Seedlings began to be evaluated when the hypocotyl emerged on the substrate in the shape of a hook (emergence finding) in more than 80% of tubes, 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, the 2nd one, on 08/04/2017 and 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 (Spectrum Technologies, Aurora, Illinois); b) shoot height (SH), measured in cm, using ruler graduated in millimeters, from the stem base up to 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 (Metrotools, São Paulo, Brazil); 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, using an electronic scale with an accuracy of 0.001 g (Shimadzu, Kyoto, Japan); 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, were calculated by weighing them in an electronic scale with 0.001 g of precision (Shimadzu, Kyoto, Japan) after being separately packed in paper bags and subjected to a drying process in an oven with forced air circulation at 65 ºC until constant weight was obtained; g) number of leaves (NF) was determined by counting the total number of leaves in the plant; h) leaf area (AF), expressed in cm^2, 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 subjected to an 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 (R^2) 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 organisation 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 behaviour depending on the irrigation depths. The maximum and minimum temperatures average within the greenhouse of all the epochs evaluated during the experiment were 37.67 ºC and 19.82 ºC, respectively. The average of the temperatures varied from 25.90 ºC in winter to 30.61 ºC in spring (Table 1). The relative air humidity average in the greenhouse was 56.38%, 57.61% and 60.13% in the autumn, spring, and winter plantings, respectively. The maximum and minimum relative humidity average recorded for the autumn planting were 86.74% and 26.01%, for the winter planting of 87.02% and 28.20% and for the spring planting of 85, 80% and 34.46%.

Table 1. Duration of cycle or days after emergence (DAE) and temperatures occurring within the greenhouse during the production of cacao tree seedlings in the three different seasons

Season	DAE (days)	Air temperature (ºC)		
		Mean	Average maximum	Average minimum
Autumn (03/16/2017 a 05/12/2017)	52	29.74	39.12	20.36
Winter (08/01/2017 a 10/06/2017)	64	25.90	34.82	16.97
Spring (10/20/2017 a 12/15/2017)	49	30.61	39.08	22.13

It is possible to observe that the winter 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 49.1ºC on 10/29/2017 (spring planting) and the lowest 12.1ºC on 08/09/2017 (winter planting). The thermal amplitude and the average values of the temperatures inside the greenhouse during the conduction of the experiment were within the ideal range of production and development of the cacao tree crop, according to Souza et al. [15].

The average reference evapotranspiration (ETo), registered outside the greenhouse, for the autumn, spring, and winter plantings were 3.90 mm d^{-1}, 2.91 mm d^{-1} and 3.37 mm d^{-1}, respectively. The maximum value of ETo registered for the first planting was 5.85 mm d^{-1} (03/26/2017; 5th DAE), 4.32 mm d^{-1} (10/06/2017; 64th DAE) in the winter planting, and 6.63 mm d^{-1} (11/28/2017; 32nd DAE) in the spring planting (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].

Cacao tree is a typical tropical plant, in the spring, when the mean highest temperatures occurred, the cycle duration of the plants was shorter, and in winter, when the mean lowest temperatures were registered, the plant cycle became longer, showing that the temperature has a direct effect on the development of the seedlings. This trend was also registered for 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 indices and growth morphological characteristics presented by the seedlings in the autumn and spring plantings showed similar behavior and values, while the winter planting ones, for several variables, showed lower values, even though most of them had similar behaviour to the other periods.

With similar patterns of behaviour, 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 behaviour, the winter planting was notable for presenting, even in the largest leaf area where the 9.44 mm d^{-1} depth was applied, a lower valuation than that recorded on the smallest depth of the autumn and spring plantings (4 mm d^{-1}). Such an effect can be explained by the climatic conditions in the second planting (cooler period) and not by the effect of the irrigation depths since these presented the same quadratic behaviour in the seedlings.

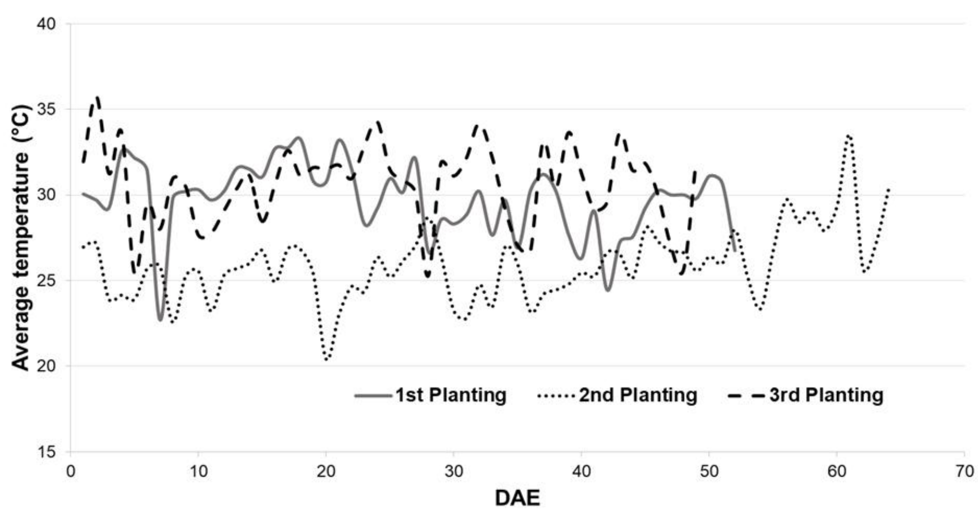


Fig. 1. Daily values of the average temperature occurred within the greenhouse, for each planting season, throughout the production period of the genotype TSH1188 cacao tree seedlings in Colatina / ES, 2017

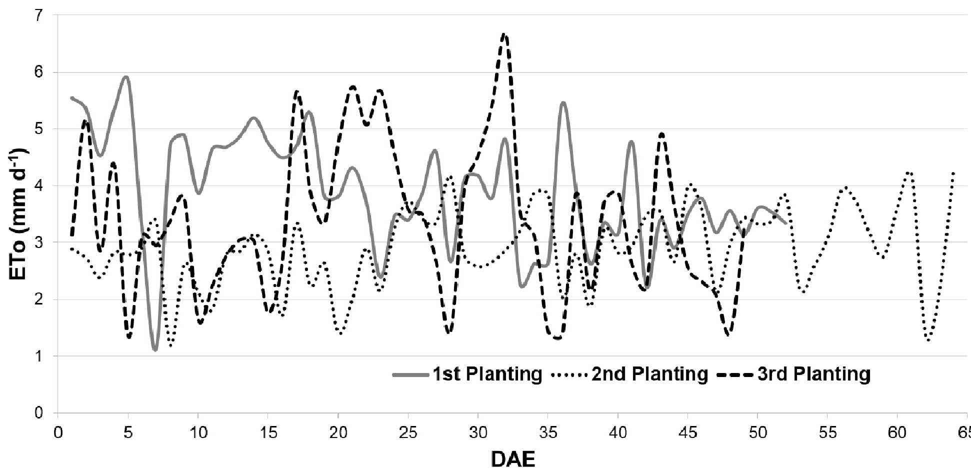


Fig. 2. Daily values of reference evapotranspiration (ETo) around the greenhouse for each planting season during the whole production period of the cacao tree seedlings at Colatina / ES, 2017

The leaf area of a plant is related to the number and size of its leaves, as well as the duration of their activity on the plant, providing an indication of the photosynthetic surface of the plant and its energy production capacity, responsible for 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 behaviour in all the evaluated epochs, with R^2 varying from 0.85 to 0.98 (Fig. 3B). It was noted that the number of leaves tended to decay in depths superior to 8 and 10 mm d^{-1}. This increase in leaf area, recorded in the depths superior to 8 mm d^{-1}, only affected the leaves sizes but not the number of leaves.

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 reduced 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 autumn and spring plantings, which could be explained by a better distribution of chlorophyll cells in the leaves with better leaf area development [25,26].

In all plantings, height presented a regression with quadratic behaviour and R^2 ranging from 0.80 to 0.99, about the treatments adopted (Fig. 5A). The maximum height in the autumn planting was reached in depth the 8 mm d^{-1} (22.2 cm), which was also responsible for providing the best results in the winter (15.0 cm) and spring plantings (22.9 cm).

The water deficit causes a reduction in seedling growth [27]. According to 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.

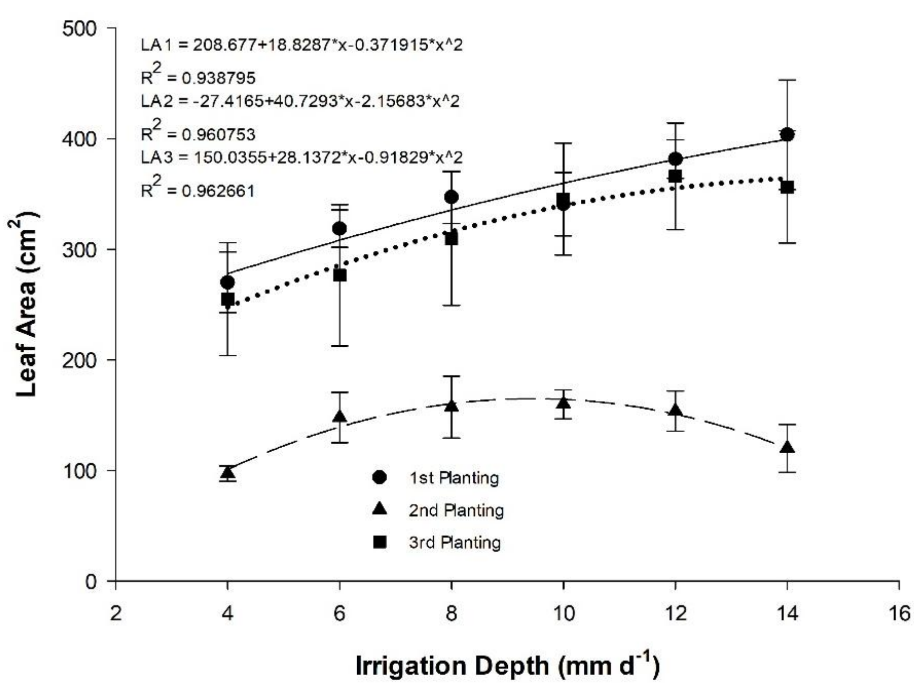
The irrigation depths corresponding to 8 and 10 mm d^{-1} were also the ones that presented the best results for the shoot diameter (SD) at all planting times. Such morphological characteristic demonstrated a quadratic regression model in all plantings, with R^2 ranging from 0.83 to 0.99 (Fig. 5B). In 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 behaviour 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 TSH1188 cacao tree seedlings. In a study made by Ramos et al. [29], with cacao tree seedlings clone PH-16, the observed behaviour 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.

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 R^2 from 0.65 to 0.97, with increasing predominance in the autumn and spring plantations, till depths the 12.7 and 11 mm d^{-1}, respectively, and in the winter planting up to the depth of 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 R^2 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 autumn and spring plantings, respectively, and 7.12 mm d^{-1}, in the winter one.

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 behaviour and regressions with R^2 ranging from 0.79 to 0.91.

A



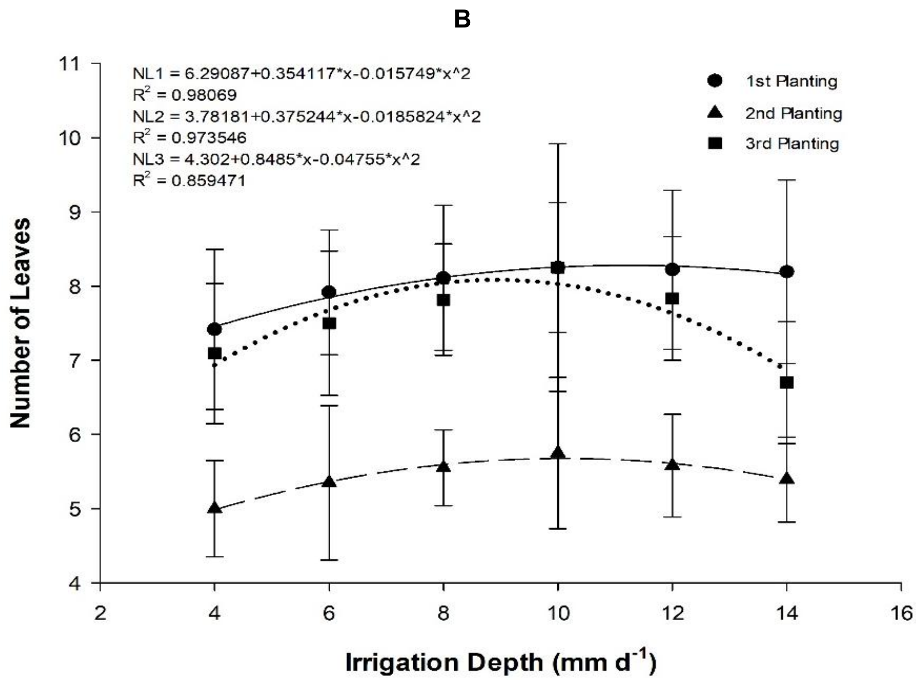


Fig. 3. Variation of leaf area (A) and number of leaves (B), in response to different irrigation depths applied in the production of genotype TSH1188 cacao tree seedlings in the three different planting seasons in Colatina / ES, 2017

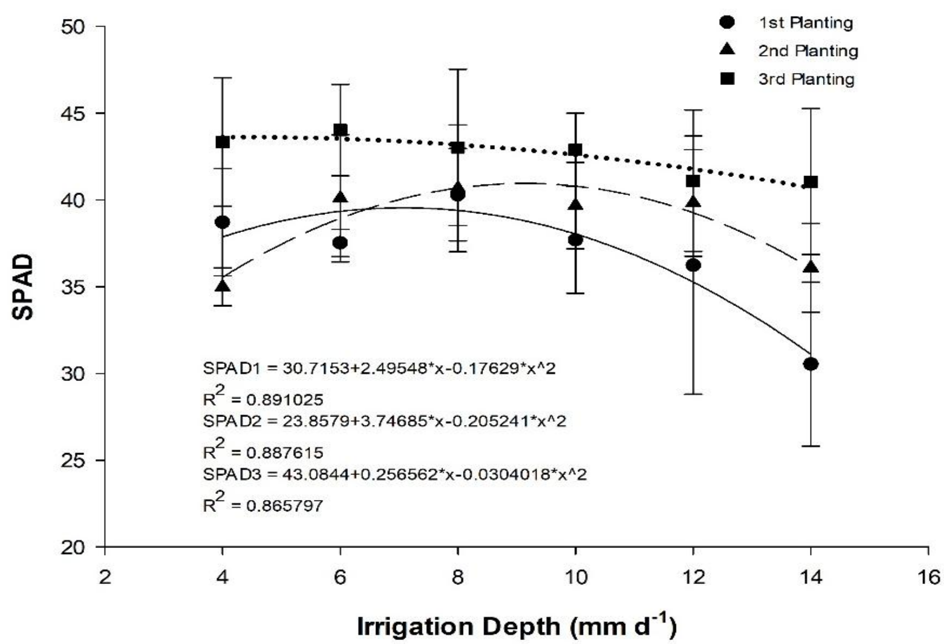


Fig. 4. Variation of chlorophyll content index (SPAD) in response to different irrigation depths, in genotype TSH1188 cacao tree seedlings at the three different planting seasons in Colatina / ES, 2017

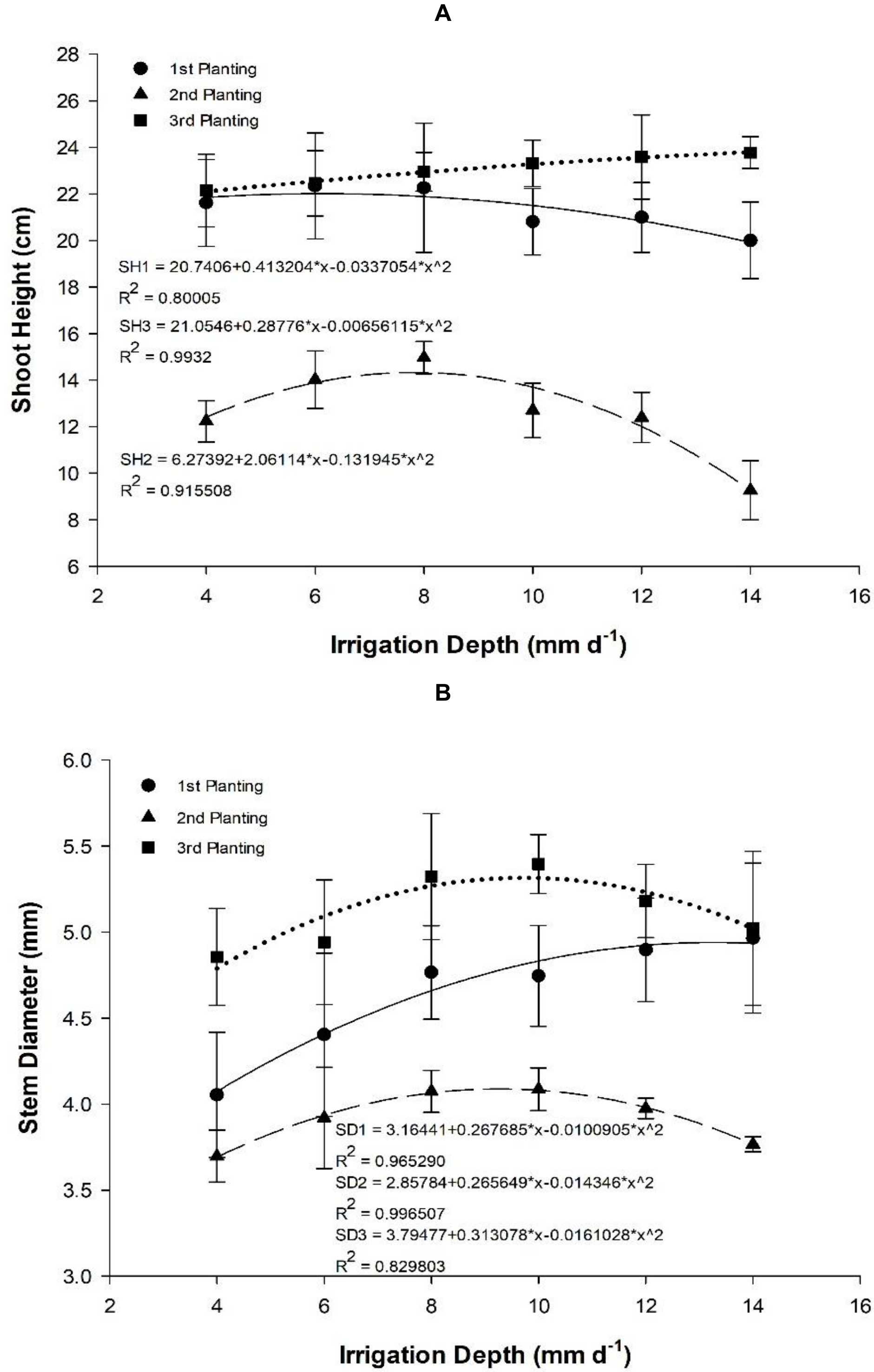


Fig. 5. Variation of shoot height (A) and shoot diameter (B) in response to different irrigation depths in the production of genotype TSH1188 cacao tree seedlings at three different planting times, Colatina / ES, 2017

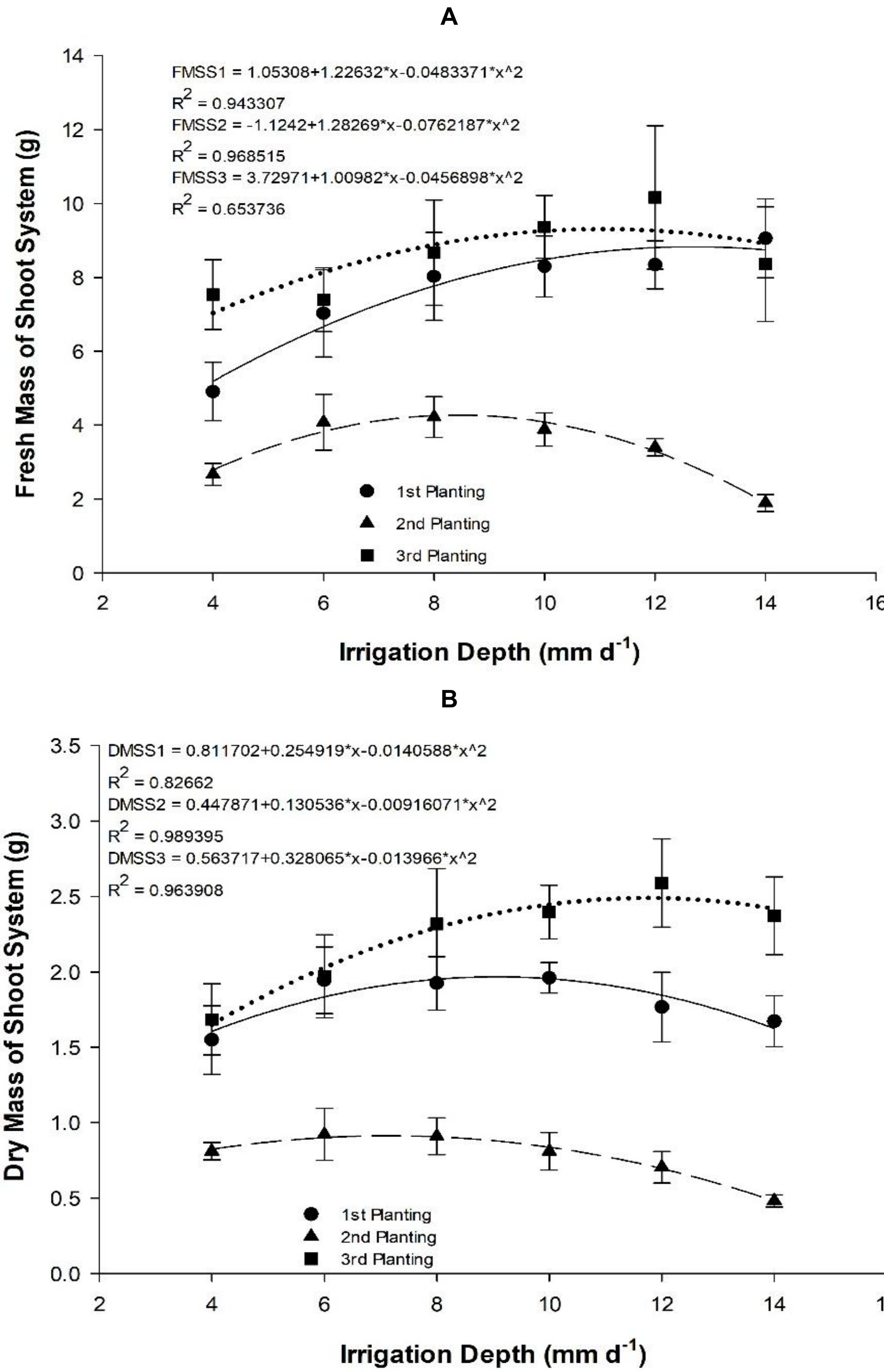


Fig. 6. Variation of the fresh mass of the shoot system (FMSS) (A) and dry matter of the shoot system (DMSS) (B) in response to the different irrigation depths in the production of genotype TSH1188cacao tree seedlings in three different seasons in Colatina / ES, 2017

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, synthesised under conditions of water stress [25].

The fresh mass of the root system presented a quadratic regression in the three planting seasons, with R^2 between 0.73 and 0.99 (Fig. 7B). In the autumn and spring plantations, there was a growth occurrence of the fresh mass in relation to the enlargement of the applied irrigation depths, but in the winter's planting, 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 R^2 varying from 0.82 to 0.96, there was growth with the increment of the applied depths in the autumn and spring plantings, while in the winter's planting, the growth of dry mass reaches its maximum at irrigation depth of 7.9 mm d^{-1}, and decreased thereafter.

Both the deficit and the excess of water present in the root system limited 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 of the 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 the dry mass of the shoot system and dry mass of the root system (RSR) showed a quadratic behaviour with R^2 0.97, 0.55 and 0.91, respectively, in the regression of the data obtained in the autumn, winter, and spring plantings (Fig. 8). The data showed the differential behaviour between the seasons of highest temperatures, autumn and spring with the winter, whose mean temperatures 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 able to supply the needs of the seedling. The best dry mass of shoot system ratio, in the winter 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}.

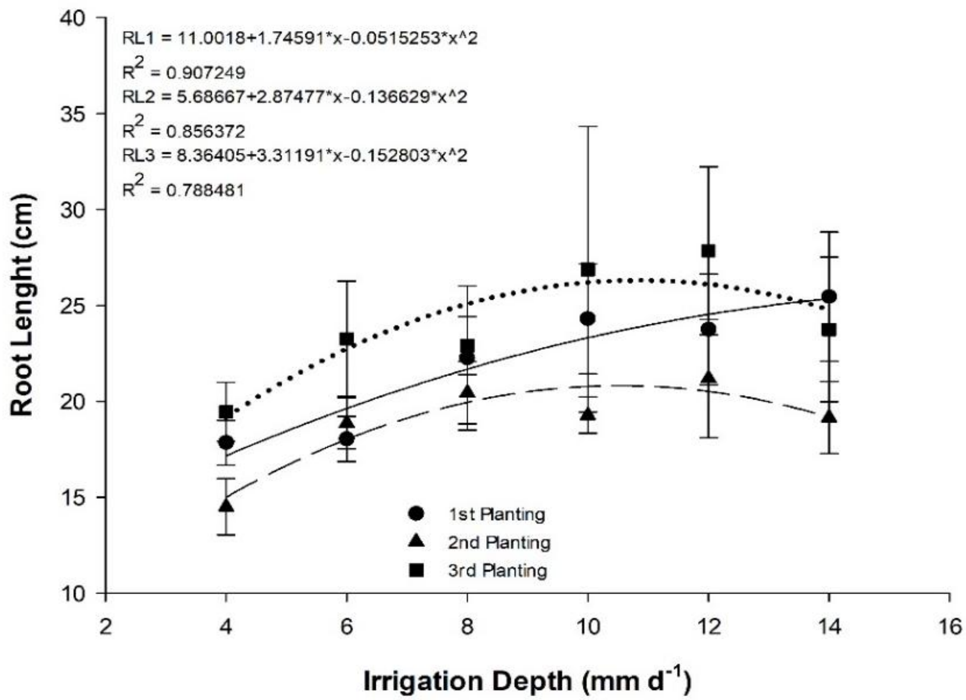
In the autumn and spring plantings, whose mean air temperatures remained higher, there was a better improvement of the shoot system of the seedlings that could not be accompanied by the root development. Thus, the irrigation depths of 8 to 10 mm d^{-1}, which presented more vigorous growth and better 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 the quality of the seedlings.

Regarding the relationship between shoot height and shoot diameter (RHD) (Fig. 9), it was also observed a different behaviour between planting times that presented higher temperatures (autumn and spring) with that in the winter's planting, when the temperature was lower. For the autumn and spring plantings, the best ratios were estimated, respectively, in irrigation depths of 11.4 and 8.48 mm d^{-1}. For the winter 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.

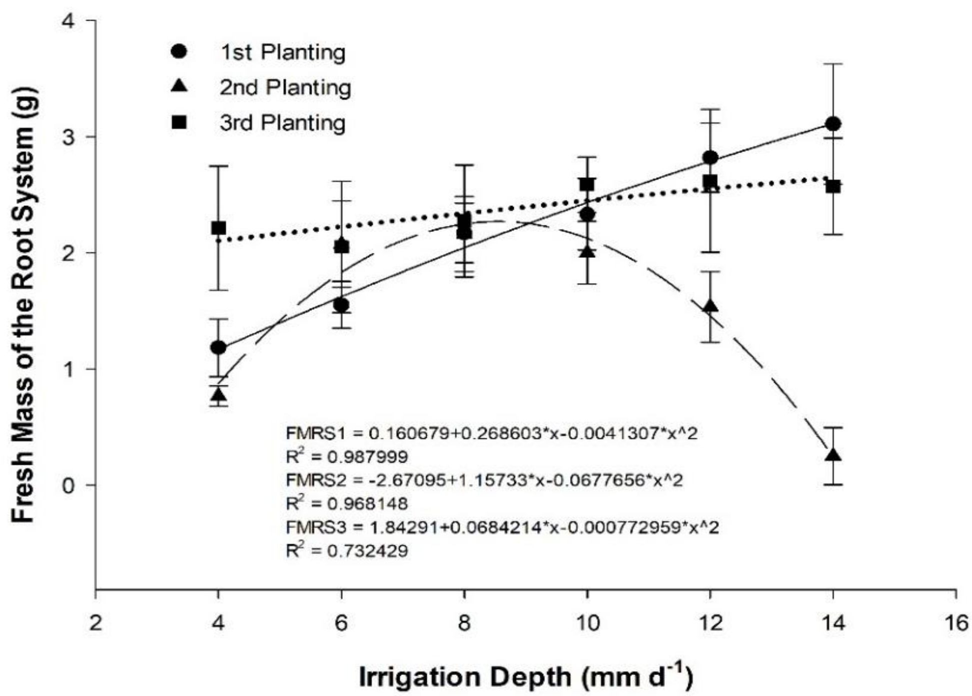
For Dassie et al. [36], easily measured morphological characteristics, such as plant height and stem diameter, are the most used as the basis for the evaluation of the transplanting point of the seedlings for the field, the highest values being desirable. The relation of these characteristics, the height 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].

The Dickson quality index (DQI) presented a 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 autumn, winter, and spring plantings (Fig. 10).

A



B



C

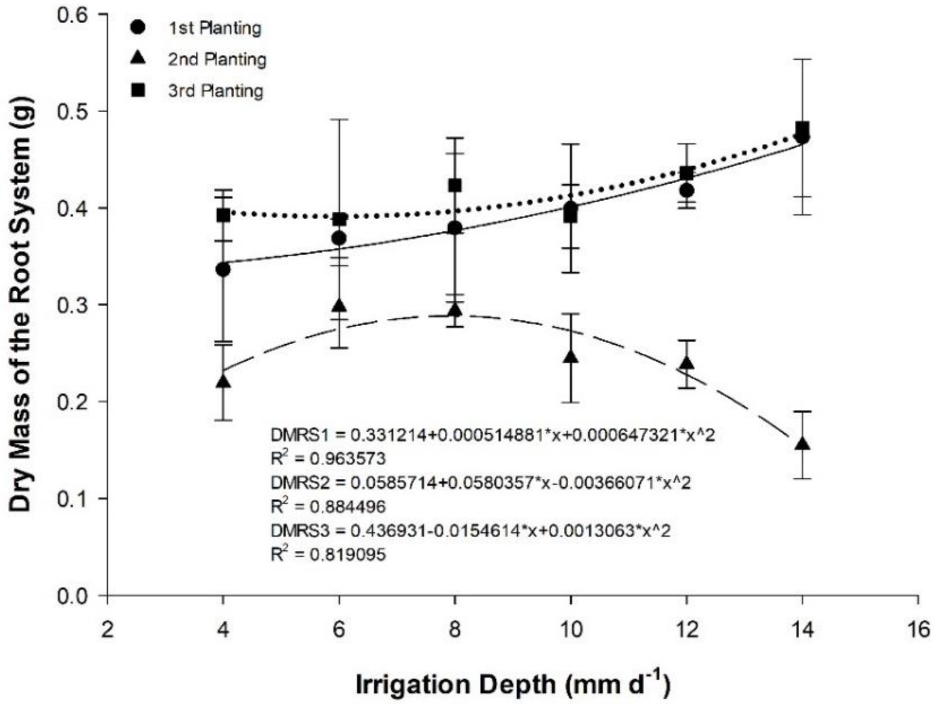


Fig. 7. Root length (A), fresh matter of the root system (B) and dry matter of the root system (C) of genotype TSH1188cacao tree seedlings in response to different irrigation depths in three different planting seasons in Colatina / ES, 2017

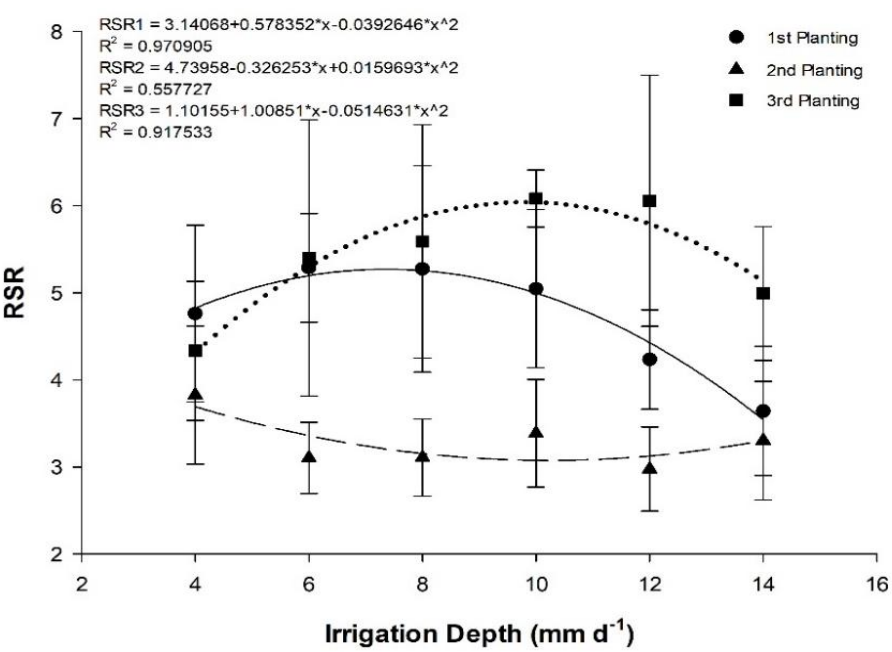


Fig. 8. The relationship between the dry mass of shoot system and the dry mass of the root system (RSR) of the genotype TSH1188 cacao tree seedlings in response to the different irrigation depths in three different planting seasons in Colatina / ES, 2017

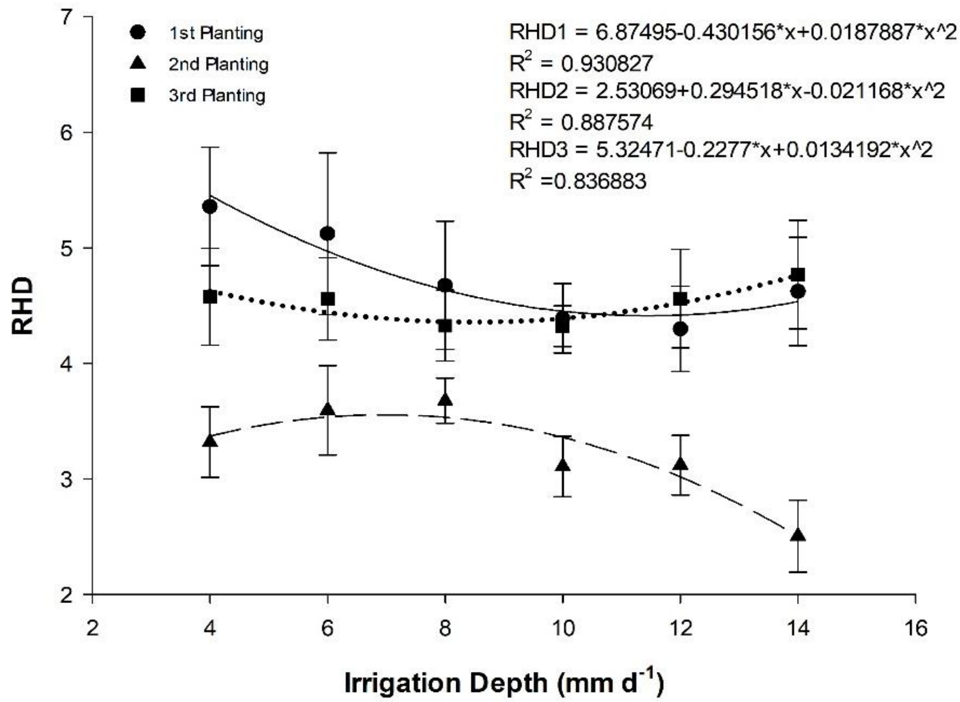


Fig. 9. The relationship between shoot height and stem diameter (RHD) of the genotype TSH1188cacao tree in response to different irrigation depths in three different planting seasons in Colatina / ES, 2017

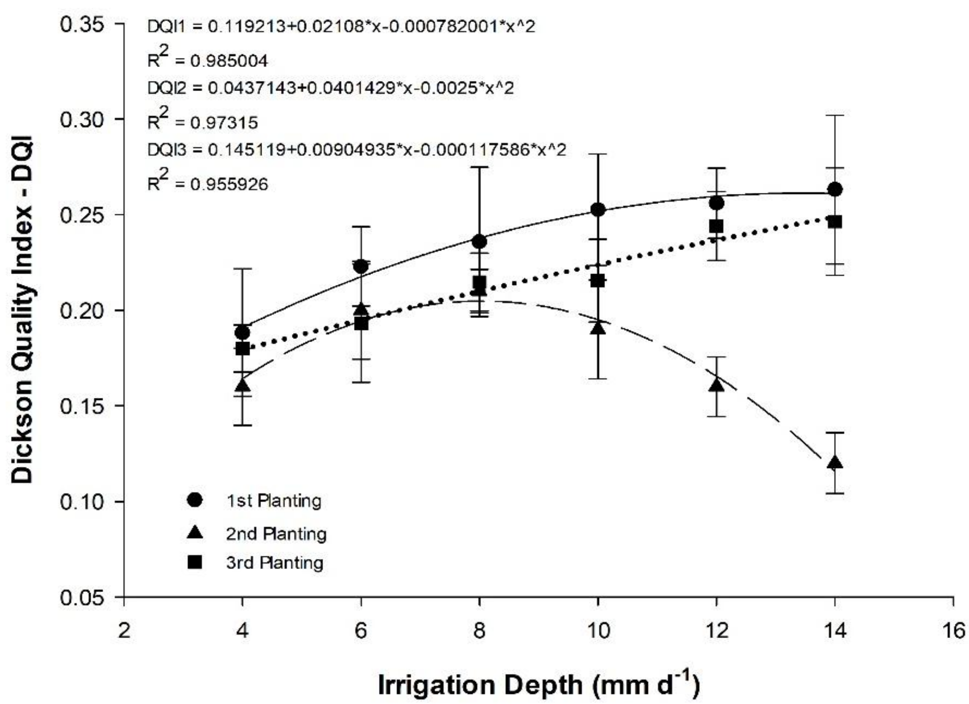


Fig. 10. Dickson quality index (DQI) of the genotype TSH1188 cacao tree in response to different irrigation depths at three different planting times in Colatina / ES, 2017

Dickson quality index (DQI) is considered an integrated morphological measure [38] and balances several parameters including 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, autumn and spring plantings, the DQI values showed increased in relation to the increase of the irrigation depths, differently from the winter's one, which had the lowest mean 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 DQI for the production of good quality seedlings. This value was found in the winter planting only on irrigation depth of 8 mm d^{-1}, while for the autumn and spring 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 characterised as being the ideal for the production of quality cacao tree seedlings, independent of the growing season, with the advantage of water saving, manpower and reduction of possible losses of nutrients by leaching. The Dickson quality index (DQI) was shown to be a good quality indicator for the seedlings of the genotype TSH1188 cacao tree.

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} 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 maximised the characteristics evaluated.

Analysing together all the growth and quality characteristics studied, through 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 for development in all the analysed planting times. Thus, to obtain quality seedlings, they must be produced with an irrigation depth of 8 mm d^{-1} because it presents, irrespective of climatic conditions, ideal growth and quality responses in 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.

Considering all the parameters in the Dickson quality index, irrigation depth of 8mm d^{-1} was found to be the best for the production of the genotype TSH 1188 cacao tree seedlings.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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