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3 **Growth and Quality of Papaya 'Golden THB'**

4 **Seedlings Cultivated Under Different Irrigation**

5 **Depths**

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11 **ABSTRACT**

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The obtainment of seedlings is one of the main stages of the papaya crop and good irrigation management provides proper water status, contributing to higher quality seedlings. Thus, this work had as objective to evaluate the growth and quality of Papaya 'Golden THB' seedlings submitted to different irrigation depths. The study was carried out at the Federal Institute of Espírito Santo, Campus Itapina, located in Colatina, Northwest region of the State of Espírito Santo, Brazil, during the period from May 16 to July 19, 2018. The experimental design was completely randomized with six treatments composed of 25 plants each, totaling 150 seedlings in the experiment. The treatments consisted in the application of six daily irrigation depths, corresponding to 4, 6, 8, 10, 12 and 14 mm. At 65 days after planting, the seedlings were evaluated for morphological characteristics: length of the root system, leaf area, plant height, stem diameter, dry mass of the aerial part, dry mass of the root system, total dry mass and Dickson quality index. Irrigation depths interfered in the growth and quality of papaya 'Golden THB' seedlings during their production period. The recommended irrigation depth for the production of papaya 'Golden THB' seedlings with high quality is 8.15 mm d⁻¹, which showed a higher Dickson quality index and good responses in all the morphological characteristics studied.

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14 *Keywords: Carica papaya L., efficiency of water use, irrigation management, Dickson index,*

15 *vegetative development, water replenishment.*

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18 **1. INTRODUCTION**

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20 The papaya (*Carica papaya* L.) is one of the most cultivated and consumed fruit trees in

21 tropical and subtropical regions, and its production is widespread in almost all tropical

22 America countries. The cultivar 'Golden THB' belongs to the 'Solo' group, being

23 characterized by high productivity, uniformity and vigor in the plantations, being destined

24 mainly for the export market [1].

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26 One of the main stages to reach the maximum genetic potential of papaya growth is to

27 obtain seedlings [2]. The correct management of irrigation of the seedlings maintains an

28 adequate water status contributing to get plants with a higher quality standard [3]. In many

29 cases, the application of water to the plants is done empirically, without technical knowledge,

30 leading to a reduction of the productive potential of the crops [4].

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32 The amount of water is a limiting factor in the development of plants and lack or excess
33 affects plant health, growth and production [5]. The lack of water creates water stress and a
34 decrease in the absorption of nutrients. The excess is conducive to disease development,
35 causes leaching of nutrients and excessive water consumption, causing socioenvironmental
36 problems [6]. So, the knowledge of the set of techniques for the production of seedlings
37 favors the elaboration of more efficient protocols for making seedlings with higher quality [7].
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39 Thus, studies are necessary to evaluate the efficiency of water use in the development of
40 papaya seedlings. The objective of this work was to evaluate the growth and quality of
41 papaya 'Golden THB' seedlings submitted to different irrigation depths.
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44 2. MATERIAL AND METHODS

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47 The study took place at the Federal Institute of Espírito Santo, Campus Itapina, located in
48 Colatina, Northwest region of the State of Espírito Santo, Brazil, located at 19°29 'South,
49 40°45' West and altitude of 62 meters, from May 16 to July 19, 2018. The climate of the
50 region, according to Köppen's classification, is Tropical Aw [8]. The zone is characterized by
51 the irregularity of the rain and the occurrence of high temperatures.
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53 The experiment was conducted in an agricultural greenhouse covered with transparent
54 plastic film and black polypropylene screen with 50% shading, linear dimensions of 25 mx 5
55 m and height of 3 m, in six individual environments (BOX) with dimensions of 2.20 m long by
56 1.10 m wide each, isolated by transparent plastic canvas on the sides. Each BOX consisted
57 of six GREEN MIST anti-mist nebulizers from NaanDanJain®, located 1 m above the
58 seedlings and spaced 0.8 m apart, with a daily watering frequency of 10 hours (from 07:00
59 am 05:00 pm), operating at a service pressure of 2 kgf cm⁻², individually controlled by
60 electronic controllers and centrifugal pumps of 0.5 hp independently installed.
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62 The treatments consisted in the application of six daily irrigation depths, corresponding to 4,
63 6, 8, 10, 12 and 14 mm d⁻¹, for the production of papaya seedlings. The experimental design
64 was completely randomized, with each treatment consisting of 25 plants, totaling 150
65 seedlings in the experiment.
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67 For the production of the seedlings were used seeds of the papaya 'Golden THB' obtained
68 from the company NorteFrut® located in Linhares-ES. The seedlings were produced in tubes
69 with a top diameter of 53 mm, 190 mm in height and 280 ml of volumetric capacity. The
70 tubes were arranged in holders with 54 cells, distributed alternately for not limiting the light in
71 the seedlings, which could lead to them to a stretching. All tubes were previously sanitized
72 and sterilized with 2% sodium hypochlorite diluted in water and filled with Tropstrato HT®
73 Vegetable substrate plus Osmocote Plus® 15-9-12 (3M), at a dosage of 3g tube⁻¹, which had
74 the following chemical composition: N = 15%, (7% ammonia and 8% nitrate), P₂O₅ = 9%,
75 K₂O = 12%, Mg = 1.3%, S = 5.9%, Cu = 0.05%, Fe = 0.46%, Mn = 0.06% and Mo = 0.02%.
76 No additional fertilization was done.
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78 During the execution of the experiment, variations in temperature and relative humidity within
79 the greenhouse were monitored by a WatchDog® Model 200 Data Logger. Externally climatic
80 variables were recorded by an ONSET® weather station, reference evapotranspiration (ET_o)
81 was estimated by the Penman-Monteith method FAO-56 Standard [9] by the equation:
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$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

83
84 in which ET_o is the daily reference evapotranspiration ($\text{mm}\cdot\text{d}^{-1}$); Rn is the daily radiation
85 balance ($\text{MJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$); G is the daily flow of heat in the soil ($\text{MJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$); T is the daily average
86 air temperature ($^{\circ}\text{C}$); u_2 is the daily average wind speed at 2 m in height ($\text{m}\cdot\text{s}^{-1}$); e_s is the
87 saturation pressure of the daily average water vapor (kPa); e_a is the daily average water
88 vapor pressure (kPa); Δ is the slope of the vapor pressure curve at the point of T ($\text{kPa}\cdot^{\circ}\text{C}^{-1}$)
89 and γ is the psychrometric coefficient ($\text{kPa}\cdot^{\circ}\text{C}^{-1}$).
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91 At 65 days after planting, the seedlings were evaluated for the following morphological
92 characteristics: a) leaf area (LA), expressed in cm^2 , estimated with LI-COR leaf area
93 measurer model LI-3100C; b) length of the root system (LRS), measured from the base of
94 the stem to the largest root length, in cm, with graduated ruler; c) plant height (PH),
95 measured in cm, with the use of a graduated ruler, from the stem to the apical bud; d) stem
96 diameter (SD), measured 2 cm above the edge of the tube, in mm, with a digital caliper from
97 Metrotools, model MPD-150; e) dry mass of the aerial part (DMAP), dry mass of the root
98 system (DMRS) and total dry mass (TDM), expressed in grams, through an electronic scale
99 with an accuracy of 0.001g; f) Dickson quality index (DQI) according to Dickson et al. [10],
100 given by:
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$$DQI = \frac{TDM}{\frac{PH}{SD} + \frac{DMAP}{DMRS}}$$

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103 To obtain the DMAP and DMRS, the plants were subjected to drying process in greenhouse
104 with forced circulation of air at 65°C for 72 hours and weighed on electronic scale with
105 precision of 0.001 g. The TDM was obtained by the sum of DMAP and DMRS.
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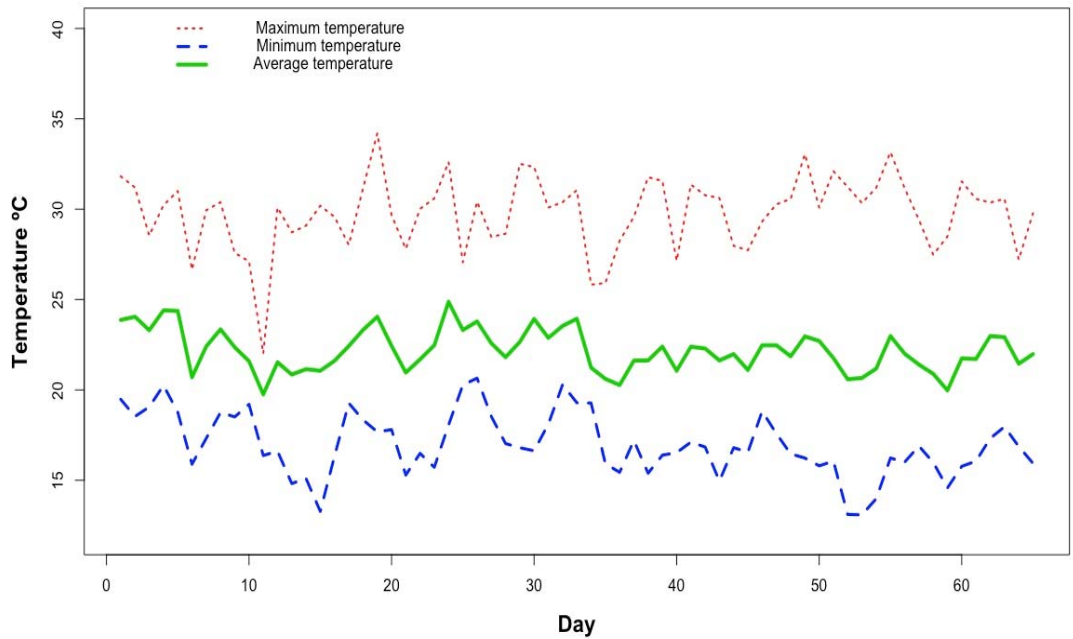
107 The data were subjected to analysis of variance by the F test, at 5% probability, when
108 significant, regression models were adjusted to better explain the effect of the irrigation
109 depths on the characteristics analyzed by the R software [11]. The maximum points were
110 determined by the first derivative of the regression equations.
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113 3. RESULTS AND DISCUSSION

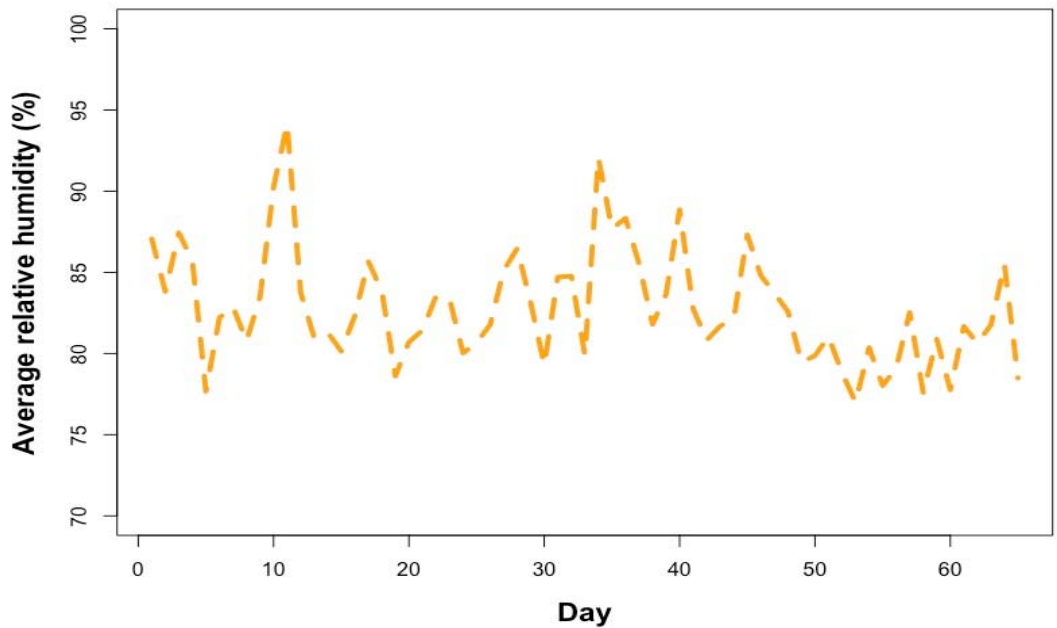
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116 During the experimental period, the external meteorological variations of the agricultural
117 greenhouse presented a maximum temperature of 22.0 to 34.2°C (average of 29.78°C),
118 average of 19.7 to 24.8°C (average of 22.18°C) and minimum of 13.1 to 20.6°C (average
119 of 16.98°C) (Fig. 1). The average relative humidity varied from 76.9 to 94.1% (average of
120 82.78%) (Fig. 2). The maximum reference evapotranspiration observed was 2.97 , minimum
121 of 1.06 and average of 2.15 mm d^{-1} (Fig. 3).



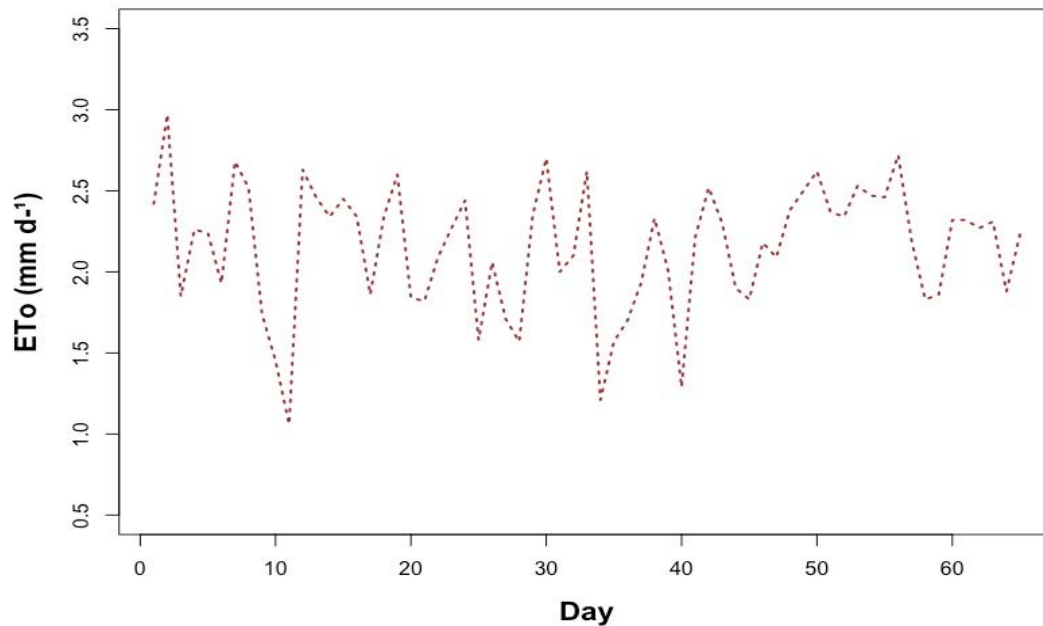
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Fig. 1. Maximum, minimum and average external temperatures during the experimental period in Colatina, Espírito Santo.



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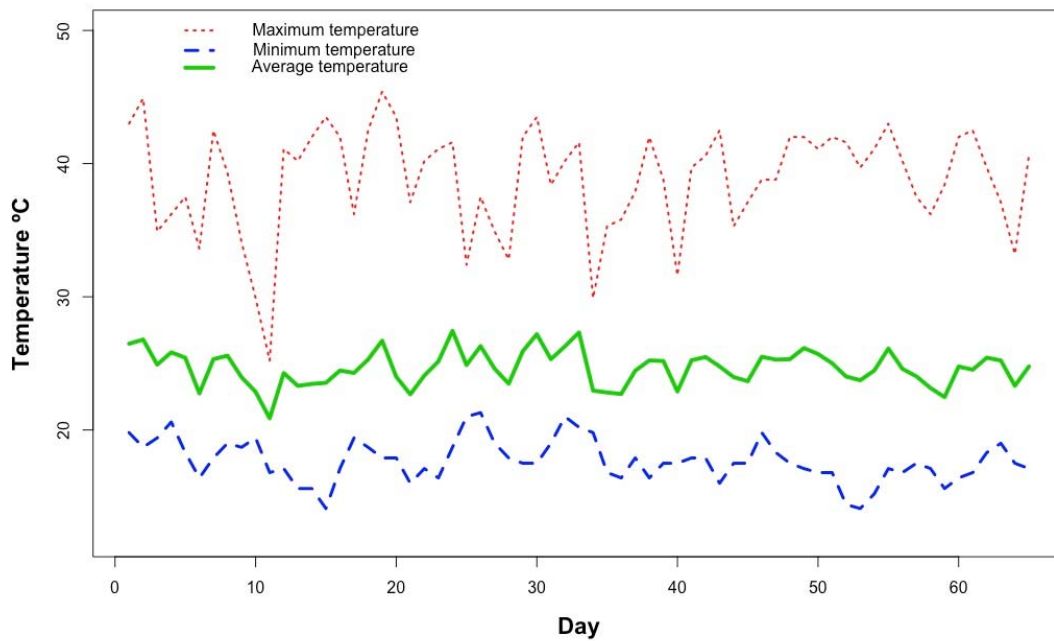
Fig. 2. External average relative humidity during the experimental period in Colatina, Espírito Santo.



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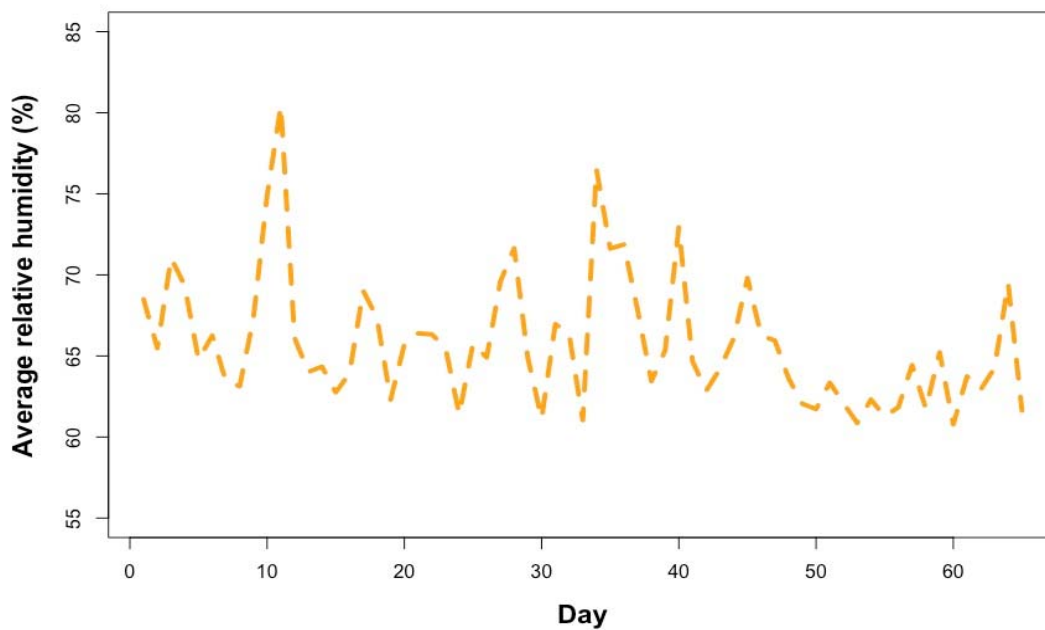
Fig. 3. Reference evapotranspiration during the experimental period in Colatina, Espírito Santo.

Within the agricultural greenhouse, the maximum temperature varied from 25.2 to 45.4 °C (average of 38.84 °C), the average temperature had variations from 20.9 to 27.5 °C (average of 24.66 °C) and the minimum temperature ranged from 14.1 to 21.3 °C (average of 17.68 °C) (Fig. 4). The average relative humidity ranged from 60.8 to 80.4% (average of 65.76%) (Fig. 5). These conditions of average temperature and relative humidity are considered ideal for the development of papaya plants [12]. On average, the maximum, average and minimum temperatures within the agricultural greenhouse were 30.42, 11.18 and 4.12% higher than the external averages, while relative humidity decreased by 20.6%.



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Fig. 4. Maximum, minimum and average temperatures within the agricultural greenhouse during the experimental period in the municipality of Colatina, Espírito Santo.



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Fig. 5. Average relative humidity within the agricultural greenhouse during the experimental period in Colatina, Espírito Santo.

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152 After analysis of variance, a significant difference ($P < 0.05$) was observed for all the
153 evaluated characteristics, noting that the application of the different irrigation depths
154 interfered in the growth and quality of the papaya 'Golden THB' seedlings.

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156 The length of the root system (LRS) showed a quadratic effect, with determination coefficient
157 (R^2) of 0.745 and maximum point with 27.78 cm in the irrigation depth of 9.44 mm d⁻¹ (Fig.
158 6A). Leaf area (LA) presented a quadratic adjustment, with its maximum point in the
159 irrigation depth of 7.28 mm d⁻¹, with an area of 116.65 cm² and R^2 of 0.9401 (Fig. 6B).
160 Measure LA is very important because the leaves are responsible for capturing the highest
161 amount of solar energy required for photosynthesis, producing photosimilates used for
162 maintenance and growth of the plant [13; 14]. So, higher AF indicates more suitable
163 seedlings the field conditions because they possess larger photosynthetically active area
164 [15].

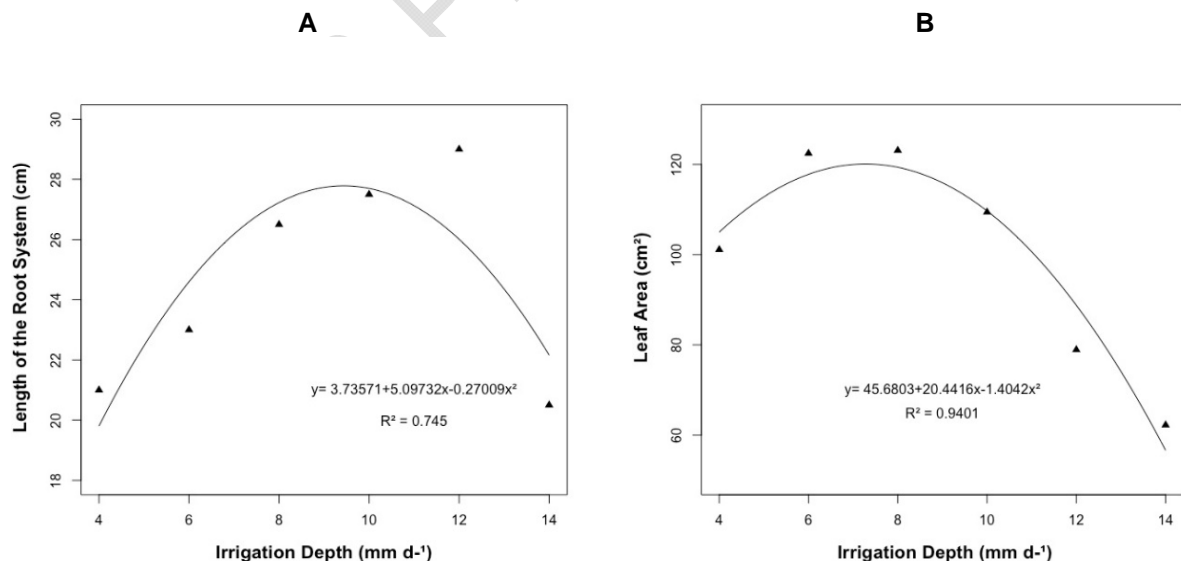
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166 Under stress conditions, plants change their morphological characteristics [16]. The water
167 deficit caused by the lack of water in the smaller irrigation depths decreases the swelling
168 pressure of the plant cells, reflecting in turgidity dependent processes, as the expansion of
169 the leaf area and the extension of the root system. The expansion of the leaf area is early
170 affected when the amount of water is reduced, this morphological change leads the plants to
171 transpire less, supporting for a longer time the availability of water in the substrate [17].
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174 On the other hand, the excess of irrigation affected the length of the root system and the
175 leaf area of the seedlings. Under such conditions plants are exposed to an oxygen-depleted
176 environment (anoxia). Virtually all plants need oxygen to perform their metabolic activities,
177 thus under anoxic conditions their development is limited. The root respiration rate is
178 diminished in anaerobic environments, causing damage to its growth. In addition, the roots
179 cannot supply the energy demand required to sustain the physiological processes of the
180 aerial part of the plants, limiting their development [17].

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182 **Fig. 6. Length of root system (A) and leaf area (B) of papaya 'Golden THB' seedlings**
183 **submitted to different irrigation depths.**

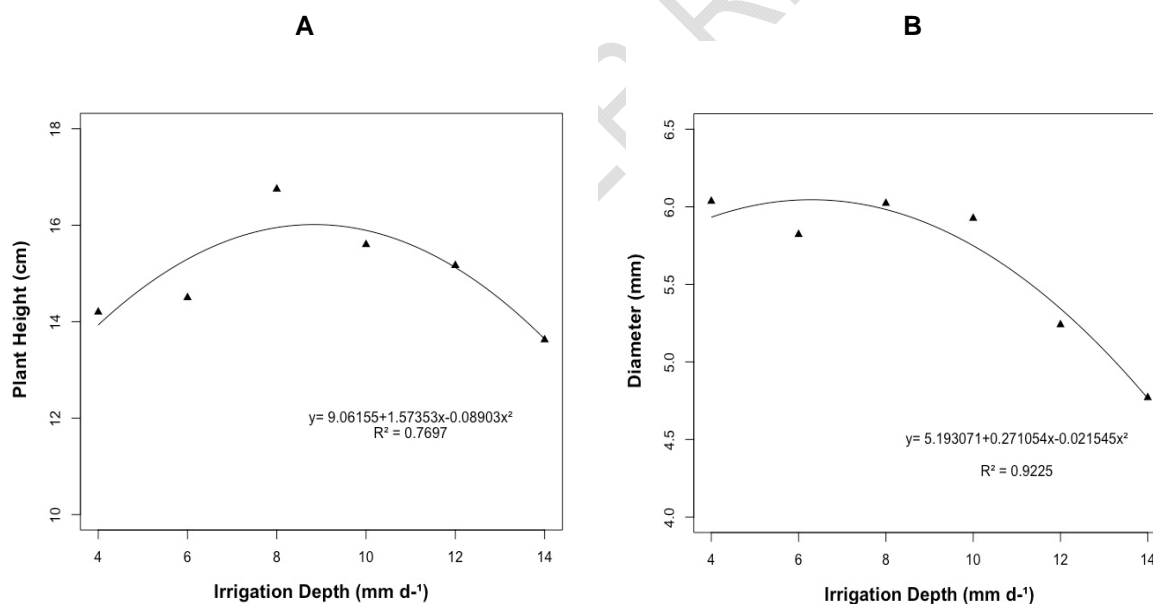
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185 The plant height (PH) presented quadratic adjustment, with R^2 of 0.7697. The maximum
186 height of 16.01 cm was observed in the irrigation depth of 8.84 mm d^{-1} (Fig. 7A). The lowest
187 heights were observed in the largest and the shortest irrigation depth. According to Delgado
188 *et al.* [7], the excess water provides greater leaching of nutrients present in the substrate,
189 limiting the size of the plants. On the other hand, lack of water prevents the expansion of the
190 cell wall due to altered hormonal balance and cellular turgidity impairing plant growth [18].
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192 The height is used as a base parameter for the transplanting of seedlings to the field, taking
193 advantage of larger seedlings, since seedlings of smaller stature can be constantly
194 damaged, impairing their development and production [5].
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196 The stem diameter (SD) presented quadratic behavior, with a maximum point of 6.04 mm in
197 the irrigation depth of 6.29 mm d^{-1} and R^2 of 0.9225 (Fig. 7B). The behavior of SD was
198 similar to that presented by LA. This fact can be explained, according to Melo *et al.* [15],
199 because of the high predictive correlation, thus, plants with larger leaf area produce more
200 photosimilates and, consequently, larger stem diameter, the opposite is observed in plants
201 with smaller leaf area that has reduced stem diameter.
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203 Stem diameter and plant height are very important characteristics, since they are related to
204 possible tipping of seedlings in the field and they are easily evaluated, expressing quality in
205 every stage of the seedling development [19].
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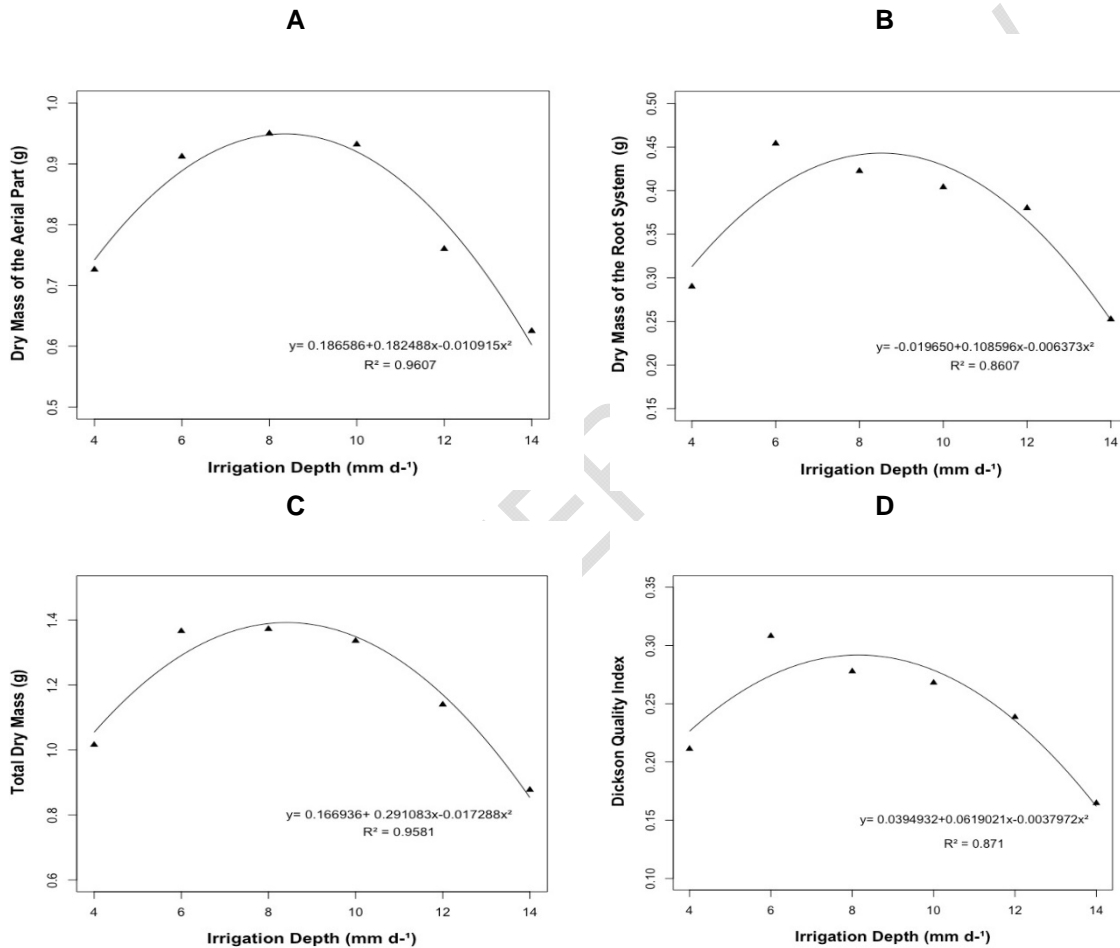


207 **Fig. 7. Plant height (A) and stem diameter (B) of papaya 'Golden THB' seedlings**
208 **submitted to different irrigation depths.**
209

210 The dry mass of the aerial part (DMAP), dry mass of the root system (DMRS) and total dry
211 mass (TDM) showed a quadratic effect, with a maximum point of 0.95 g, 0.44 g and 1.39 g
212 irrigation depths of 8.36, 8.52, 8.42 mm d^{-1} and R^2 of 0.9607, 0.8607 and 0.9581,
213 respectively (Fig. 8A, 8B and 8C). There is similarity in the adjustments of LA, DMAP, DMRS
214 and TDM, so it can be observed that the increase in foliated area allowed greater light
215 uptake for the practice of photosynthesis, providing better growth and accumulation of dry
216 mass by plants [15]. It is clear that both the excess and the lack of water caused a decrease
217 in the accumulation of DMAP, DMRS and TDM by plants.

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The excess water creates anaerobic conditions in the roots, reducing the transport of electrons, damaging the photosynthetic apparatus and the accumulation of carbohydrates by the roots, limiting the growth of the plants, so under these conditions there is a decrease in the total dry mass production of the plant [20; 21; 22; 23]. Like the excess, the water deficit caused by the lack of water generates inhibition of the photosynthesis by the plants inducing the accumulation of abscisic acid (ABA) promoting the closure of the stomata and limiting the gas exchanges reducing the production of photosimilates and consequently the total dry mass of the plant [17].



228 **Fig. 8. Dry mass of aerial part (A), dry mass of the root system (B), total dry mass (C)**
229 **and Dickson quality index (D) of papaya 'Golden THB ' seedlings submitted to**
230 **different irrigation depths.**

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The Dickson quality index (DQI) presented quadratic adjustment, with a higher index of 0.29 in the irrigation depth of 8.15 mm d⁻¹ and R² of 0.871 (Fig. 8D). Posse *et al.* [24], found that the 8 mm d⁻¹ depth is the most adequate for the formation of yellow passion fruit seedlings. Posse *et al.* [25], also observed that, no matter the climatic conditions, the 8 mm daily depth was the one that provided the best formation of cacao seedlings TSH1188 genotype, with quality and economic use of water and energy.

239 The DQI is an indicative of quality of seedlings considering in its formula growth
240 characteristics of all parts of the plant. Hunt [26], establishes a minimum DQI value of 0.20 to
241 obtain a quality seedling. Considered also by Johnson and Cline [27], as a promising
242 morphological measure, the DQI reflects the quality of the seedlings considering in its
243 calculation the robustness (TDM) and the balance of the phytomass distribution. The
244 Dickson quality index proved to be a good indicator of quality for the papaya 'Golden THB'
245 seedlings.
246

247 In addition, low-DQI seedlings reflect higher mortality rates when they are taken to the field,
248 because they present lower lignification, which would imply a lower survival capacity, thus,
249 seedlings with higher indexes are more likely to survive [28; 29].
250

251 **4. CONCLUSION**

252 The irrigation depths interfered in the growth and quality of papaya 'Golden THB' seedlings
253 during their production period.
254

255 For production of papaya 'Golden THB' seedlings with high quality, the indicated irrigation
256 depth is 8.15 mm d⁻¹ as it presented the highest Dickson quality index as well as good
257 responses in the morphological characteristics studied: length of the root system, leaf area,
258 plant height, stem diameter, dry mass of the aerial part, dry mass of the root system and
259 total dry mass.
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262 **COMPETING INTERESTS**

263 Authors have declared that no competing interests exist.
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