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Water depletion on substrate and soil conditioner doses in the yellow passion fruit seedling formation

Depleção de água no substrato e doses de condicionador de solo na formação de mudas de maracujazeiro amarelo

J. C. F. Melo Júnior[1]*; M. S. Rodrigues[2]; A. M. N. Lima[3]; E. S. Gervásio[4]; A. Figueiredo Neto[5]

[1]*College of Agronomic Engineering/Agricultural Drainage Laboratory, Federal University of Vale do São Francisco (UNIVASF), 56300-990, Petrolina-PE, Brazil*
[2]*College of Agronomic Engineering/Soil Physics Laboratory, Federal University of Vale do São Francisco (UNIVASF), 56300-990, Petrolina-PE, Brazil*
[3]*College of Agronomic Engineering/Soil Chemistry Laboratory, Federal University of Vale do São Francisco (UNIVASF), 56300-990, Petrolina-PE, Brazil*
[4]*College of Agronomic Engineering/Irrigation Laboratory, Federal University of Vale do São Francisco (UNIVASF), 56300-990, Petrolina-PE, Brazil*
[5]*College of Agricultural and Environmental Engineering/Post-harvest Laboratory, Federal University of Vale do São Francisco (UNIVASF), 48902-300, Juazeiro-BA, Brazil*

**julio.melo@univasf.edu.br*
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The cultivation of passion fruit requires constantly updated technical information to achieve competitive results. In this context, a commonly discussed aspect is the development of vigorous seedlings. The aim of this study was to assess water depletion levels in a substrate (WDL) and TerraCottem® doses for the formation of yellow passion fruit seedlings. The experimental design used was split plots in a completely randomized design, with four replications. The treatments consisted of 5, 15, 25, 35% of NDA and 0, 2.5, 5.0, 7.5, and 10.0 kg m-3 of TerraCottem® doses. The following variables were measured: plant height (PH), stem diameter (SD), number of leaves (NL), dry biomass of the aerial part (DSB), root system (DRS), total dry biomass (TDM), and the Dickson Quality Index (DQI) was calculated. WDL treatments did not influence the evaluated variables. NL, PH, SD, DSB, DSR, TDM, and DQI showed increases of 12.3, 13.4, 10.0, 30.1, 28.1, 29.5, and 26.8%, respectively, when comparing the highest TerraCottem® dose to the control treatment. Sliced interaction showed double gains for the highest TerraCottem® dose for SD and PH. The plants responded to higher doses of TerraCottem®, indicating synergy of the water-retaining polymer in the plant's water supply, especially in the presence of higher WDL.
Keywords: *Passiflora edulis*, TerraCottem®, water-absorbent polymer.

O cultivo do maracujazeiro demanda informações técnicas sempre atualizadas para atingir resultados competitivos. Nesse contexto, um aspecto comumente discutido é a formação de mudas vigorosas. O objetivo deste estudo foi avaliar os níveis de depleção de água em um substrato (NDA) e doses de TerraCottem® para a formação de mudas de maracujazeiro amarelo. O delineamento utilizado foi em parcelas subdivididas, com delineamento inteiramente casualizado, com quatro repetições. Os tratamentos consistiram em 5, 15, 25, 35% de NDA e 0, 2,5, 5,0, 7,5 e 10,0 kg m^{-3} de doses de TerraCottem®. Foram medidas as variáveis: altura da planta (ALT), diâmetro do caule (DC), número de folhas (NF), biomassa seca da parte aérea (BPA), sistema radicular (BSR) e biomassa seca total (BT) e calculado o índice de qualidade de Dickson (IQD). Os tratamentos com NDA não influenciaram as variáveis avaliadas. O NF, ALT, DC, BPA, BSR, BT e IQD apresentaram aumentos de 12,3, 13,4, 10,0, 30,1, 28,1, 29,5 e 26,8%, quando se comparou a maior dose de TerraCottem® ao tratamento controle, respectivamente. A interação fatiada mostrou a ocorrência de ganhos duplos para o tratamento de maior dose de TerraCottem® para DC e ALT. As plantas responderam a doses mais altas de TerraCottem®, ocorrendo sinergia do polímero retentor de água no suprimento de água da planta, para o maior NDA.
Palavras-chave: *Passiflora edulis*, TerraCottem®, polímero hidroabsorvente.

1. INTRODUCTION

Brazil is currently the world's largest producer of passion fruit with an annual production of 683,993 Mg in 2021, in a cultivated area of 45,089 ha, highlighting the Northeast region, accounting for 69.6% of the national production with a cultivated area of 32,341 ha [1].

Yellow passion fruit is an important species of the Brazilian agribusiness due to the high price of its juice in the international market, and the demand for fresh fruit in the domestic market, which promotes its commercialization in values that have allowed high profits to farmers. Moreover, the external demand for fruit and by-products has increased its exportation, which has as the main destination, European countries [2].

The greater interest in the cultivation of the species has generated an intense demand for technical information, mainly, in the irrigation depth [3]. Therefore, one aspect commonly addressed is the formation of vigorous seedlings, to be used in the establishment of productive orchards, resistant to diseases, able to produce fruits of high-quality standard [2].

According to Meletti (2011) [2], the cultural techniques applied to the formation of fruit plant seedlings have undergone rapid and remarkable changes during the last three decades. The use of greenhouses, automated irrigation systems, controlled release fertilizers, and hydro-polymer, have contributed to increase the quality of seedlings and ensure the implementation of productive orchards. In addition, the production of fruit plants seedlings goes through a transition phase, in which the bag-type production container is gradually being replaced by tubes [4].

As the plant containers, the conventional substrate is being replaced by organic materials such as commercial products formed by a mixture of peat and pine bark, coconut powder, charcoal rice husk, vermiculite, among other materials [5-10].

The cultivation of the seedlings in tubes compared to the polyethylene bag shows important differences such as a reduced volume of the substrate with high porosity, which reflects in a limited amount of readily-available water, as well as excessive leaching and reduced availability of nutrients. In addition, the importance related to advection. According to Melo Júnior et al. (2015) [10], these particularities imply a risk of water stress and nutritional deficiency, which should be prevented with greater control of irrigation and the use of slow-release fertilizers.

The smaller area of infiltration of the tube compared to the polyethylene bag, the "umbrella effect" due to the overlapping of the leaves of the neighboring seedlings, the leaf architecture of the passion fruit seedlings and the low uniformity of distribution of the irrigation depths, often act in a combined way to restrict the substrate water supplying, resulting in water deficiency. Thus, what is observed in commercial nurseries is excessive irrigation to compensate for the effect of water stress. According to Silvestre et al. (2016) [3] the seedlings irrigation, has been totally empirical, without any criterion to guide the amount of water to be daily applied.

A viable alternative to increase the water and nutrient retention capacity in the substrate, avoiding water stress and lack of nutrients between the application intervals, would be the use of a hydro-polymer and slow-release fertilizers.

Several authors have evaluated hydro-absorbent polymers, as well as substrate conditioners consisting of polymers, controlled release fertilizers, and root growth stimulants, among other constituents, in the formation of coffee tree seedlings and forest species, take into account the quantitative and/or qualitative limitation of the irrigation water [11-15].

Melo et al. (2005) [4] observed a decrease in the values of the root system dry matter and plant height for Arabic coffee seedling when treated with TerraCottem®. Lima et al. (2003) [16] evaluating doses of the water-absorbent polymer Hidroplan in the production of Arabic coffee seedlings verified a significant effect for dry leaf biomass and plant height. Vale et al. (2006) [17] evaluating doses of water-absorbent polymer Stocksorb® in the initial development of Arabic coffee plants did not find statistical differences between the treatments. Navroski et al. (2015) [18] studying the influence of the hydrogel on the growth and nutrient content of *Eucalyptus dunnii* seedlings verified significant effects for the variables stem diameter, shoot dry matter, and Dickson quality index obtaining the highest mean values for the 4.5 kg m^{-3} dose. According to Terracottem (2023) [19], the recommended dose for the formation of seedlings in containers is between 3 to 6 kg m^{-3}.

Therefore, the objective of this study was to evaluate water depletion levels in the substrate, defined as a fraction of the mass of container capacity, as well as TerraCottem® conditioner doses in the formation of yellow passion fruit seedlings in tubes.

2. MATERIALS AND METHODS

The experiment was carried out in an agricultural nursery at the Federal Univesity of Vale do São Francisco (Univasf), located at the campus of Agrarian Sciences in Petrolina, Pernambuco state (9°19'35" S, 40°32'53" W and 370 m asl.) from July to October 2016. According to Köppen's climate classification, the region is classified as BSwh', defined as a very hot and semi-arid climate.

The mean daily air temperature during the experimental period was 26.4±0.2°C, with extreme values of maximum and minimum daily temperatures equal to 38°C and 16°C, respectively. The rains occurred at the beginning and at the end of the experiment, totaling less than 1% of the total irrigation depth applied in the treatments. The agricultural nursery used to conduct the experiment had an area of 256 m^2 totally covered by a shading screen with 50% attenuation.

The cultivar of yellow passion fruit (*Passiflora edulis* Sins. f. *flavicarpa* Deg.) was the FB 300, characterized by high yield of juice (above 42%), yellow-orange pulp, soluble solids content of 15° Brix, the average productive potential of 50 Mg ha^{-1} $year^{-1}$ and average fruit weight of 0.12 kg [20].

The experimental design was completely randomized in a split-plots scheme with four replications. The treatments were constituted by levels of water depletion in the substrate, defined as a fraction of the mass of the container capacity (MCC), which were 5, 15, 25, and, 35% of the MCC and doses of conditioner TerraCottem®, which were 0, 2.5, 5.0, 7.5 and 10.0 kg m^{-3} substrate. According to Melo Júnior et al. (2015) [10], the concept of container capacity can be understood as the amount of water that remains in the substrate after the natural drainage and prior to evaporation, that is, after the empty of the volume of the substrate referent to the aeration capacity.

The plots were represented by sixteen countertops, with 1.9 m in length, 1.2 m in width and 0.8 m in height. Each plot was divided into five subplots, each having five rows and a total of 45 plants. For the evaluations of the vegetative variables, the middle row of each subplot was used, in which the five central plants were considered the experimental plot.

A mixture of three products was used for filling the tubes. 1) Plantimax®, a commercial organic substrate enriched with macro and micronutrients based on a vegetal peel, processed peat, and vermiculite; 2) 3 kg m^{-3} of Osmocote Plus®, an NPK (15-9-12) slow-release fertilizer with a release time of 3 to 4 months; 3) TerraCottem® a substrate conditioner consisting of a mixture of 23 substances from four different groups, among them volcanic rock (49.75%), fertilizers (10.5%): macronutrients: N (5%), P (1%) and K (4%), micronutrients: B (0.01%), Cu (0.005%), Fe (1.25%), Mn (0.03%), Mo (0.001%) e Zn (0.003%) growth stimulants of mineral and organic origin (0.25%) and hydro-absorbent organic polymers (39.5%). For this last one, the doses followed the treatments [19].

For seedlings irrigation, a micro-sprinkler system was used, in which three lateral rows were installed in each plot, spaced 0.8 m along the lateral rows and 0.8 m between the rows. The emitters were installed at a height of one meter of the bench and providing a flow of 38 L h^{-1} at a service pressure of 300 kPa. On July 15, 2016, two seeds per tube were sown, initiating the experiment.

The procedure for determining the MCC of the treatments was initially performed by saturating the substrate of the trays of tubes monitored by the mini-lysimeters, applying a high irrigation depth, and after waiting for the moment in which the natural drainage of the containers occurred to quantify the MCC.

From the germination stage until the complete emergence of the seedling, three irrigations were performed daily, evenly distributed in the day, applying about 10 mm d^{-1} depth. After this period, the irrigations were reduced to two daily applications, totaling a 9.3 mm irrigation depth per day until the treatments were differentiated.

The thinning as performed on August 7 when the seedlings presented a pair of vigorous true leaves. From August 10, the differentiation of the irrigation treatments was started, based on the levels of water depletion in the substrate, obtained through the mini-lysimeters coupled to an automated irrigation system.

The irrigation was automated by a mass-sensor monitoring system (strain gauge) and drive of hydraulic valves and motor-pumps, where the mass variation of a tray, consisting of 27 plants, was monitored between the intervals of MCC and critical mass (CM). Thus, when the current mass of the set of containers (CMC), monitored by the automation system, reached the level below the treatment CM, the irrigation system was activated to add the amount of water needed by the plant until the CMC was immediately higher than MCC and then, the system stopped irrigation. Table 1 shows the volumes of water applied for irrigation treatments during the conduct of the experiment.

In relation to the frequency of irrigation, accumulated values of 5.8, 3.0, 2.0, and 1.6 waterings were observed for three days, respectively, for treatments of 5, 15, 25 and 35% of MCC.

Table 1. Total water volumes (TW), daily average (DA), total average per treatment (TAT) and daily average per plot (DAPP), applied by the micro-sprinkler irrigation system during the experiment.

Volume	Irrigation treatments			
	5% MCC	15% MCC	25% MCC	35% MCC
TW (m^3)	52.804	54.618	62.823	80.481
DA (m^3)	0.539	0.557	0.641	0.821
TAT (m^3)	13.201	13.655	15.706	20.120
DAPP (m^3)	0.135	0.139	0.160	0.205

During the conduction of the experiment, phytosanitary treatments based on Neem oil (*Azadirachta indica*) were carried out twice a week, using the 0.33% dose of the commercial product Max Neem®.

The experiment was completed on October 24, at 101 days after sowing. In this date, plant height (PH), stem diameter (SD), number of leaves (NL), dry shoot biomass (DSB), and root system (DRS) were measured. A digital caliper with a precision of $1x10^{-5}$m and a metal ruler with a resolution of $1x10^{-3}$m were used for the determination of SD and PH. The dry matter of the aerial part and of the root system was dried in a forced-air ventilation oven at 65°C for subsequent quantification on an analytical scale, with an accuracy of $1x10^{-6}$ kg.

The Dickson quality index (DQI) was used to evaluate the quality of the seedlings to compare the treatments, according to Eq. 1 [21]. According to Smiderle and Souza (2016) [22], the DQI expresses the relationship between the morphological characteristics, total dry matter (TDM), PH, SD, DSB, and DRS in a balanced way. The higher the value, the better the quality of the seedling to be transplanted.

$$DQI = \frac{TDM}{\frac{PH}{SD} + \frac{DSB}{DRS}} \quad (1)$$

Where: DQI = Dickson quality index (g); TDM = total dry matter (g); PH = plant high (cm); SD = stem diameter (mm); DSB = dry shoot biomass (g); e DRS = dry root system (g).

The analysis of variance was performed using the F test at the 5% level of significance. The mean values for the water depletion levels in the substrate and the doses of TerraCottem® were submitted to the Scott-Knott test and the regression analysis, respectively.

All morphometric variables were subjected to correlation analysis, obtaining Pearson correlation coefficients. This analysis determines the degree of relationships among the studied variables.

3. RESULTS AND DISCUSSION

The analysis of variance for the morphological variables is presented in Table 2. For all the analyzed variables the levels of water depletion treatments were not significant, according to the F test. However, most of the variables showed a statistic difference at 1% of probability for the TerraCottem® doses, except for the dry shoot and root matter relationship (DSRM), which showed no significant difference between treatments. The interaction between the factors was significant at the 5% probability level, only for the PH and SD variables.

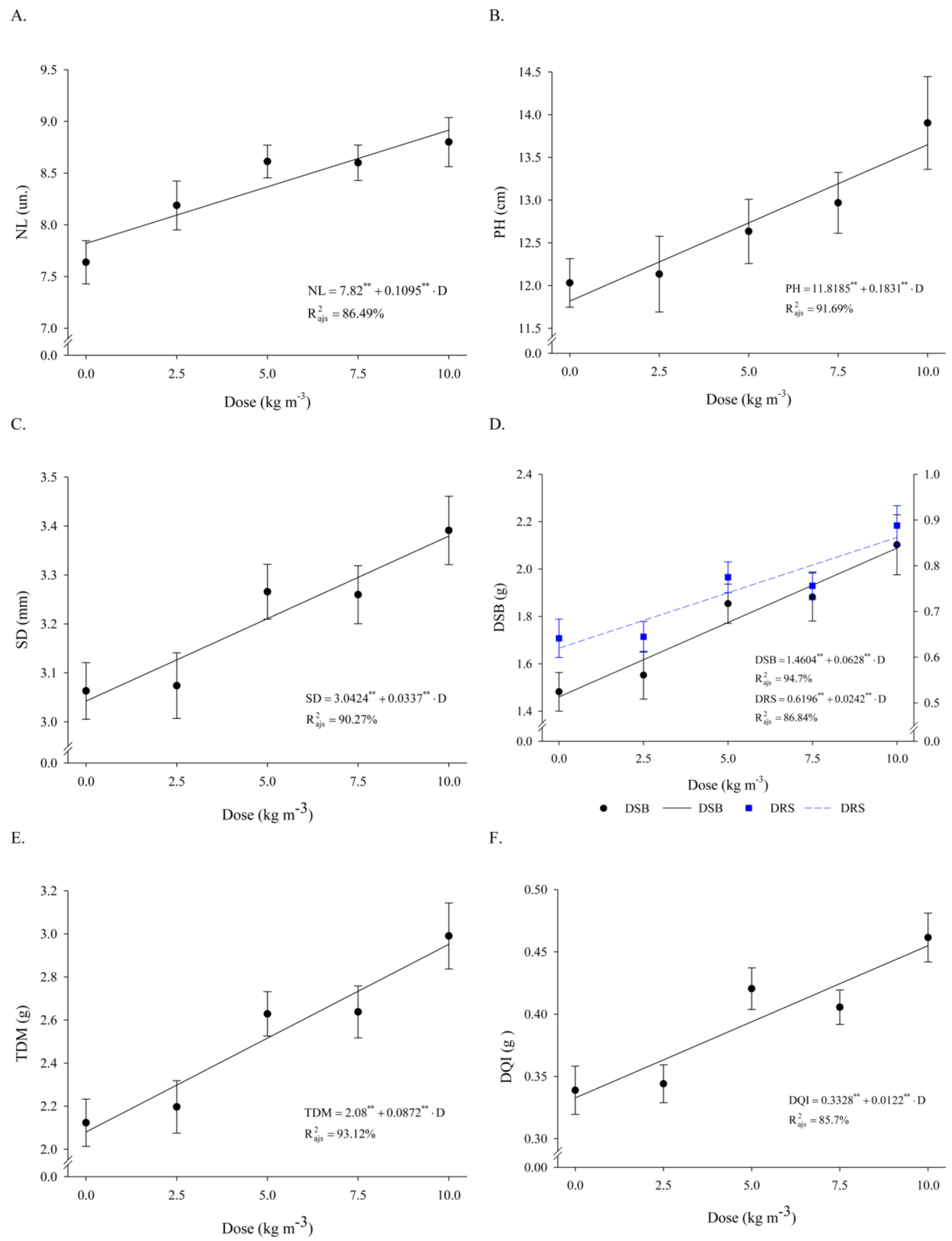
Table 2. Mean square of the variables plant height (PH), stem diameter (SD), number of leaves (NL), dry shoot biomass (DSB), dry root system (DRS), total dry matter (TDM), the dry shoot and root matter relationship (DSRM) and Dickson quality index (DQI), depending on the substrate water depletion level (WDL) and TerraCottem® dose (D) in the production of yellow passion fruit seedlings.

Source of variation	GL	PH (cm)	SD (mm)	NL (leaf)	DSB (g)	DRS (g)	TDM (g)	DSRM	DQI (g)
WDL	3	1.1338^{ns}	0.0921^{ns}	1.2912^{ns}	0.2969^{ns}	0.0154^{ns}	0.3458^{ns}	0.5566^{ns}	0.0039^{ns}
Residuos (WDL)	12	6.8606	0.1463	1.2842	0.343	0.0253	0.3864	0.8396	0.0040
Dose	4	9.1365**	0.3145**	3.4658**	1.042**	0.169**	2.039**	0.0352^{ns}	0.0436**
WDL x Dose	12	3.5483*	0.077*	0.7641^{ns}	0.1742^{ns}	0.0242^{ns}	0.2901^{ns}	0.1631^{ns}	0.0055^{ns}
Residuos	48	1.5153	0.0354	0.4575	0.1023	0.0212	0.1865	0.1249	0.0046
CV (WDL) %		20.57	11.91	13.54	33.0	21.46	24.71	37.67	16.14
CV (Dose) %		9.67	5.86	8.08	18.02	19.65	17.17	14.52	17.20
Mean		12.7338	3.2109	8.3675	1.7745	0.748	2.5158	2.4326	0.3939

** significant at the 1% probability level by the F test; * significant at the 5% probability level by the F test; and ns not-significant.

In relation to the DQI for the level of water depletion in the substrate, it is not verified differences between the treatments, showing for the lowest level of depletion the highest average of the variable, which was 0.41±0.02 g. Melo Júnior et al. (2015) [10] evaluating levels of water depletion in the substrate and doses of slow-release fertilizer (Osmocote® Plus 15-9-12) for passion fruit seedlings production, also did not find a statistical difference between the levels of water depletion for the DQI variable.

Figure 1 shows the mean values of the morphological variables, in which significant differences were observed between the doses of TerraCottem® treatments, as well as the fitted regression models.



**significant at the 1% probability level by the F test.

Figure 1. Measured values and linear regression models adjusted according to the dose (D) of TerraCottem®, for the variables number of leaves "NL" (A), plant height "PH" (B), stem diameter "SD" (C), dry shoot biomass "DSB" e dry root system "DRS" (D), total dry matter "TDM" (E), and Dickson quality index "DQI" (F).

For the morphological variables, the fitted regression models had a linear behavior showing a positive regression coefficient and an adjusted coefficient of determination greater than 85.7%. This result can be explained due to the plants satisfactorily responded to the higher doses of TerraCottem®, presenting a linear response to the substrate conditioner. In addition, there may be a dose of TerraCottem®, higher than those that were evaluated, that maximizes the response of the yellow passion fruit seedlings. An increase of 12.3, 13.4, 10.0, 30.1, 28.1, 29.5 and 26.8% was observed for NL, PH, SD, DSM, DRS, TDM and DQI variables, when comparing the results of the highest evaluated dose of TerraCottem® in relation to the control treatment, respectively.

It was observed that the highest DQI mean value 0.45 g found for the 10 kg m^{-3} dose was higher than the minimum value 0.2 g recommend as an indicator of seedling quality for transplanting according to [21]. Melo Júnior et al. (2015) [10] studying yellow passion fruit seedlings observed that DQI value of 0.6 g for the 9 kg m^{-3} Osmocote® Plus (15-9-12) dose. Posse et al. (2018) [15] found the best DQI value of 0.2 for depths 8, 10, and 12 mm d^{-1} treatments. According to Navroski et al. (2015) [18], the Dickson quality index for Eucalyptus dunnii seedlings was higher for the higher doses of the hydrogel, presenting a maximum of 0.07 for the 4.6 g L^{-1} dose. In addition, the authors consider it a good parameter to indicate the quality standard of seedlings grown under different doses of the hydrogel.

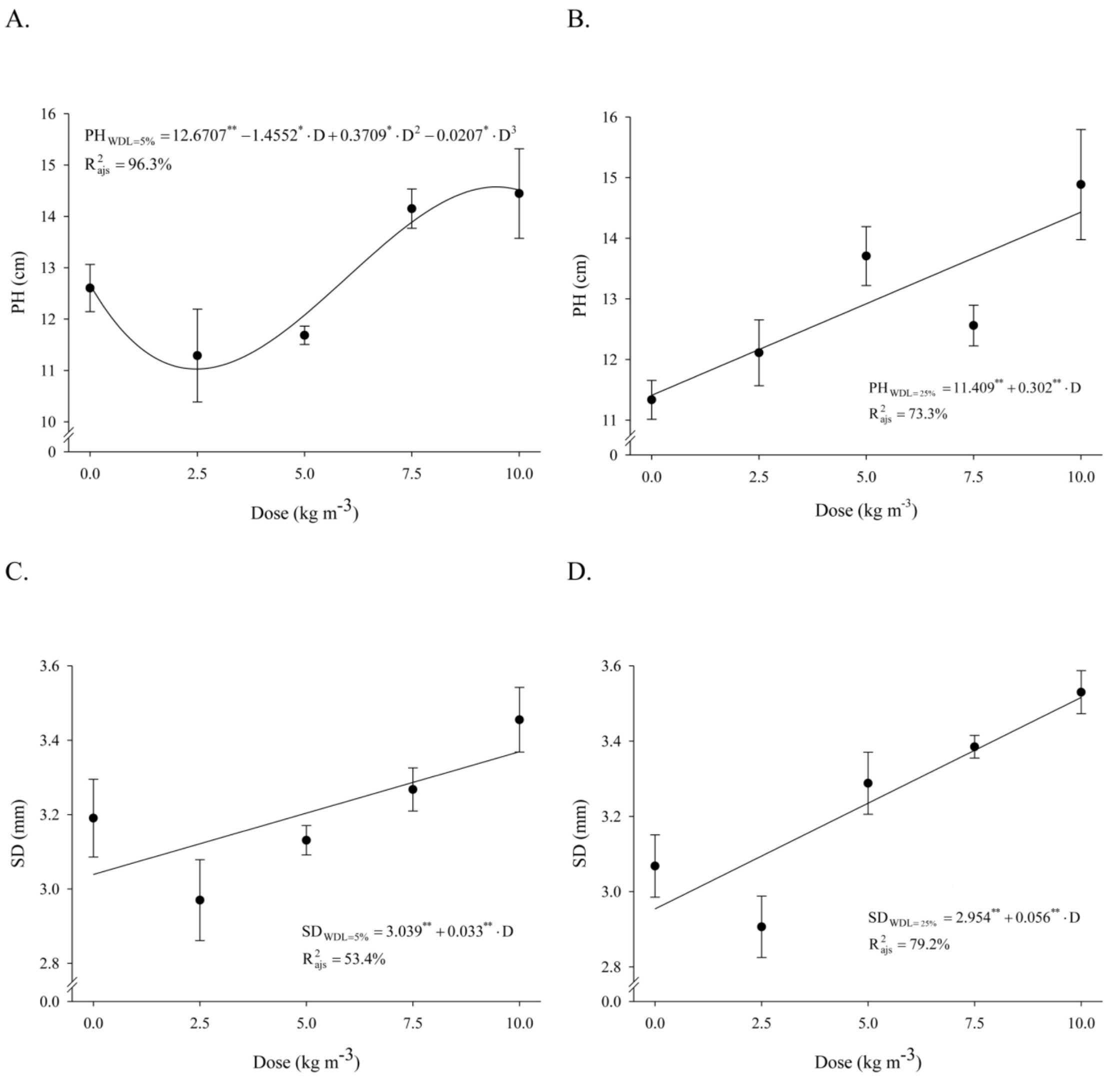
Table 3 shows the Pearson correlation coefficients, among the morphometric variables measured for yellow passion fruit. The DQI (eq. 1) is directly correlated to TDM and inversely correlated to the sum of the relationships between PH and SD, and DSB and DRS. The denominator of the DQI is represented by the sum of the relations PH SD^{-1} and DSB DRS^{-1}, and that to maximize the index, these relations must tend to equilibrium. High values of PH SD^{-1} and DSB DRS^{-1} represent, respectively, etiolation in plants and a root system which will have difficulties in maintaining the aerial part after transplanting. A higher value of DQI will be the reference to infer in the good quality of the seedling [21].

Table 3. Pearson correlation coefficient among the variables (VAR), number of leaves (NL), stem diameter (SD), plant height (PH), dry shoot biomass (DSB), dry root biomass (DRS), dry biomass total (TDM) and Dickson quality index (DQI).

VAR	NL	SD	PH	DSB	DRS	TDM	DQI
NL	1	0.72**	0.76**	0.81**	0.58**	0.81**	0.64**
SD		1	0.81**	0.90**	0.60**	0.88**	0.73**
PH			1	0.88**	0.50**	0.84**	0.53**
DSB				1	0.64**	0.97**	0.75**
DRS					1	0.80**	0.96**
TDM						1	0.87**
DQI							1

The highest correlations in descending order among the DQI and the morphometric variables were observed for the DRS, TDM, DSB, and SD variables. Only the SD variable can be measured without the destruction of the plant, thus, it becomes very important for evaluating the quality of the seedlings. The others were related to the dried phytomass, presenting the highest correlation observed between the DQI and the DRS. Navroski et al. (2015) [18] evaluating Eucalyptus dunnii seedlings response to hydrogel use, observed that the highest value was found between DQI and SD ($r = 0.73$). The other correlation coefficients between the DQI and the dried phytomass were in descending order for root, total, and shoot. Binotto et al. (2010) [23] found correlations between the measured variables and the DQI and verified the highest coefficient for the root dry biomass.

The adjusted regression models for the PH and SD variables as a function of the TerraCottem® doses, which were decomposed for the WDL treatments, are showed in Figure 2.



**significant at the 1% probability level by the F test; *significant at the 5% probability level by the F test.

Figure 2. Decomposed regression models and observed data related to water depletion level in the substrate (WDL), for the variables, PH (A = 5% of the WDL and B = 25% of the WDL) and SD (C = 5% of the WDL and D = 25 % of WDL), whose interactions between treatments were significant at a 5% probability level.

For the two variables, which the interaction between water depletion factors in the substrate and dose of TerraCottem® were significant at the 5% level, it was observed that the fitted of the regression models had a linear behavior (Figures 2b, cc), except for the PH variable the decomposition regarding WDL 5%, where the best fit was observed for a third-degree polynomial model (Figure 2a). It was observed that the TerraCottem® dose equal to 9.47 kg m^{-3} was the one that maximized the height of the plant to 14.57 cm. For the other decomposition that was considered significant, the behavior of the modeling can be explained because the plant has satisfactorily responded to the higher doses of the substrate conditioner, and also based on the observed data, comparing to the control treatment, can be verified an increase of 8.5, 15.0, 14.6 and 31.3%, for the variables SD and PH, for the 5 and 25% WDL decomposition, respectively.

Lima et al. (2003) [16] evaluating the hydro-absorbent polymer (Hidroplan), in the formation of coffee seedlings, did not observe the interaction between dose and irrigation depth applied based on the evaporation of the "Class A" tank, in the variables plant height, stem diameter and dry biomass of shoot and root. Melo et al. (2005) [4] evaluating doses of Terracottem® and irrigation frequencies in the production of coffee tree seedlings in tubes showed that there was only dependence among the factors for dry root phytomass. In addition, the best result was verified for the Terracottem® dose of 3g L^{-1} and irrigation once daily. Also, for the highest evaluated dose (9 g L^{-1}) there was no difference between the irrigations performed three times every two days, once a day, and once every two days.

The decomposition showed that there were approximate twice the gains for the treatment of higher WDL. With this result, the synergy of the copolymer of acrylic and acrylamide-potassium-based, which constitutes 39.5% of the Terracottem® substrate conditioner, became evident for the supply of water to the plant at the largest intervals between irrigations, the situation in which water stress occurred for the yellow passion fruit seedlings.

Although the behavior of a second-degree regression model was not observed in the models adjusted for the evaluated variables, overall, yellow passion fruit seedlings cultivated in containers, specifically 0.18 L tubes, responded very well to the highest evaluated dose, which was 10 kg m^{-3} of substrate.

4. CONCLUSION

Yellow passion fruit seedlings, cultivar FB300, responded satisfactorily to the highest doses of the TerraCottem® soil conditioning, with the appropriate dose for yellow passion fruit being higher than that recommended by the manufacturer.

The synergy of the hydro-absorbent polymer, showed in the product Terracottem®, occurred in the water supply to the plant, referring to the longer interval between irrigations that corresponded to the greater depletion evaluated.

5. ACKNOWLEDGMENT

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