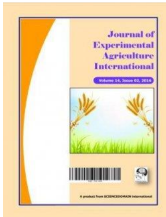

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Growth and Quality of Yellow Passion Fruit Seedlings Produced under Different Irrigation Depths

Robson Prucoli Posse[1*], Francielly Valani[1], Ariane Martins Silva Gonçalves[1], Evandro Chaves de Oliveira[1], João Marcos Louzada[1], Waylson Zancanella Quartezani[2] and Marta Cristina Teixeira Leite[1]

[1]Instituto Federal de Ciência e Tecnologia do Espírito Santo – Campus Itapina, Brasil.
[2]Instituto Federal de Ciência e Tecnologia do Espírito Santo – Campus Montanha, Brasil.

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 and AMSG managed the writing of the manuscript. Authors RPP, ECO and WZQ managed the analyses of study. Author JML performed the statistical analysis. Author MCTL performed translation of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The aim of this study was to evaluate the effect of irrigation depths on growth and quality of yellow passion fruit seedlings produced in containers. The experiment was carried out under a greenhouse in individualized environments, with 2.20 m long and 1.10 m wide, isolated by transparent plastic canvas on the sides. The treatments consisted in the application of six daily irrigation depths, corresponding to 4, 6, 8, 10, 12 and 14 mm d^{-1} for the production of yellow passion fruit seedlings. The experimental analysis was used completely randomized design (CRD), where each treatment was composed of 48 plants, all useful, totalizing in the experiment 288 seedlings. Results showed that depths of 8 mm d^{-1} was more suitable for the formation of yellow passion fruit seedlings in

**Corresponding author: E-mail: rpposse@gmail.com;*

containers, with higher water economy, obtaining similar growth and quality observed with depths of 10 and 12 mm d^{-1}, which maximized the evaluated characteristics. Depths of 8, 10 and 12 mm d^{-1} presented Dickson quality index above 0.26 and, the best ratio between shoot dry weight and root system dry weight which should be 2.2 to 2.4 to characterize a quality seedling.

Keywords: Passiflora edulis sims; vegetative propagation; containers; water replenishment; dickson quality index.

1. INTRODUCTION

The yellow passion fruit (*Passiflora edulis* Sims), also known as passion fruit is the most cultivated and marketed in Brazil [1], reaching a production of 703,489 tons of passion fruit in 2016, in a harvested area of 49,889 hectares, with a national average yield of 14,101 kilograms per hectare [2].

The passion fruit culture, explored in tropical and subtropical regions, presents reasonably short production cycle and good profitability by area, showing good potential as an alternative income, particularly for family farmers [1]. Its main destination is for fresh consumption and juice production [3].

The passion fruit seedlings must be of good quality, thus contributing to the growth and development of the plants in the field [4], with a shorter production time, aiming at reducing the costs of inputs and labor [5]. The production of seedlings is possible through several techniques: micropropagation, grafting, cutting and seed germination [6].

Passion fruit seedlings intended for commercial planting are preferentially derived from seedlings grown in nurseries obtained by seed germination [4], which present, as well as other Passifloracea, irregular germination with a time interval between the beginning and the end of the germination from ten days to three months [7].

One of the possible limiting factors of the percentage, speed and uniformity of germination of yellow passion fruit seeds is the availability of water [8]. The water is directly linked to the whole productive process of the passion fruit, not being different in relation to the production of its seedlings in nursery, where it directly influences the quality of the seedlings [9].

However, the excess or deficit of water may limit the development of the seedling, since, in low quantity, it causes water stress and less absorption of nutrients, while in high quantity, it raises the cost of production due to the energy consumption for the irrigations and expenditures on inputs, labor and equipments used to correct leaching of nutrients. In addition, excess water provides the formation of a microclimate conducive to disease development and contributes negatively to socio-environmental issues of water waste [9;10].

Due to the lack of knowledge about the ideal amount of water to be used in the production of passion fruit seedlings in nurseries, this study aimed to evaluate the effect of different irrigation depths on the growth and quality of yellow passion fruit seedlings produced in tubes.

2. MATERIALS AND METHODS

The study was developed in the Horticulture sector of the Federal Institute of Espírito Santo, Itapina Campus, in Colatina County, Espírito Santo state (19°29' S, 40°45' W; 62 m altitude), Brazil. The climate of the region is Tropical Aw, according to the Köppen classification [11]. The region is characterized by irregular rainfall and high temperatures.

The experiment was conducted from March 16, 2017 to May 11, 2017 within an agricultural greenhouse with linear dimensions of 25 m x 5 m and 3 m right foot with transparent plastic film and polypropylene mesh black with 50% shading. In the interior of the greenhouse were six individual environments (boxes), 2.20 m long by 1.10 m wide, insulated by transparent plastic canvas on the sides. Inside each box were installed six NaanDanJain® GREEN MIST anti-mist nebulizers, located one meter above the seedlings and spaced 0.8 m apart, with watering frequency individually controlled by electronic controllers and centrifugal pumps of 0.5 cv independently installed, operated by frequent pulses and distributed for 10 hours per day at a service pressure of 2.0 kgf cm^{-2}.

The treatments consisted of the application of six daily irrigation depths, corresponding to 4, 6, 8, 10, 12 and 14 mm d^{-1} for the production of yellow passion fruit seedlings. The experimental design was completely randomized (CRD), where each treatment was composed of 48 plants, all of them useful, totalizing in the experiment 288 seedlings.

The seedlings were produced in tubes with a diameter of 53 mm, 190 mm in height and 280 ml of volumetric capacity. The tubes were carried in holders with a capacity of 54 cells, distributed in alternating cells in order not to limit the arrival of light in the seedlings which could lead to etiolation. All tubes were prewashed and sterilized with 2% sodium hypochlorite diluted in water. The tubules were filled with Tropstrato HT Vegetable substrate plus Osmocote Plus 15-9-12 (3M), at the dosage of 3 g tube^{-1}, which had 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%. No additional fertilization was done.

The seeds of yellow passion fruit (*Passiflora edulis* Sims) used were obtained in the local market, through the acquisition of fruits of canary yellow color, oval, with smooth bark and without stains. The fruits were sectioned horizontally and the pulp removed for extraction of the mucilage, which was removed by friction in a sieve with sand in running water. After extraction, the seeds were dried in the shade on paper sheets for 24h and then seeded, one per containers. Variations in temperature and relative humidity within the greenhouse were monitored throughout the seedling production period by a WatchDog® Model 200 Data Logger. Externally, climatic variations and estimated reference evapotranspiration (ETo) were recorded using the FAO-56 Standard Penman-Monteith method using an ONSET® weather station installed near the experiment [12], Equation 1.

$$ETo = \frac{0{,}408\Delta(Rn - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0{,}34 u_2)} \quad (1)$$

where 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 average daily air temperature (°C); u_2 is the average daily wind velocity at 2 m in height (m s^{-1}); e_s is the saturation pressure of the daily mean water vapor (kPa); e_a is the daily mean water vapor pressure (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 emerged 12 days after sowing and at 44 days after emergence, the following morphological characteristics were evaluated: a) shoot height (SH), measured in cm, using a ruler graduated in millimeters, from the stem base until the apical gem; b) stem base diameter (SBD), measured 2 cm above the edge of the tube, in mm, with a digital meter of the brand Metrotools, model MPD-150; c) root length (RL), measured in cm, with ruler graduated in millimeters, from the stem base to the largest root length; d) fresh weight of shoot system (FWSS) and the fresh weight of the root system (FWRS), expressed in grams, determined by the weighing after cutting at the height of the stem base, through an electronic scale with an accuracy of 0.001 g; e) shoot system dry weight (SSDW), root system dry weight (RSDW) and total dry weight (TDW), obtained by the sum of SSDW and RSDW, 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 a forced air circulation incubator at 65°C up to constant weight; f) Number of leaves (NL), determined by counting the total number of leaves per plant; g) leaf area (LA), 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 base diameter (RHD); b) relationship between shoot dry weight and dry weight of the root system (RSR); c) Dickson quality index (DQI), by the formula: DQI = [TDW / (RHD + RSR)] [13].

The results were submitted to analysis of variance of the regression by the test F, at a significance level of 0.01, and, when significant, regression models were adjusted that better represent the effect of the applied irrigation depths on the analyzed variables. The maximum points were determined by the first derivative of the regression equations. In addition, the degree of association between the growth and quality data of the seedlings as a function of the applied irrigation depths was obtained by the Pearson correlation analysis.

3. RESULTS AND DISCUSSION

During the period of the experiment, meteorological variables external to the greenhouse were monitored. The values of mean, maximum and minimum temperature observed were 26.9°C, 38.8°C and 16.8°C, respectively (Fig. 1A), and average, maximum and minimum relative humidity were 70.3%, 99.0% and 13%, respectively (Fig. 1B). The reference evapotranspiration (ETo) reached a maximum value of 5.85 mm d^{-1} and a minimum of 1.14 mm d^{-1}, presenting an average value during the period of 3.95 mm d^{-1} (Fig. 1A).

Regarding the meteorological variables monitored inside the greenhouse, it was observed that the average temperature during the whole period was 29.9°C, presenting a maximum of 44.4°C and a minimum of 17.5°C (Fig. 2A). These values represented 11.15%, 14.43% and 4.17%, respectively, higher than the external environment. The average relative humidity inside the greenhouse was 56.7%, reaching a maximum of 93.9% and a minimum of 20.7% (Fig. 2B). These conditions are considered favorable for the production of yellow passion fruit seedlings [7,6].

According to the summaries of variance analyzes, the significant interaction (P < 0.01) between the water depths and each of the morphological characteristics studied was observed (shoot height, root system length, leaf area, number of leaves, shoot diameter, fresh weight of the shoot and the root system, dry weight of the shoot and of the root system), thus demonstrating the effect of irrigation depths on the quality and development of yellow passion fruit seedlings produced in tubes. The shoot height (SH) presented a quadratic behavior, with coefficient of determination (R^2) of 0.9485, reaching its maximum development in a depth of 9.61 mm d^{-1}, with 18.15 cm high. The length of the root system (RL) presented increasing linear behavior with the increase of water depths, with R^2 of 0.9303 (Fig. 3A). The stem base diameter (SBD) of the yellow passion fruit seedlings presented a quadratic behavior as a function of the applied water depths with determination coefficient of 0.8891, with the largest diameter being 3.9 mm for the 9.55 mm d^{-1} depth (Fig. 3B).

Considering the estimated regression models, the maximum fresh matter produced from the aerial part (7.29 g) as well as the root system (3.98 g) was obtained with a daily application of 10.44 mm and 11.4 mm, respectively (Fig. 3C). Likewise, the maximum dry weight of shoot was 9.59 mm d^{-1}, with 1.3 g and the maximum dry weight of the root system was 0.56 g for the irrigation depth of 10.0 mm d^{-1}, with determination coefficient of 0.9469 (Fig. 3D). For the number of leaves variable (NL) the highest averages were observed with the 10 mm d^{-1} irrigation depth, with a determination coefficient of 0.9913 (Fig. 3E). Directly linked to the photosynthetic capacity of the plant, the leaf area presented quadratic behavior and a determination coefficient of 0.9005, with a maximum value of 278.04 cm^2 for an irrigation depth of 9.88 mm d^{-1} (Fig. 3F).

Except for the root lenght (RL), all other growth patterns were adjusted to a quadratic function, due to the effects caused by water stress and excess water applied, which promoted a significant reduction in seedling quality. Water deficits affect plant metabolism and stimulate adaptation reactions. One of the first symptoms is the reduction of the turgidity, which depending on the duration and the phase of the affected plant can inhibit the cell expansion and cause reduction of the leaf expansion. Reduction of the leaf area is considered the first line of defence to the water deficit, which also causes, among other consequences, increased respiration, lower photosynthetic rate with lower dry matter yield [14;15].

Excess water may be as much as or more harmful than its absence to the seedlings because it provides an environment conducive to disease emergence and causes substrate nutrient leaching problems [16]. On the other hand, the production of seedlings in containers presents problems for conditioning small volume of substrate that added to the presence of irrigation, especially in higher irrigation depths, causes nutrients reduction in a few weeks due to leaching. Thus, a nutritional supplementation through fertilization, usually in plots, becomes necessary for the proper development of the seedlings, which increases the costs of production [17].

Regarding the analyzes of the indexes of quality of yellow passion fruit seedlings, the height-to-shoot ratio (HSR) for treatments 4, 6, 8, 10, 12 and 14 mm d^{-1} presented values of 3.80; 4.73; 4.82; 4.28; 4.74 and 4.37, respectively. Regarding the analysis of HSR in the daily depths applied, the regression analysis was non-significant, and then the mean value of 4.46 should be considered. This value is lower when compared to forest species, whose range considered adequate for this relationship is 5.4 to 8.1 [18] and close to the values found by [19], for coffee seedlings produced in containers. It should be noted that the value of RHD demonstrates the growth balance since it provides information about the thickness of the seedlings [20].

However, the dry weight ratio of the shoot by dry weight of the root system (RSR) presented significant interactions (P < 0.01) between the applied irrigation depths. The best RSR values are between 2.2 to 2.4 and correspond to irrigation depths ranging from 8 to 12 mm d^{-1}. The RSR values were adjusted to a quadratic function with a determination coefficient of 0.9778, where the lowest value (2.26) was obtained with the 10.56 mm d^{-1} blade, resulting in the best balance between the dry weight of the shoot and the dry weight of the root system (Fig. 4). However, for an applied irrigation depth of 8 mm d^{-1} the value of the RSR (2.39) is not far from the minimum value found in this experiment (2.26), characterizing the importance of a smaller water application, guaranteeing the same quality.

Dickson quality indexes (DQI) ranged from 0.15 to 0.27 with quadratic effect as a function of the daily irrigation depth applied, presenting a significant regression at 1% probability with coefficient of determination (R^2) equal to 0.9495 (Fig. 5).

Analyzing the behavior of the functions of Fig. 3, we can observe that the points of maximum growth/development are in the ranges of the applied irrigation depths of 8 to 12 mm d^{-1}. Given that Dickson's quality indexes presented values above 0.2, this is the minimum established by Hunt [21] to obtain a quality change. However, in order to save water, manpower and possible nutrient losses due to leaching, the daily

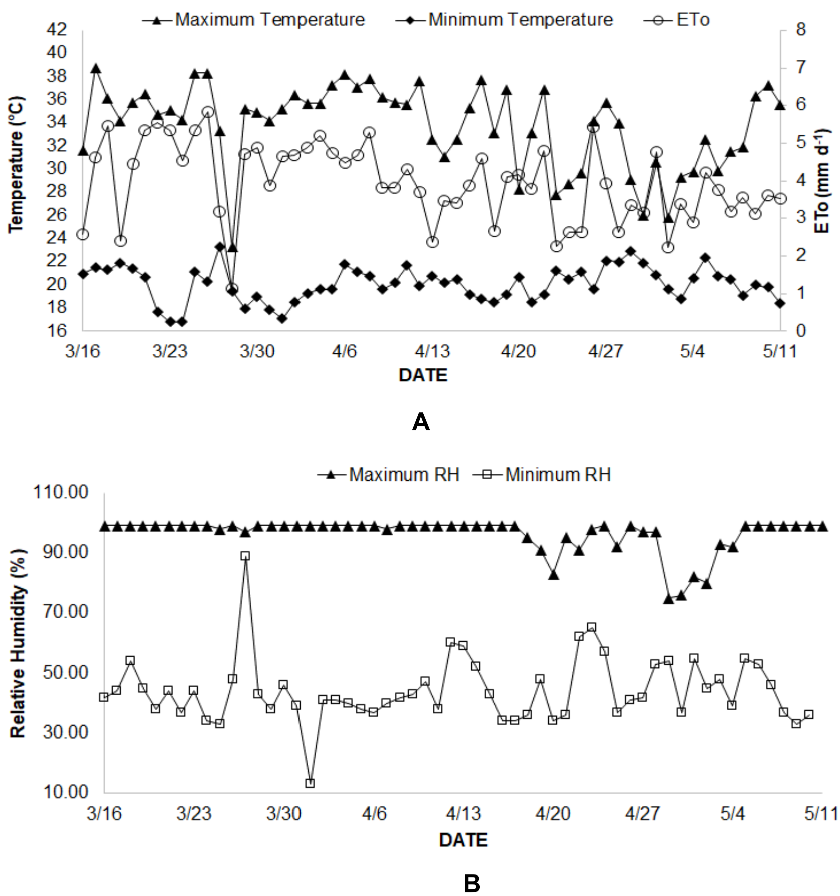

Fig. 1. Values of the reference evapotranspiration (ETo), the maximum and minimum temperature (A) and the maximum and minimum relative humidity (B) of the external environment, during the period of formation of the yellow passion fruit seedlings (March to May 2017) in Colatina-ES

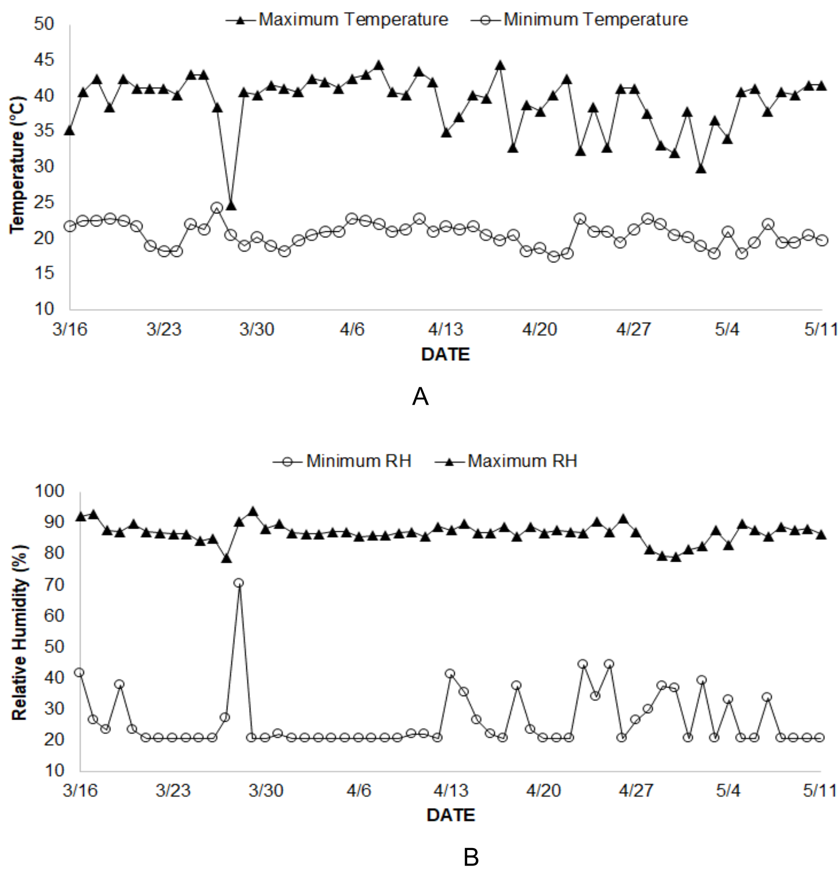

Fig. 2. Values of maximum and minimum temperature (A), maximum and minimum relative humidity (B) of the indoor environment (Greenhouse), during the period of formation of the yellow passion fruit seedlings (March to May 2017) in Colatina-ES

irrigation depth of 8 mm d^{-1} is recommended for the production of yellow passion fruit, which is approximate twice the reference evapotranspiration (ETo), measured in an external environment (Fig. 1A). This irrigation depth is indicated, since the substrate has low water retention capacity, requiring more frequent irrigations. A similar result was found by Morais et al. [9] who, when studying Aroeira Vermelha seedlings, found that their ideal daily irrigation depth occurred between 10 and 12 mm, but that the use of the 10 mm of water depth promoted a satisfactory development of the seedling and the rational use of water. Works to determine the ideal water depth have been performed with seedlings of native species. In a study of three different species of native seedlings under different water management, [22] observed that in Ingá and Canafístula seedlings the 10 mm d^{-1} depth and twice-daily frequency provided seedlings with better vigor and, for Jatobá seedlings the ideal irrigation depth is 6 mm d^{-1} with a frequency of four times a day, because it is a slow-growing seedling.

The main causes of plant mortalities in the first years of crop implantation are related to a problem in the production of seedlings in nurseries [23]. The morphological parameters, which are determined physically and visually, are being studied in order to correlate with the success of field seedlings after planting [24]. Table 1 presents the Pearson correlation (r) values between the different variables studied. High correlations indicate direct effect with the main variable, indicating cause and effect. Thus, we observed that SBD (r = 0.895), NL (r = 0.891), LA (r = 0.704), FWRS (r = 0.852), RSDW (r = 0.955) and TDW (r = 0.859) were the variables that had a great direct effect on the

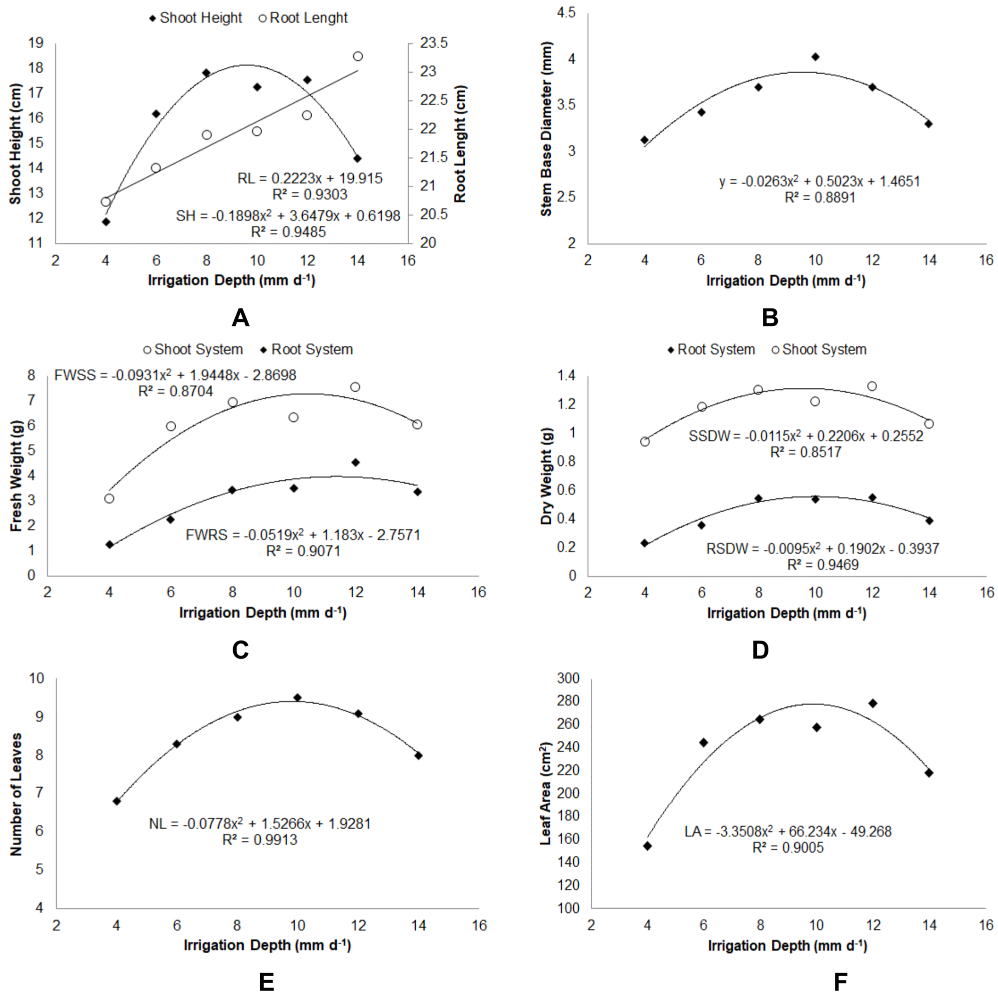

Fig. 3. Variation of shoot height and root length (A), stem base diameter (B), fresh weight shoot system and fresh weight root system (C), shoot system dry weight and root system dry weight (D), number of leaves (E) and leaf area (F) of yellow passion fruit seedlings as a function of the daily applied irrigation depths, Colatina-ES, 2017

Dickson quality index (DQI), presenting a high positive correlation.

Aerial and root weights, fresh and dry, are good criteria for determining the quality of seedlings [25], and the dry matter of the shoot is a good indication of rusticity and, consequently, good survival and initial performance in the field [26].

Considered also by Johnson et al. [20] as a promising morphological measure, the DQI reflects the quality of the seedlings considering in its calculation the robustness (TDW) and the balance of the phytomass distribution (RHD and RSR). In order to assist in the proper management of young plants in the nursery, the DQI can be monitored using the stem base diameter (SBD), since, as shown in Fig. 6, it presents a strong linear correlation with the DQI, presenting a significant linear regression at 1%, with a coefficient of determination of 0.8015, besides being a non-destructive method.

The minimum value of 0.20 for the Dickson Quality Score (DQI) has been shown to be a good indicator of quality for yellow passion fruit seedlings. However, it is worth noting that in addition to estimating the DQI value using only the SBD, it is advisable that the seedlings have a height equal to or greater than 17.6 cm and a larger number of leaves equal to 9, to guarantee the quality and survival of the seedlings in the field.

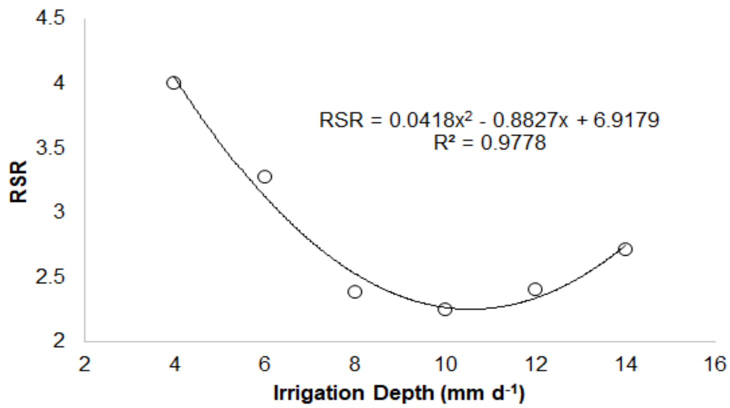

Fig. 4. Variation of the relation between shoot dry weight and root dry weight (RSR) of yellow passion fruit seedlings as a function of daily applied irrigation depths, Colatina-ES, 2017

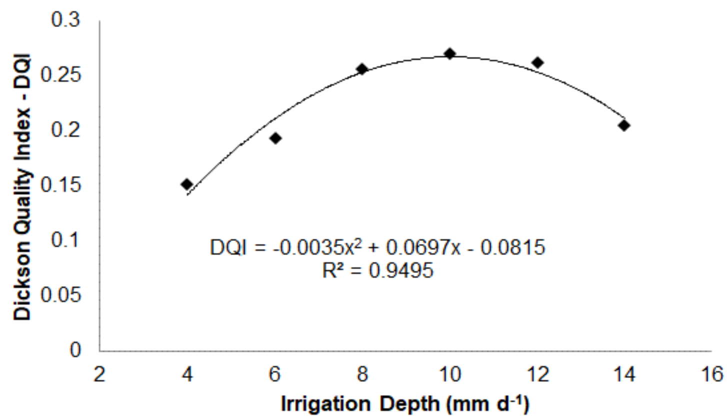

Fig. 5. Variation of the Dickson quality index (DQI) of yellow passion fruit seedlings as a function of daily applied irrigation depths, Colatina-ES, 2017

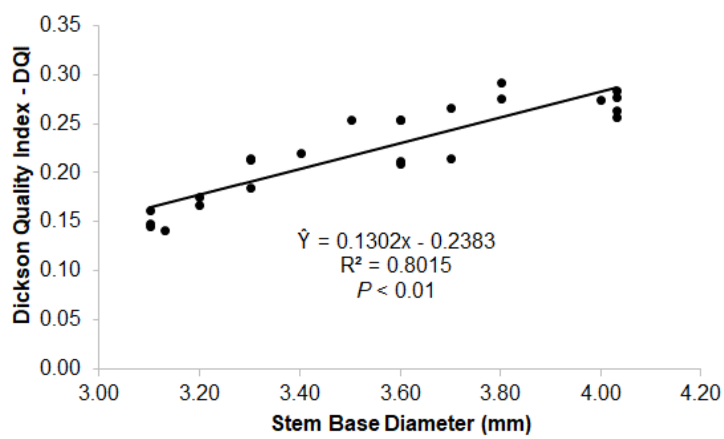

Fig. 6. Influence of stem base diameter (mm) on determination of the Dickson Quality Index (IQD) for production of yellow passion fruit seedlings, Colatina-ES, 2017

Table 1. Table of Pearson correlation coefficients (r) between the variables Dickson quality index (DQI), shoot height (SH), in cm, root length (RL), in cm, stem base diameter (SBD), in mm, number of leaves (NL), leaf area (LA), in cm^2, fresh weight of shoot system (FWSS), in g, fresh weight of the root system (FWRS), in g, dry weight of the shoot system (SSDW), in g, dry weight of the root system (RSDW), in g, total dry weight (TSW), in g, shoot height ratio by stem base diameter (RHD) and relation between shoot dry weight and root system dry weight (RSR), in seedlings of *Passiflora edulis* Sims, Colatina-ES, 2017

	DQI	SH	RL	SBD	NL	LA	FWSS	FWRS	SSDW	RSDW	TDW	RHD	RSR
DQI	1												
SH	0.598	1											
RL	0.234	0.140	1										
SBD	0.895	0.587	0.143	1									
NL	0.891	0.829	0.258	0.863	1								
LA	0.704	0.886	0.294	0.661	0.843	1							
FWSS	0.670	0.864	0.364	0.536	0.833	0.860	1						
FWRS	0.852	0.591	0.433	0.660	0.795	0.707	0.791	1					
SSDW	0.683	0.759	0.108	0.552	0.719	0.828	0.674	0.644	1				
RSDW	0.955	0.766	0.237	0.835	0.936	0.794	0.810	0.865	0.711	1			
TDW	0.859	0.822	0.175	0.723	0.873	0.878	0.788	0.794	0.948	0.898	1		
RHD	0.105	0.817	0.076	0.017	0.421	0.628	0.685	0.259	0.545	0.351	0.500	1	
RSR	-0.785	-0.529	-0.306	-0.700	-0.754	-0.505	-0.702	-0.739	-0.253	-0.828	-0.532	-0.157	1

4. CONCLUSION

The ratio of the dry weight of the aerial part by the dry weight of the root system showed a significant interaction between the applied irrigation depths, where the best values should be from 2.2 to 2.4 to obtain a seedling of good quality, which was obtained when applying irrigation depths varying from 8 to 12 mm d^{-1}.

Irrigations depths of 8, 10 and 12 mm d^{-1} presented a Dickson quality index above 0.26, and non-destructively, the diameter of the stem base can be used to estimate Dickson's quality index by nurserymen and producers of yellow passion fruit seedlings.

Although the irrigations depths applied in the range of 10 to 12 mm d^{-1} represent the best growth and quality characteristics, the 8 mm d^{-1} irrigation depth, which is approximately twice the reference evapotranspiration (ETo) measured in an external environment, is more suitable for the formation of yellow passion fruit seedlings in greater water economy, with similar growth and quality of the irrigations depths that maximized the characteristics evaluated.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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