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NÍVEIS DE IRRIGAÇÃO NO CULTIVO DE *Amaranthus cruentus* L. EM FUNÇÃO DA EVAPORAÇÃO DE MINI-TANQUE EVAPORÍMETRO

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1 RESUMO

As pesquisas com amaranto ainda são incipientes no Brasil, no entanto a cultura apresenta perspectivas promissoras, dessa forma, é importante que se realize mais estudos para verificar quais processos fisiológicos, mudanças morfológicas e fenológicas da planta se alteram em função da irrigação. Objetivos da pesquisa foi determinar a real necessidade hídrica do amaranto, por meio de diferentes lâminas de irrigação e estudar o efeito sobre o rendimento e características do amaranto. Os tratamentos avaliados foram: 90%; 120%; 150%; 180%; 210% da evaporação. A evaporação diária foi observada por um mini-tanque evaporímetro. Os parâmetros medidos e avaliados foram número de folhas, diâmetro do caule e altura, comprimento das raízes, massa fresca da parte aérea, massa fresca das raízes, massa seca da parte aérea e massa seca das raízes. Comprimento, largura, peso fresco e seco da inflorescência e produção comercial por plantas e peso de mil sementes. As lâminas deficitárias bem como excessivas promoveram menores médias observadas, na maioria dos parâmetros avaliados; a lâmina de 180% foi a que melhor favorece o desenvolvimento final; e a lâmina que proporcionou maior produtividade foi a de 210%. Conclui-se que o amaranto tem elevada necessidade hídrica.

Palavras chaves: lâmina de irrigação, amaranto, produção, morfológicas.

MELO, M. R. M.; LAMBERT, R. A.
LEVELS OF IRRIGATION ON GROWING *Amaranthus cruentus* L. DEPENDING ON THE EVAPORATION OF MINI-TANK EVAPORIMETER.

2 ABSTRACT

Research on amaranth is still incipient in Brazil, however the culture has promising prospects, and it is important to conduct more studies to verify which physiological processes, morphological and phenological changes of the plant change as a function of irrigation. The research objectives were to determine the real water requirement of amaranth, through different irrigation depths and to study the effect on the yield and characteristics of amaranth. The treatments evaluated were 90%; 120%; 150%; 180%; 210% evaporation. Daily evaporation was observed by a mini-tank evaporimeter. The parameters measured and evaluated were the number of leaves, stem diameter and height, root length, shoot fresh mass, root fresh mass,

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shoot dry mass and root dry mass. Length, width, fresh and dry weight of the inflorescence and commercial production per plant and weight of a thousand seeds. Deficit as well as excessive water depths promoted the lowest observed averages in most of the evaluated parameters; the 180% blade was the one that best favors the final development; and the blade that provided the highest productivity was 210%. It was concluded that amaranth has a high water requirement.

Keywords: irrigation depth, amaranth, production, morphological.

3 INTRODUCTION

The global interest in amaranth is very recent. Many countries currently cultivate amaranth for various purposes. Costa; Melo; Ferreira (2007) noted that although there are research and initiatives to incorporate the leaves and grains of this pseudocereal into human nutrition and the enrichment of food products, Brazil is not yet listed as an amaranth consumer. The agronomic characteristics that encourage the growth of amaranth include its rapid growth, tolerance to water deficit, large biomass production and nutrient cycling, in addition to being a very rich source of proteins, minerals and vitamins that can be used in both human and animal nutrition (SANTOS; COSTA, 2007).

Amaranth can be cultivated in three seasons—harvest, off-season, and winter—and productivity depends on the amount of water available for irrigation and rainfall during a period. Soil correction, irrigation, and appropriate equipment ensure sustained production (TAGUCHI, 2011). Studies on amaranth are still in their infancy, but the crop offers promising prospects. Therefore, it is important to conduct further research to determine which physiological, morphological, and phenological changes in plants are altered by water deficit (SILVA, 2015).

Vieira *et al.* (2014) reported that agricultural production is a human activity that accounts for a large portion of water use, making it necessary to implement efficient irrigation systems and methods that quantify the actual water needs of crops to avoid waste. One factor that needs to be thoroughly studied is the quantity and frequency of water application. Currently, managing the total amount of water required can involve the use of various methods, such as tensiometers, automated meteorological stations, and Class A tanks (BERNARDO, 1989).

Golin (2014) stated that evaporimeters are instruments that allow direct measurement of the evaporative power of the atmosphere, which is subject to the effects of radiation, temperature, wind, and relative humidity. The best-known evaporimeters are atmometers and evaporation pans. However, mini-tank evaporimeters are widely used in the field today because they are easy to operate, have low investment, and can be installed in the middle of the crop, which favors the assessment of water demand, as the structure favors evaporation.

Lisboa *et al.* (2011) argued that the use of alternative tanks to measure evaporation can be a useful tool for irrigation management, especially for small farmers who lack access to the meteorological data required for the equations. These same tanks offer the advantage of directly measuring evaporation, which is correlated with crop evapotranspiration.

Considering these aspects, this study aimed to determine the actual water requirements of crops at different irrigation depths. The effects of irrigation depth on the yield and characteristics of amaranth grown in a protected environment in the municipality of Itumbiara, Goiás, were studied, with the aim of defining criteria for appropriate irrigation management.

4 MATERIALS AND METHODS

The experiment was conducted at the experimental campus of the agronomy program at the Lutheran Institute of Higher Education of Itumbiara-GO (ILES/ULBRA). The city is located in the Central-West region, at an average altitude of 440 m at 18°26' South latitude 49°13' West longitude. According to INMET (2020), the climate of this region is characterized as hot and dry, with temperatures ranging from 19°C to 42°C. The precipitation varies from 1400 mm to 1800 mm, with regular rainfall occurring from October to March and a dry season from April to November. The experiment was conducted from December 1, 2013, to March 30, 2014.

The experiment was set up in a greenhouse with a total area of 168 m² and a ceiling height of 2.3 m, which was covered with 50% heat-reflective mesh (Aluminet®). The roof structure was arched with transparent plastic, the sides were made of black mesh, and the floor was made of beaten earth covered with gravel.

Liming and fertilization were performed on the basis of the chemical and physical analysis of the soil (Table 1) and followed the recommendations available for amaranth crops. Fertilization was performed at planting and as a topdressing application. The dosage used was 500 kg ha^{-1} 4-24-16 formula, 10 kg ha^{-1} zinc, 5 kg ha^{-1} boron, and a topdressing application of 80 kg ha^{-1} N.

Table 1Results of chemical and textural analysis of the soil used for growing amaranth (*Amaranthus cruentus* L.) in pots, Itumbiara, GO.

Soil	pH	P	K	Here	Mg	SB	CTC	H+Al
	$CaCl_2$	mg.dm $^{-3}$			C mol c/dm $^{-3}$			
Sample 01	6.2	11.81	224.0	3.45	1.30	63.96	5.32	3.0

Soil composition	Unit	Value
Sand	%	35
Silt	%	53
Clay	%	12

Source: Soil Analysis Laboratory ILES/ULBRA.

The amaranthus cultivar BRS-Alegria from EMBRAPA Cerrados was used. Planting was carried out on December 20, 2013, with 10 seeds per pot. Germination began four days after sowing (DAS), and thinning was carried out at 12 DAS, with only one plant per pot remaining. No other supplementary product was applied during the experiment.

Before planting, the soil was filled to field capacity. The pots were arranged with 22 cm row spacing. Pots with a 15-liter capacity were used, with a shade cloth lining to aid drainage.

The experimental design used was completely randomized, involving 5 treatments with 4 replicates, totaling 20 pots, according to the area sketch (Figure 1). The treatments evaluated were as follows: Treatment 01: 90% evaporation; Treatment 02: 120% evaporation; Treatment 03: 150% evaporation; Treatment 04: 180% evaporation; and Treatment 05: 210% evaporation. By observing the daily evaporation value of the minitank evaporimeter, the blade value was calculated for the evaluated treatments.

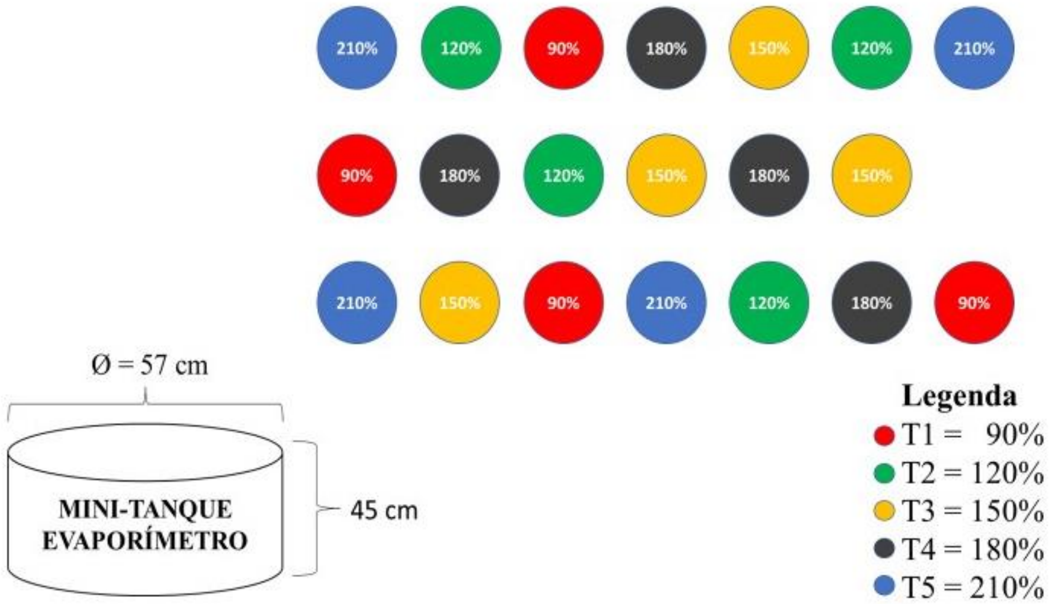
The calculation used to obtain the water depth required for the experiment is detailed below (Equation (1)):

$$\mathrm{Lt} = \mathrm{Emt} \times \mathrm{Tr} \times \mathrm{Av} \quad (01)$$

and in which:
Lt = Total irrigation depth used (mL);
Emt = Evaporation in the mini tank (cm);
Tr = Treatment used in decimal form;
Av = Area of the vessel (cm²).

The mini tank used in the alternative evaporimeter had the following characteristics: a circular shape constructed from a painted metal drum with a capacity of 200 L, an internal diameter of 57 cm and a depth of 45 cm. The mini-tank was supported on a wooden platform 15 cm above the ground (Figure 1). Water was placed in the tank up to a level 40 cm below the free edge, where it had a 50 cm ruler for reading the daily evaporation.

Figure 1 Experiment with amaranth (*Amaranthus cruentus* L.) depending on the irrigation depth, with a graphical representation of the dimensions of the mini-tank evaporimeter, Itumbiara, GO.



These water level readings in the mini tank were taken daily at 9:00 a.m. at 24-hour intervals. After the evaporation rate in cm from the mini tank was recorded, the total irrigation depth was calculated, and the amount of water required for each treatment was determined.

During the study, the maximum and minimum ambient temperatures were measured daily via a maximum and minimum hood-type thermometer with a central button designated for this purpose, which was installed in a shelter in the greenhouse.

The parameters measured and evaluated during the experimental period were divided into three sets: those related to initial development, those related to final development, and those related to production. In terms of initial development, the following morphological characteristics were determined at 20, 40, and 60 days: number of leaves, stem diameter, and height. The second set was related to final development at 90 days: stem diameter, shoot length, root length, shoot fresh weight, root fresh weight, shoot dry weight, and root dry weight. For the last set of parameters, the following parameters were determined: length, width, inflorescence fresh and dry weight, commercial production per plant, and 1,000-seed weight.

To assess plant diameter, a digital caliper graduated in millimeters was used, always measuring 5 cm above the ground. Length was assessed via a graduated ruler. To obtain the dry weight of the inflorescences, whole plants were harvested and air-dried until they reached a constant weight. The seeds were then threshed and passed through a blower. and weighed. After being weighed, the fresh masses of the aerial parts and roots were placed in an oven and dried at 65°C for 72 hours to obtain their dry matter.

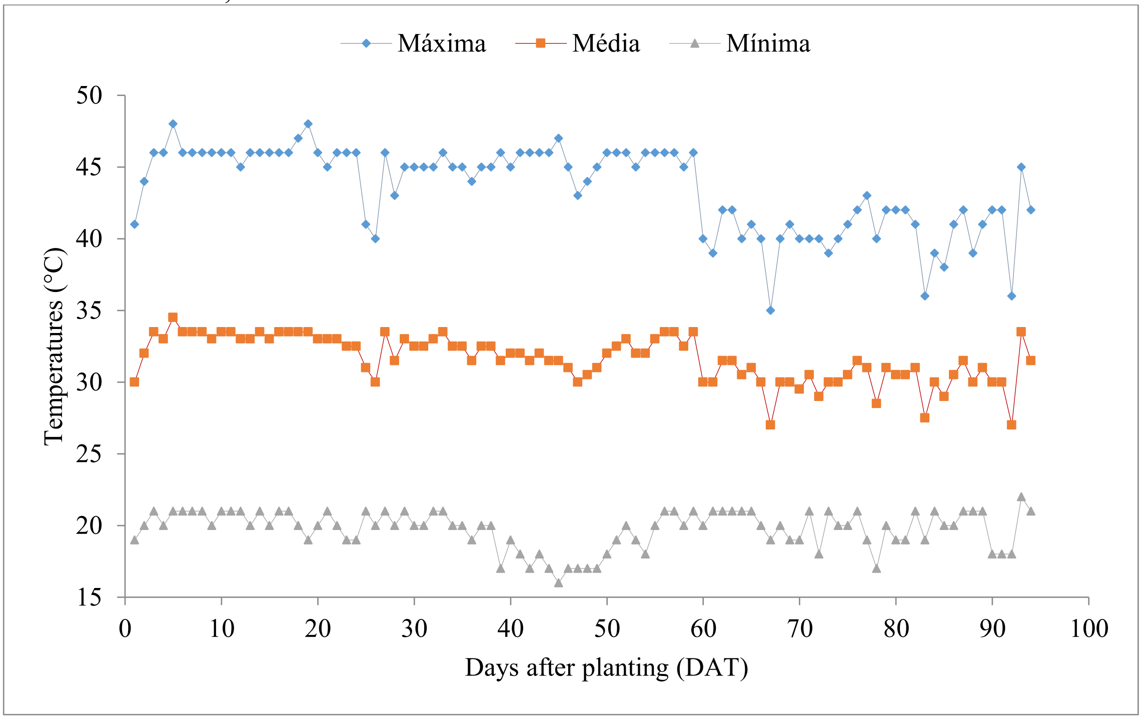
The statistical evaluation of the experiment was performed via the SISVAR (FERREIRA, 2003) computer program, a system for analysis of variance. The data were subjected to analysis of variance, and the means were subjected to regression analysis at 1% and 5% probability, using means from each evaluation, where the equations that best fit the data were chosen on the basis of the significance of the regression coefficients and the highest coefficient of determination (R^2).

5 RESULTS AND DISCUSSION

The maximum, minimum, and average temperatures inside the greenhouse during the experiment are shown in Figure 2. During this period, the average air temperature inside the greenhouse was 31.64 °C; the minimum temperature was between 16 and 22 °C, and the maximum temperature was between 35 °C and 48 °C. According to Gonçalves; Mustafá; Gerencer (2012), for amaranth cultivation, the average ambient temperature must be higher than 25 °C, and they state that amaranth does not grow at temperatures below 18 °C. Farfan; Marcílio; Spehar (2005) reported that amaranth plants have the ability to develop and bear fruit in environments with high light and high temperatures (35 to 45°C). This explains the adaptation process of the species in the cerrado region.

The average values of the maximum (43.53°C) and minimum (19.76°C) temperatures found in this study are within the ranges recommended by the authors. These climatic conditions, within the appropriate range, provided an optimal environment for the development of the experiment.

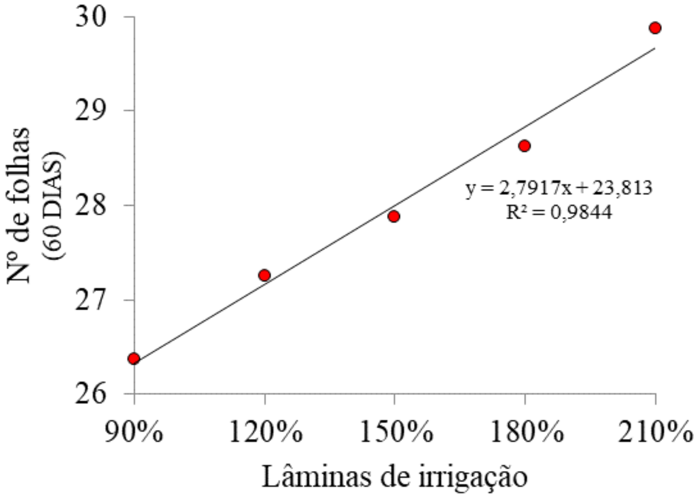
Figure 2. Maximum, minimum and average temperatures inside the greenhouse, recorded during the execution of the experiment with amaranth (*Amaranthus cruentus* L.), Itumbiara, and GO.



According to the results of the analysis of variance for the mean stem diameter, there was no significant difference for any of the days evaluated. Silva *et al.* (2007) also reported the absence of a significant effect of irrigation depth on the stem diameter characteristics of sunflower crops. In contrast, Oliveira (2013), working with corn under different irrigation depths, reported that greater water depths represented a decrease in the evaluated diameter.

The results of the analysis of variance for the mean leaf number showed that in the evaluations at 20 and 40 days, there was no significant difference, but at 60 days, there was a significant difference at the 5% probability level. A linear response was obtained for the mean leaf number at 60 days, which increased proportionally with increasing irrigation depth (Figure 3). Boareto *et al.* (2012), working with sunflowers based on the application of water depths, reported that the number of sunflower leaves was influenced by irrigation management.

Figure 3. Graphical representation and regression equation of the number of leaves (60 days) of amaranth plants as a function of irrigation depth .



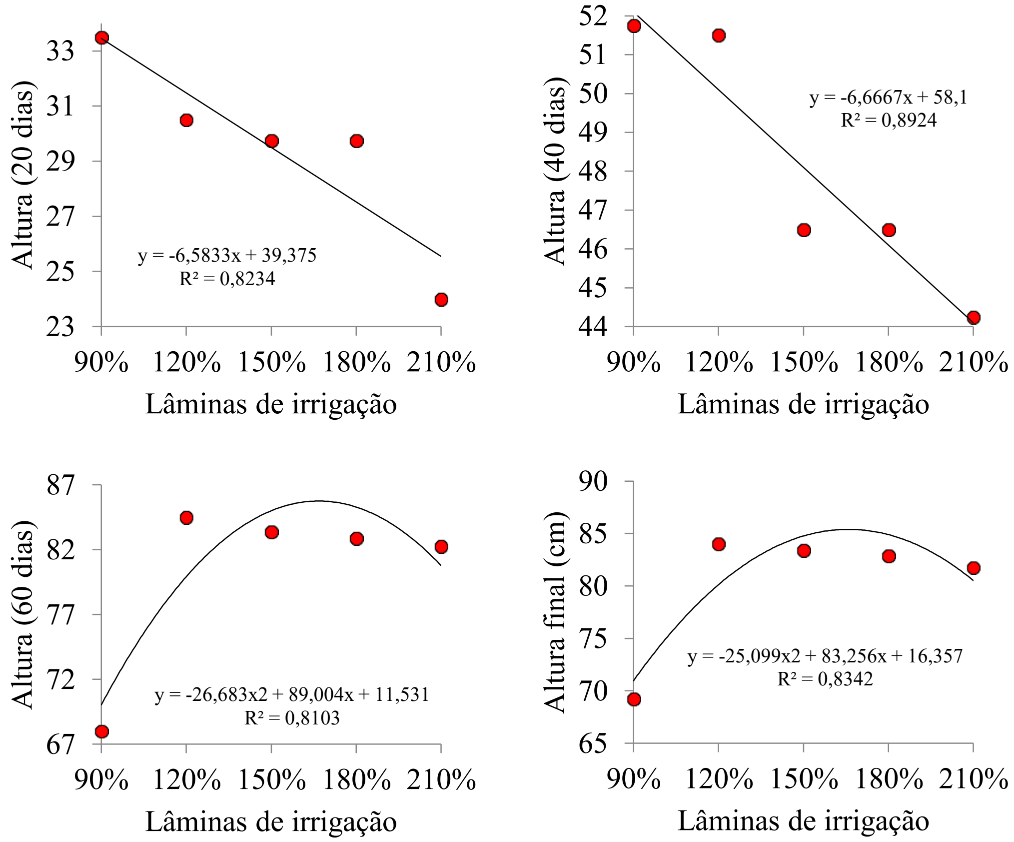
The results of the analysis of variance for the height parameter demonstrated a significant difference at the 1% probability level at 20 and 60 days and at the 5% level at 40 days. Figure 4 shows the plant height at 20 and 40 days according to the treatments applied, with average values of 33.5, 30.5, 29.75, 29.75 and 24.0 cm at 20 days and 51.75, 51.5, 46.5, 46.5 and 44.25 cm at 40 days, for the levels of 90%, 120%, 150%, 180% and 210% evaporation, respectively, and a linear reduction in the length of the aerial part was observed. Thus, the increasing water depth applied to the soil for the amaranth crop during the initial development of the plants for up to 40 days affected the development of the stem of this crop, as a greater water depth can mean that the plants have greater difficulty removing water from the soil, resulting in a smaller growth in the length of the aerial part.

For the height at 60 days, a quadratic regression was obtained. The 120% water treatment resulted in greater shoot development. On the other hand, greater water depths favored a significant decline in shoot development. The 90% water depth stood out, favoring better performance up to 40 days, but at 60 days, this water depth least favored shoot growth. This can be explained by the fact that the larger the plant is, the greater its water demand (Figure 4). Plants with lower water availability tend to be shorter, as water restriction can affect the metabolic processes of plant growth (TAIZ; ZAGER, 2004).

For the final height characteristic, regression analysis yielded a quadratic curve fit of 0.83. According to the fitted equation, the maximum height value was 84 cm, which was obtained at 120% depth. At depths of 150%, 180%, and 210%, there was a decrease in development. The 90% depth was the worst among the treatments (Figure 4). Ferreira (2012) estimated that amaranth plants have an average height of 1.80 m. Since much lower heights were observed in the present study, we emphasize that protected cultivation may have negatively affected their development.

This result is in agreement with that of Vidal (2012), who noted that the irrigation depth at 150% presented a height 2.21 times greater than that of the plants irrigated with a depth of 25% of evapotranspiration in corn with different irrigation depths; in the same way, depths with a greater percentage decreased. Similarly, Gomes *et al.* (2003) reported that the height of sunflower plants increased as the applied depth increased. Domingos *et al.* (2005) reported that the highest yields of amaranth grains were related to the tallest plants, regardless of the cultivar.

Figure 4. Graphical representation and regression equation of the height (20, 40, 60 days and final) of amaranth plants as a function of irrigation depth.



The dry mass of the aerial parts was significant at the 5% probability level. The stem diameter, aerial part length, root length, fresh mass of the aerial part, fresh mass of the roots and dry mass of the roots evaluated were significant at the 1% probability level.

The results of the regression analysis for stem diameter are presented in Figure 5. As the amount of irrigation water increased, the plants responded better. This shows that 180% irrigation was the best treatment for the variable tested, with a difference between the smallest treatment (90%, 2.2925 mm), whereas the largest treatment (210%) presented a decrease in response. Stallknecht and Schulz-Schaeffer (1993) reported that the amaranth stem varies between 2.54 and 15 cm, depending on the plant density and soil surface moisture.

Figure 5. Graphical representation and regression equation of the stem diameter of amaranth plants as a function of irrigation depth.

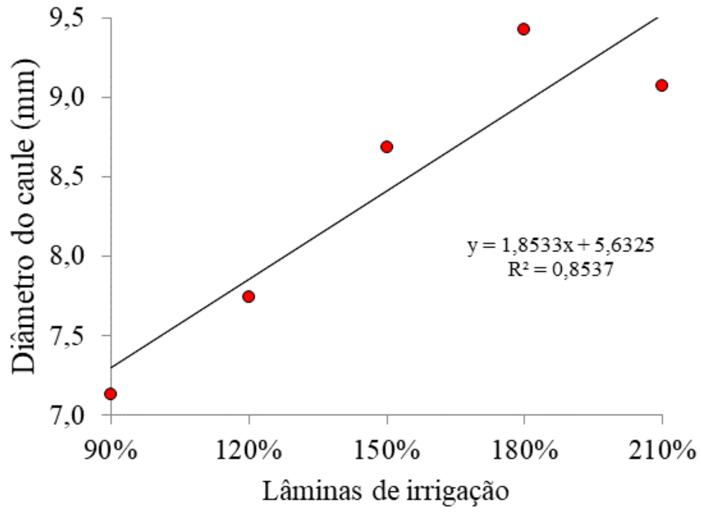
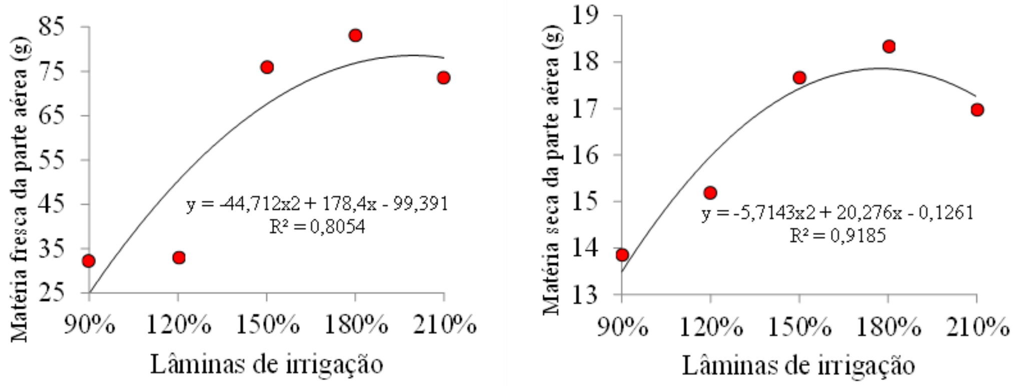


Figure 6 shows the behavior of the data for fresh shoot mass and dry shoot mass as a function of the applied irrigation depth, based on evaporation from the mini-tank evaporimeter. The depth factor had significant effects; the average plant mass values maintained a quadratic trend as a function of the applied depth. The 180% depth stands out from the other depths in both parameters mentioned.

Fasina; Awe; Aruleba (2008) demonstrated that irrigating amaranth crops daily resulted in the highest biomass yield. Similar results were reported by Gomes *et al.* (2003), who evaluated the impact of water supplementation on sunflower dry matter accumulation and partitioning. They reported that plant mass increased as irrigation depth increased. According to Paiva *et al.* (2005), decreasing soil water reduces leaf water potential and stomatal conductance, promoting stomatal closure and blocking CO2 flow to leaves, affecting photoassimilate accumulation. Conversely, plants respond positively to more favorable soil water conditions, maintaining high photosynthetic rates, resulting in greater photoassimilate production and resulting in higher fresh matter yields.

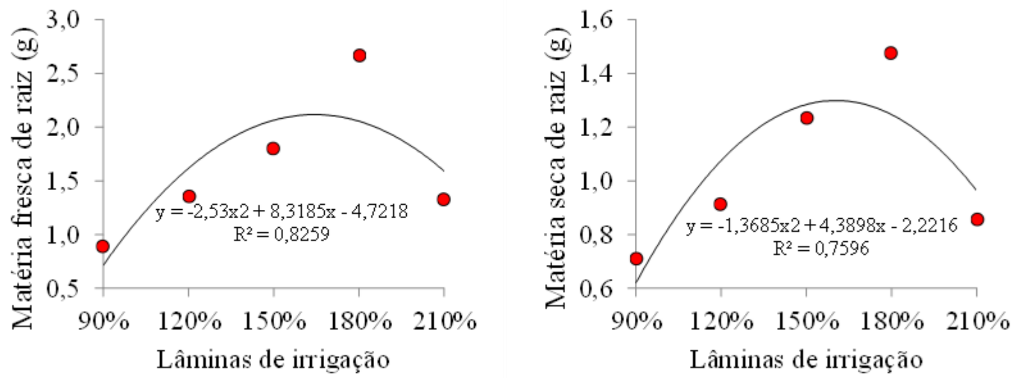
Figure 6. Graphical representation and regression equation of the fresh mass of the aerial part and dry mass of the aerial part of amaranth plants as a function of irrigation depth.



Water deficit reduces cell multiplication and expansion, resulting in reduced canopy growth. In general, plant growth is affected by soil water availability, as the plastic and elastic extensibility of tissues decreases when plants are exposed to limited water availability, reducing canopy expansion (NEUMANN, 1995).

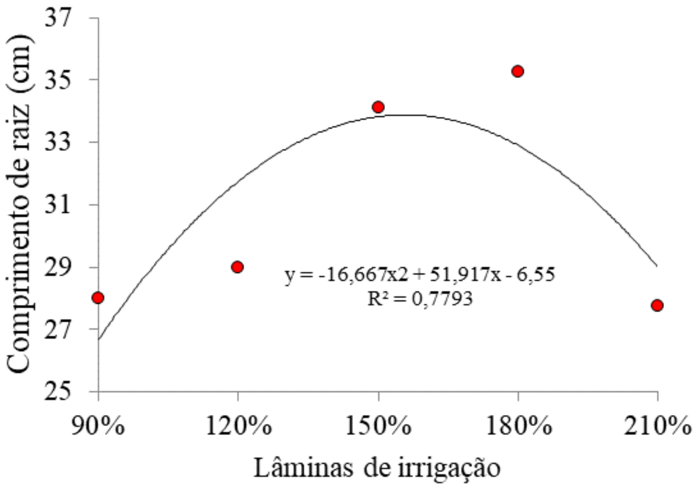
Given the significance of the influence of the irrigation depth factor, the polynomial regression analysis indicated a second-degree polynomial as the equation that best describes the behavior of fresh root mass and dry root mass as a function of the applied depth (Figure 7). Taiz and Zeiger (2004) stated that the best way to evaluate the growth of a plant would be the dry mass, as fresh mass is a parameter that is very sensitive to water fluctuations, since most plants are formed by water.

Figure 7. Graphical representation and regression equation of fresh root mass and dry root mass of amaranth plants as a function of irrigation depth.



On the basis of the significance of the influence of irrigation depth on root length, a regression analysis was performed, which revealed a quadratic equation (Figure 8). The roots of the plants grown at depths of 90%, 120%, and 210% developed the least. The 180% depth resulted in the greatest increase in root length, closely followed by the 150% depth. Pinto *et al.* (2011) reported a reduction in the average length of roots and shoots. The roots were shorter, averaging 1.09 cm, whereas the control averaged 2.33 cm.

Figure 8. Graphical representation and regression equation of the length of the roots of amaranth plants as a function of irrigation depth.

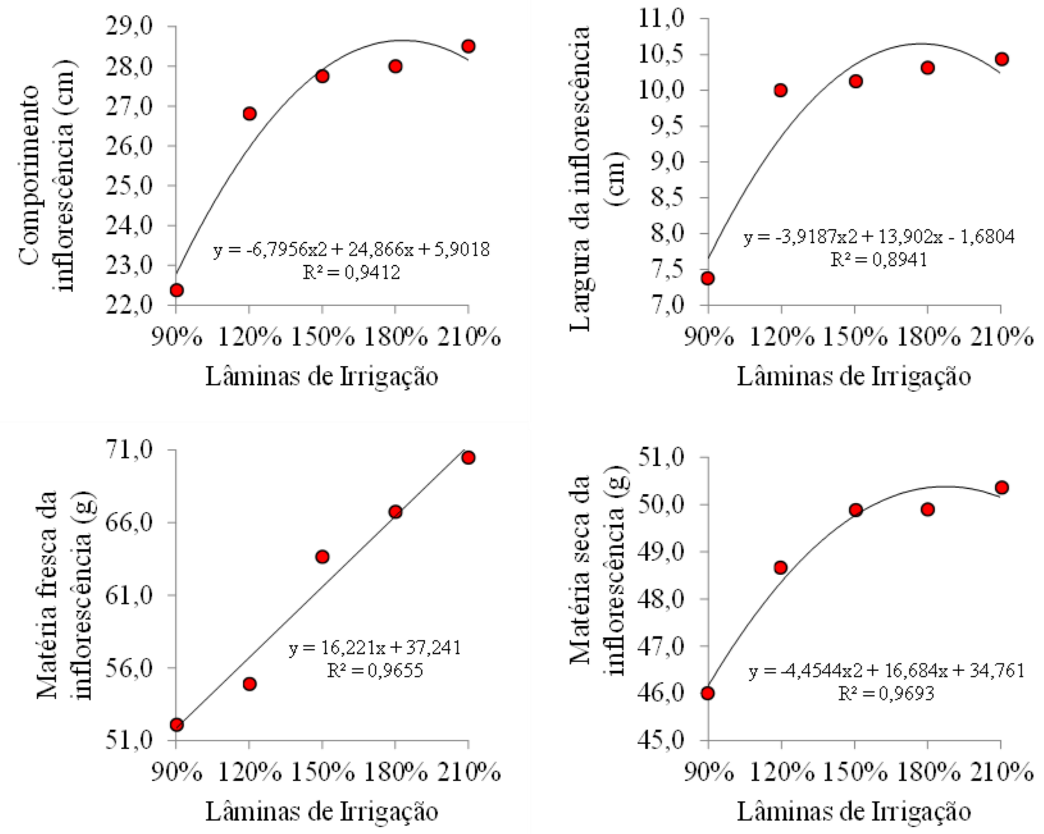


The results were significant according to the F test ($p < 0.01$) for the inflorescence length and width parameters. Figure 9 shows the quadratic trend for inflorescence length. The largest blade, 210%, which is equivalent to 894.6 mm of applied blades, was the one that stood out from the other blades, and the variation between treatments increased. The trend of increasing inflorescence width is shown in Figure 9. The inflorescence width exhibited a similar trend to that of the inflorescence length, since the inflorescence width in the treatment group was 210%, which is equivalent to 894.6 mm for the applied blade. The smallest blade, 90%, which is equivalent to 383.4 mm, developed the least.

The parameters fresh and dry matter of the inflorescence were significant according to the F test ($p < 0.01$). Figure 9 shows the regression analysis for the fresh matter of the inflorescence, which revealed a linear trend. A growing line is observed according to the applied water depths: 90% (383.4 mm), 120% (511.2 mm), 150% (639.0 mm), 180% (766.8 mm) and 210% (894.6 mm). Figure 9 shows a quadratic trend for the dry matter of the inflorescence. A growing development is observed with increasing water depth, with an emphasis on the treatment of 894.6 mm of applied water.

Ribeiro; Pieterse; Famba (2018) reported that the lengths of panicles and internodes, as well as the straw and grain yields of both amaranth cultivars, decrease with decreasing soil water content.

Figure 9. Graphical representation and regression equation of inflorescence length, inflorescence width and fresh and dry matter of the inflorescence of amaranth plants as a function of irrigation depth.



The parameters productivity per plant and weight of a thousand seeds were significant according to the F test ($p < 0.01$) . The values of the applied blades (during the entire crop cycle), the observed averages of the productivity parameters and the weights of a thousand seeds for each replacement level (treatments) are shown in Table 2. It is known that irrigation aims to meet the water demand of plants during critical periods, and it is necessary to apply it in the correct quantity. If insufficient, it harms the development of the plant, and if excessive, it wastes water, energy and nutrients (SILVA *et al.*, 2008).

Table 2. Applied blades, productivity and weight of a thousand seeds of amaranth plants as a function of irrigation depth, Itumbiara-GO.

Treatment (%)	**Applied blades (mm)**	**Productivity (g plant)**	**Weight of a thousand seeds (g)**
90%	383	3.20	0.690
120%	511	4.41	0.750
150%	639	4.58	0.787
180%	766	4.86	0.792
210%	894	5.55	0.795

Table 2 shows that the following increases in production occurred between the smallest and largest treatments, with the 90% treatment presenting a productivity of 3.20 g. The other treatments presented increases of 37.81, 43.12, 51.87 and 73.43% for the 120%, 150%, 180% and 210% blades, respectively, in relation to the 90% blade. Thus, we can affirm that with the 210% blade, it is possible to produce, on average, 73.43% more blades than with the 90% blade.

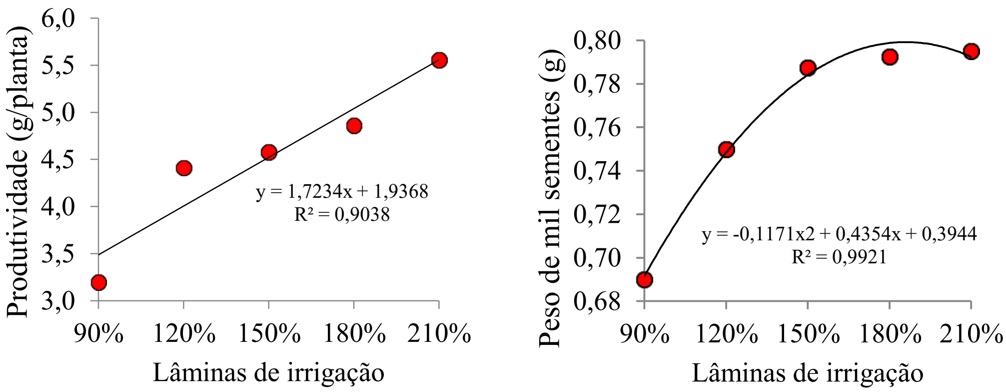
The opposite result was reported by Costa and Santos (2009), in which the treatments did not interfere with the development of amaranth, the production of fresh and dry biomass, or the production of amaranth grain. Studies carried out in cerrados by Spehar *et al.* (2003) reported the production of 2,359 kg ha $^{-1}$ of grains and 5,650 kg ha $^{-1}$ of total biomass in Amaranthus cruentus over a 90-day cycle.

An increase in water use efficiency was observed due to water replenishment. Figure 10 shows a linear trend. Again, there was growth as the water depth increased. The 210% water depth provided the highest average productivity. Soil water availability, which is affected by the application of greater irrigation depths throughout the crop cycle, likely meets the water demand required for greater production.

Amaranth tends to have the highest production biomass at relatively high water levels and is responsive to irrigation, which suggests that its planting should be promoted to increase water availability (JAYME-OLIVEIRA *et al.*, 2017). The BRS Alegria amaranth variety showed greater sensitivity to water restriction, which led to significant decreases in productivity and a lower harvest rate (SILVA, 2015). Costa and Santos (2009), when cultivating this same vegetable, reported an average production of 39.54 g plant $^{-1}$. Silva *et al.* (2019), using the cultivar BRS Alegria, reported better productivity in a treatment without water restriction, with an average of 2,008.6 kg ha $^{-1}$.

Figure 10 shows the behavior of the weight of a thousand seeds as a function of water replacement level, presenting a quadratic trend for the evaluated parameter. The values of the 150%, 180% and 210% treatments were very close, with averages of 0.787, 0.792 and 0.795, respectively.

Figure 2 Graphical representation and regression equation of the productivity and weight of a thousand seeds of amaranth plants as a function of irrigation depth.



Spehar *et al.* (2003) reported that grains prepared for storage with 12% moisture have an average weight of 0.68 g per 1,000 seeds. Viana (2012), working with sunflower crops, reported a linear increase in the mass of 1,000 achenes as a function of the increase in the number of applied blades. The blade that provided the highest values for the evaluated characteristic (48.23 g) was the 807.1 mm blade (125% of the ECA), and the lowest (38.49 g) was the 378 mm blade, equivalent to 25% of the ECA, with an experimental average of 43.58 g.

Steven *et al.* (2019) reported that appropriate irrigation levels need to be selected, which increases amaranth crop yields. Lavini *et al.* (2015) reported that a 50% reduction in irrigation volume did not cause a significant reduction in amaranth production. Toyin *et al.* (2015) reported that amaranth cultivation requires much more water application during the vegetative period and flowering stages than during emergence and senescence.

6 CONCLUSIONS

The blades near the mini-tank evaporation evaporimeter did not meet the needs of the crop, indicating high water requirements. The depth that provided the highest productivity was 210% (894.6 mm) of the evaporation depth of the mini tank. The levels below and well above evaporation did not produce the best biometric results for the crop. The values of 120% to 180% evaporation generally showed the best development across all the observed aspects of the amaranth crop.

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