CROP PRODUCTION

Gas exchanges of melon under water stress in the Submedium region of the São Francisco River Valley

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ABSTRACT. The current scenario of increased water scarcity is due to climate change and directly affects food production. It is thus necessary to develop strategies to mitigate the impacts of low water availability. Therefore, the goal of the present study is to evaluate the physiological behaviour of melon cultivars under water stress. The experiment was conducted in a protected environment in the experimental Submedium region of the São Francisco River Valley in the period ranging from October to December. In this study, we used the melon cultivars 'Amarelo' and 'Piel de Sapo'. The experiment was conducted in a randomized block design with three replicates that were subdivided into plots, where the plots were comprised of four irrigation rates (50, 75, 100, and 125% of crop evapotranspiration – CET), subplots were comprised of the two melon cultivars, and sub-subplots were comprised of samplings for physiological analyses (15, 30, and 45 days after transplanting). The parameters evaluated were stomatal conductance, transpiration, net photosynthesis, relationship CI/CA, and accumulated dry matter. Water stress reduced the stomatal conductance, transpiration, net photosynthesis, CI/CA, and accumulated dry matter. 'Piel de Sapo' showed a higher photosynthetic adjustment than 'Amarelo' melon due to the gas exchange behaviour of the former, and it was, therefore, more tolerant to water stress.

Keywords: photosynthetic adjustment; tolerance; dry matter; *Cucumis melo L.*

Introduction

The Brazilian semiarid region is characterized by water deficits, high temperatures, and low relative humidity, considerably restricting agriculture in this region due to low water availability and thereby limiting cultivation to irrigated regions. In addition, water scarcity and its spatial distribution have worsened due to climate change (Marengo, 2008); the largest drought of the last 50 years was recorded in the semiarid region, seriously harming the population, as well as food production, according to Clemente and Ermaela (2015).

Based on this emergency situation, studies on the physiological behaviour of plants under low water availability are required, particularly in melon, in view of its adaptation to edaphoclimatic conditions and its socioeconomic importance. According to studies evaluating melon irrigation (Sensoy, Ertek, Gedik, & Kucukyumuk, 2007; Oliveira, Medeiros, Lima, Dutra, & Oliveira, 2008; Souza, Bezerra, Sousa, & Santos, 2010), some melon types are susceptible to water stress.

Photosynthesis is one of the processes affected by water stress (Xu, Zhou, & Shimizu, 2010). Plants develop many physiological responses to water scarcity to reduce water loss via transpiration, e.g., stomatal closure (Teixeira, Nogueira, Maltarolo, Ataíde, & Oliveira Neto, 2015). Hence, plants do function even in poor conditions to maintain turgidity and metabolic processes (Beauzamy, Nakayama, & Boudaoud, 2014).

Plant physiological adaptations to environmental stress vary greatly depending on the genotype and intrinsic mechanisms to reduce oxidative damage (Farooq, Wahid, Kobayashi, Fujita, & Basra, 2009; Waseem et al., 2011). Therefore, the goal of the present study is to evaluate gas exchange and dry matter accumulation in protected-grown melons under different irrigation rates.

Material and methods

This study was conducted in a protected environment in the experimental area of the State University of Bahia in the Submedium region of the São Francisco River Valley, municipality of Juazeiro, Bahia State, Brazil (9°24' S; 40°30' W; 368 m of altitude), in the period ranging from October to December 2015. The

local weather is hot semiarid (BSh) according to the Köppen classification. The protected environment structure was arch-type, 3.5 m height (ceiling height), 10 m width, and 30 m length, with a 45% shading screen installed in the east-west direction.

Seeds were sown in polyethylene trays with a commercial substrate, and when plants had two pairs of definitive leaves, they were transferred to 5-liter pots. Pots were spaced at 50.0 x 50.0 cm between plants and rows; after the acclimatization period of 10 days after transplanting, four irrigation rates were initiated: 50, 75, 100, and 125% of crop evapotranspiration using the weighing lysimeter method.

Irrigation was performed daily using an automated dripping system. Plants received Hoagland's nutrient solution (Hoangland & Arnon, 1950) on a weekly basis according to crop demand. The characteristics associated with gas exchange were evaluated using a portable CO_2 infrared analyser (IRGA), LICOR 6400 model, and determined every 15 days (15, 30, and 45 days after rate differentiation) on sunny days and under weather conditions typical of the dry season (October to December 2015).

Meteorological data (temperature, relative humidity, air (wind) speed, and solar radiation) were obtained at a station located inside the greenhouse, as shown in Figure 1.
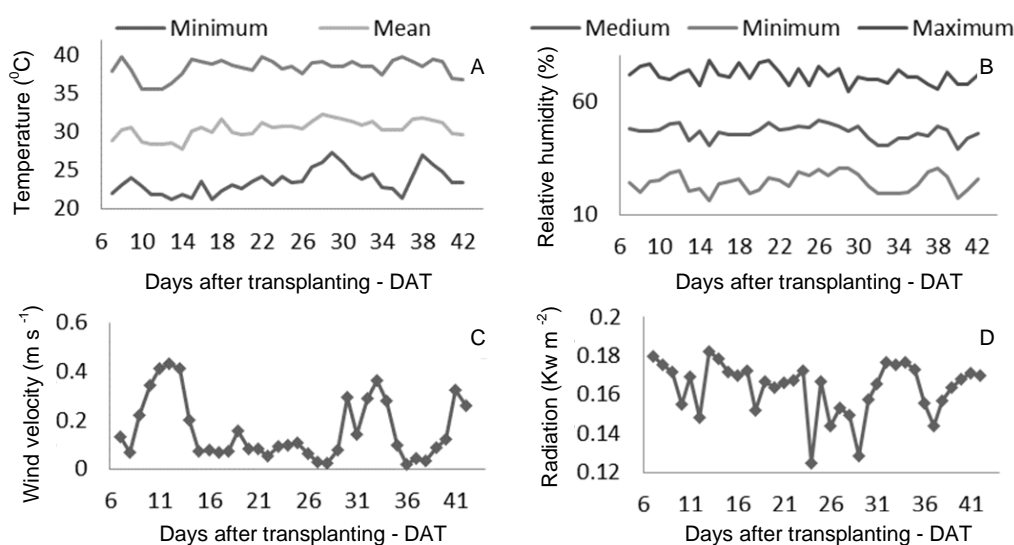

Figure 1. A) Internal temperature, B) Relative humidity, C) Air (wind) velocity, and D) Solar radiation inside the protected environment. Juazeiro, Bahia State, UNEB, 2017.

Evaluations were performed at approximately 9:00 am and 11:00 am (solar time) in mature and completely expanded leaves, obtaining the stomatal conductance, foliar transpiration, CI/CA (internal CO_2/external CO_2) ratio, and net photosynthesis. At 45 days after transplanting, plants were removed from the pots, and the aerial part and roots were separated to determine the weights of leaf, stem, and root dry matter.

The experiment was conducted in a randomized block design replicated three times, and subdivided into plots; plots were comprised of four irrigation rates (50, 75, 100, and 125% of crop evapotranspiration – CET), subplots were comprised of the two melon cultivars (the hybrids were Juazeiro and Mandacaru), and sub-subplots were sampled 15, 30, and 45 days after transplanting. Data were submitted to an analysis of variance, and when significant, they were submitted to Tukey's test at 5% significance and to a regression analysis using the statistical program SISVAR 5.6.

Results and discussion

Stomatal conductance (gs) is of great importance to physiological processes since open stomata allow for the entrance of CO_2 via diffusion and closed stomata allow for the conservation and maintenance of plant turgidity, thus reducing the risks of water loss (Nascimento, Bastos, Araújo, Freire Filho, & Silva, 2011).

The full activity of stomatal conductance allows a rapid alteration of the stomatal opening after an external stimulus as the ions are activated through the protective cell membranes to maintain the turgor of the protection cell. Alternatively, a regulation of the pore areas occurs where the turgor of the guard cells

increases, and the stomatal behaviour also follows the turgor of the whole leaf, which in conditions of water deficit, are drastically affected, and in this way, (gs) is considered passive (Chater, Gray, & Beerling, 2013).

This variable did not vary according to the melon cultivar, and there was no interaction between the evaluated factors; however, stomatal conductance was influenced by the irrigation rates. The data showed better adjustment to the quadratic polynomial regression model, as shown in Figure 2.

Water stress reduced (gs) values; there is an increasing trend in (gs) with increasing rates up to full irrigation (irrigation rate of 100% of CET), and then this variable declines. Both melon cultivars had a decrease in (gs), and consequently, decreased foliar transpiration (E) and net photosynthesis (A), with decreasing gas exchange. Decreased (gs) is directly related to the soil water content (Xu, Zhou, & Shimizu, 2009); depending on the plant, there might be changes in stomatal opening and closure under water deficit.
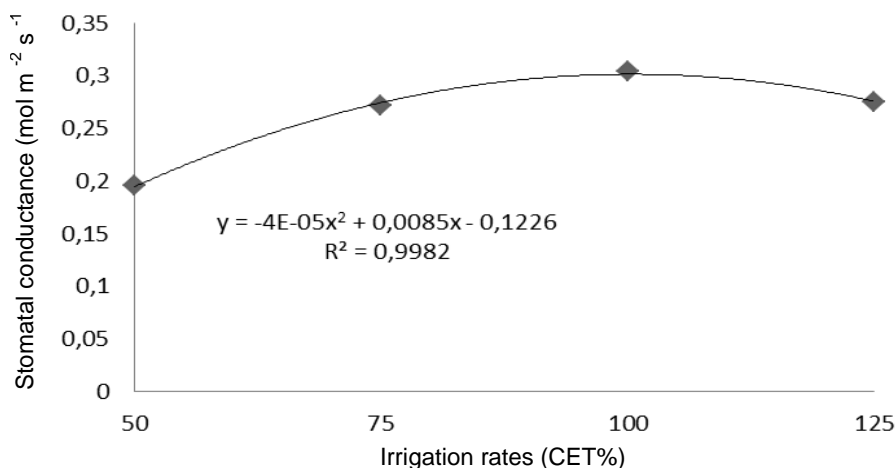

Figure 2. Change in stomatal conductance of melon cultivars according to irrigation rates. Juazeiro, Bahia State, UNEB, 2017.

There was also a difference between seasons; stomatal conductance changed in melons throughout harvests (15, 30, and 45 DAT), and a decreasing linear regression was the method that best adjusted to the data (Figure 3). The decrease in (gs) throughout the phenological cycle might be explained by photosynthetic adjustment with the course of development and changes in melon development stages, such as 15 days after transplanting: vegetative, 30 days after transplanting: flowering, and 45 days after transplanting: fruiting.

Throughout its development, the plant increases its foliar area and its vegetative parts, and consequently, the number of stomata, thus increasing its potential for gas exchange. If this process is not effective, both melon cultivars lose more water than necessary, thus causing dehydration, which might hinder their growth and development.
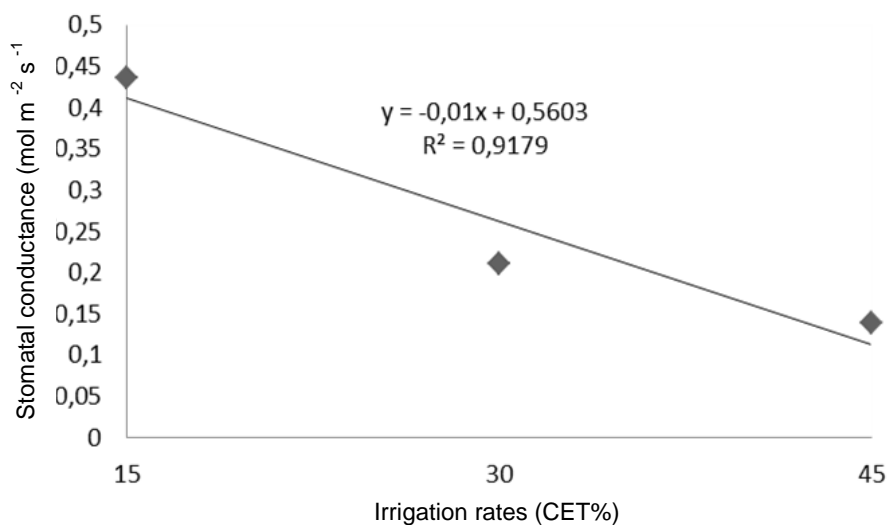

Figure 3. Change in stomatal conductance of melon according to the number of days after transplanting (DAT). Juazeiro, Bahia State, UNEB, 2017.

The results are corroborated by Dalastra et al. (2014), who evaluated the gas exchange and quality of 'Amarelo' melon fruits cultivated at one and two fruits by plant. Throughout the development of the crop, both factors decreased with plant age.

Silva et al. (2015) evaluated the gas exchange and chlorophyll fluorescence in eggplant plants under irrigation slides, and the results corroborate the present work, as a gradual effect was also observed with the increased availability of water, which provided a larger stomatal opening and conditions for the plant to perform physiological processes without there being a negative influence on the stomatal opening.

Regarding transpiration (E), there was no significant difference either in the 1st sampling (15 DAT) or the 3rd sampling (45 DAT); however, there was a three-way interaction in the 2nd sampling (30 DAT) with irrigation rates and melon cultivars (Figure 4) at 5% of significance, and the trend was adjusted to the quadratic polynomial model.

'Piel de Sapo' showed a decreasing trend in (E) with water stress. Foliar transpiration decreased as the stomata closed to reduce water loss to the atmosphere, thus reducing CO_2 assimilation via diffusion and avoiding dehydration.

'Amarelo' melon did not show photosynthetic adjustment; it had a decreasing trend in (E) with increased water availability, thus losing more water, affecting turgidity and hindering cell expansion and division, which influenced plant growth.
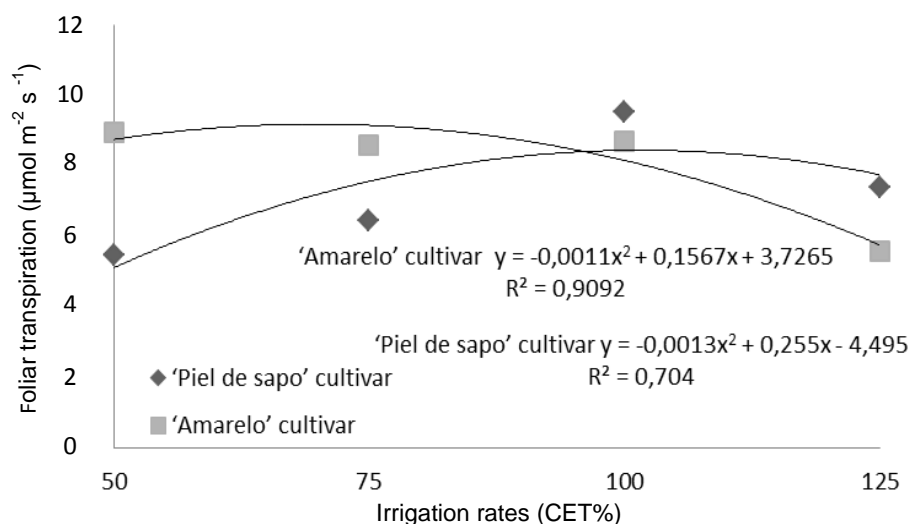

Figure 4. Change in foliar transpiration in the interaction between irrigation rates (crop evapotranspiration: CET), the 2nd sampling, and 'Piel de Sapo' and 'Amarelo' cultivars. Juazeiro, Bahia State, UNEB, 2017.

The works of Silva et al. (2015) and Lima, Bezerra, Gomes Filho, Pinto, and Enéas Filho (2010) corroborate the results of transpiration (E) as a function of the irrigation rates, since it presented an increasing effect with the increase of the irrigation slides, in which stomatal behaviour determines the transpiration demand to which the leaves are potentially subject by controlling their loss of water to the environment in the form of water vapour. In this way, with the ideal water conditions (field capacity), plants generally have high transpiration rates so that, as the soil water becomes scarce, the plant begins to reduce their transpiration rates to reduce water loss. This fact justifies the increase in transpiration and stomatal conductance when the plants were irrigated with larger amounts of water.

These results support the fact that the transpiration rate in melons increases under optimal water conditions, and this is related to (gs) since stomata are the major path for water loss in the plant (Pereira-Filho, Bezerra, Chagas, Silva, & Pereira, 2015). Reduced stomatal conductance induced by water stress contributed to decreased CO_2 assimilation via diffusion, as the internal CO_2/external CO_2 ratio (CI/CA) in the 1st sampling (15 DAT) of 'Piel de Sapo' showed a significant and three-way interaction with irrigation rates and the 1st sampling (Figure 5) when adjusted by the quadratic polynomial method, which did not occur in 'Amarelo'. There is an increasing trend in (CI/CA) with increasing irrigation rates, with its highest value occurring closer to the 100% rate, and a decrease in (CI/CA) thereafter, mostly influenced by excess water.
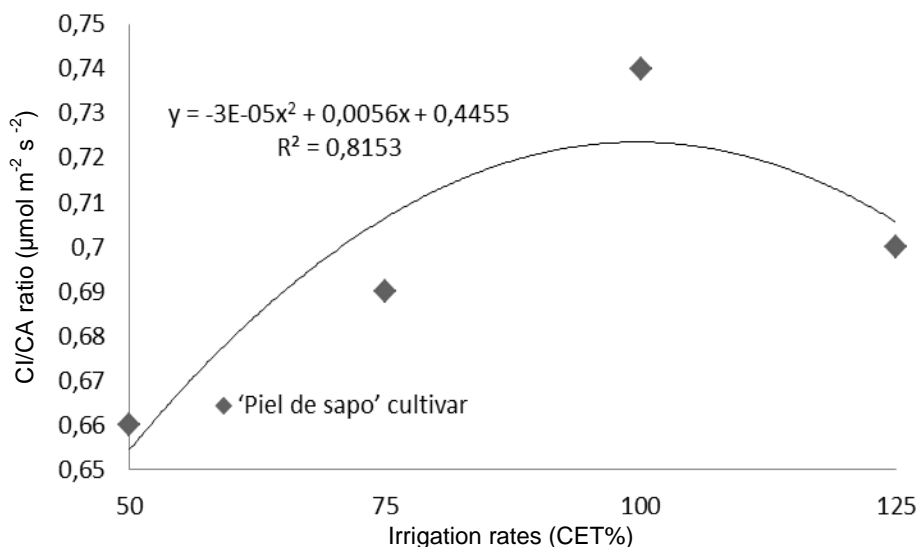
$$y = -3E\text{-}05x^2 + 0{,}0056x + 0{,}4455$$
$$R^2 = 0{,}8153$$

Figure 5. Change in the external carbon/internal carbon ratio in the interaction between irrigation rates (crop evapotranspiration: CET), the 1st sampling, and 'Piel de Sapo'. Juazeiro, Bahia State, UNEB, 2017.

In the 2nd sampling (30 DAT) there was a significant and three-way interaction between irrigation rates and 'Piel de Sapo' and 'Amarelo' cultivars (Figure 6). These results were similar to the 1st sampling of 'Piel de Sapo' as (CI/CA) values decreased, and the highest values occurred closer to the 100% rate.

The 'Amarelo' cultivar showed a gradual effect, as the highest (CI/CA) contents occurred with the lowest irrigation rate; hence, atmospheric CO_2 assimilation via diffusion was not harmed. However, damages caused by stomata opening at 30 DAT under water stress might affect the accumulation of photoassimilates due to its higher water loss than that of 'Piel de Sapo'.
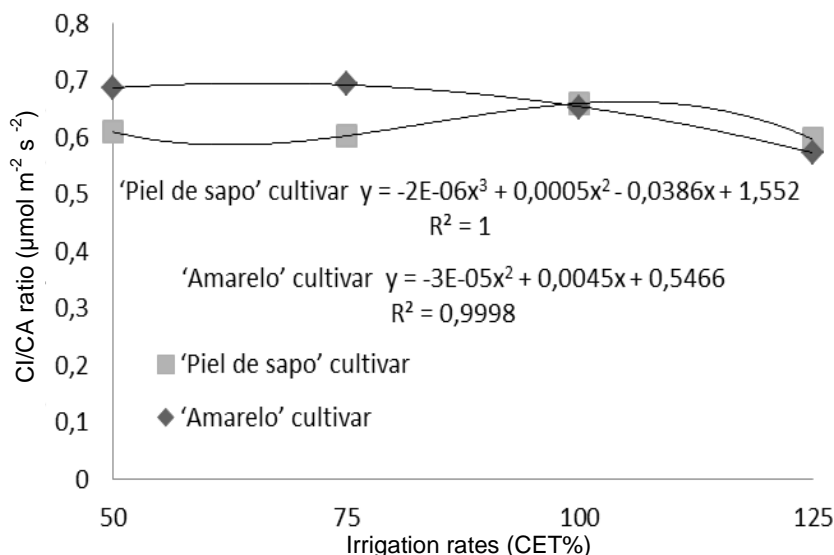

'Piel de sapo' cultivar $y = -2E\text{-}06x^3 + 0{,}0005x^2 - 0{,}0386x + 1{,}552$
$$R^2 = 1$$

'Amarelo' cultivar $y = -3E\text{-}05x^2 + 0{,}0045x + 0{,}5466$
$$R^2 = 0{,}9998$$

Figure 6. Change in the external carbon/internal carbon: CI/CA ratio in the interaction between irrigation rates (crop evapotranspiration: CET), the 2nd sampling (30 DAT), and 'Piel de Sapo' and 'Amarelo' cultivars. Juazeiro, Bahia State, UNEB, 2017.

In the 3rd sampling (45 DAT), there was a significant and three-way interaction with irrigation rates and both melon cultivars (Figure 7). 'Piel de Sapo' showed similar behaviour in the three evaluation samplings; reduced water availability decreased the CI/CA ratio, thus causing the gradual effect.

The 'Amarelo' cultivar at 30 DAT showed adjustment to the results obtained, with a similar result to that of 'Piel de Sapo'; this might be explained by development phase since plants change their metabolism for fruit development. Moreover, the onset of senescence also contributed to the lowest CI/CA results in the lowest application rates.
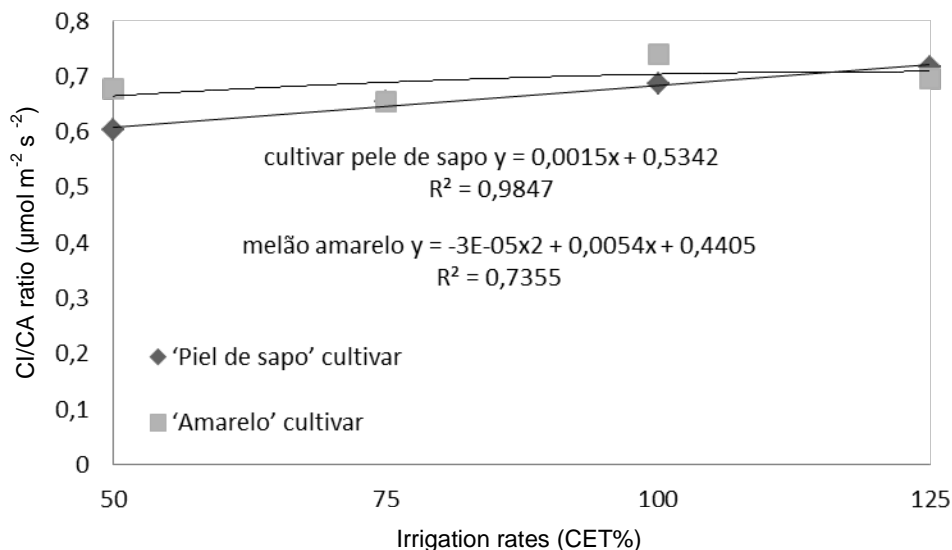
Figure 7. Change in the external carbon/internal carbon (CI/CA) ratio in the interaction between irrigation rates (crop evapotranspiration: CET), the 3rd sampling, and 'Piel de Sapo' and 'Amarelo' cultivars. Juazeiro, Bahia State, UNEB, 2017.

These results differ from the findings of Suassuna et al. (2014), who worked with citrus under water stress; there were no significant differences either in internal CO_2 concentrations or CO_2 concentrations in the substomatal chamber between treatments.

Based on the results obtained for stomatal conductance, foliar transpiration, and internal CO_2/external CO_2 ratio, which act directly on gas exchanges, there was an observable significance in net photosynthesis (A) and a two-way interaction between irrigation rates and the three samplings (1st sampling: 15 DAT, 2nd sampling: 30 DAT, and 3rd sampling: 45 DAT) when adjusted with the quadratic polynomial regression method, and a two-way interaction between melon types and the three samplings, adjusted with the linear regression method.

Figure 8 shows a gradual increasing trend in (A) in the 1st (15 DAT) and 3rd (45 DAT) samplings with increased water availability up to the 75% rate; thereafter, there was a decreasing trend with the increasing amount of water provided to the plant. This trend was slightly different in the 2nd sampling (30 DAT), which exhibited an increase in (A) with increasing water availability and a peak in values closer to the 100% rate; after that, there was a decreasing trend.
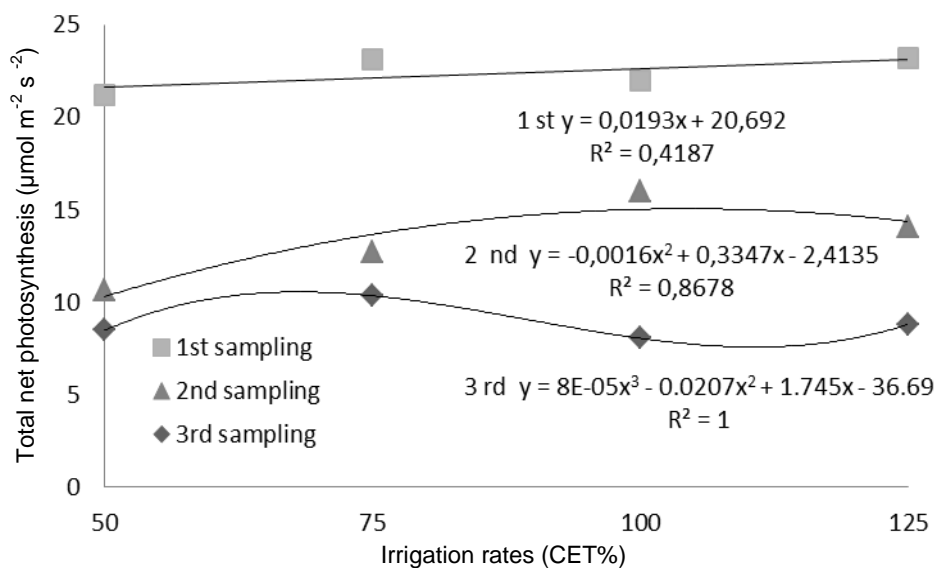

Figure 8. Change in net photosynthesis in the interaction of irrigation rates (crop evapotranspiration: CET) with the three samplings (15, 30, and 45 days after transplanting). Juazeiro, Bahia State, UNEB, 2017.

Therefore, it is evident that water stress, either deficit or excess, is harmful to (A) contents. These results are in agreement with the other variables evaluated: (gs), (E), and (CI/CA), which decreased under water stress.

In gas exchanges, the factor that was most affected was (A) under water stress conditions because it is dependent on the stomatal opening for CO_2 inlet and water outlet, and with less water availability, less ATP and NADPH are formed and, as a consequence, less CO_2 is fixed. Photosystem II depends on water for the generation of chemical energy, required for CO_2 fixation, showing then that variations in water availability generate less efficiency in photosystem II. The effect of the lowest water depths was not due to stomata.

Overall, water stress decreased the gas exchanges that contribute to increases in accumulated dry matter; regarding the dry matter content in the roots, there were differences between cultivars, as shown in Table 3. 'Piel de Sapo' showed a higher dry matter content than 'Amarelo', which is related to a higher adjustment, as the decrease in foliar transpiration due to the water deficit contributed to the maintenance of cell turgidity even under stress conditions, and this higher accumulation might have been a way for this hybrid to endure this adverse condition, increasing the root system in search for a higher soil water volume.

Table 3. Statistical differences in root dry matter between melon cultivars.

Cultivars	Root dry matter (g^{-1})
'Piel de Sapo'	3.12 a
'Amarelo'	2.32 b
CV (%)	24.55

Statistical difference at 5.0% of probability; mean values were submitted to Tukey's test.

Leaf dry matter content (LDM) (Figure 9A) showed no significant differences for the factor melon cultivar or the interaction with irrigation rates; however, there were significant differences between irrigation rates.

Stem dry matter content (SDM) (Figure 9B) follows leaf behaviour; however, the only irrigation rate that stands out among the others is the 125% irrigation rate; the others showed quite similar results. Decreases of 50% and 25% in the optimal water amount did not drastically affect stem dry matter accumulation. There was no interaction between cultivars and irrigation rates; however, irrigation rates were significantly different from each other (Figure 9C). It is noticeable that a higher increase in water causes an increase in RDM, even though it is slight.
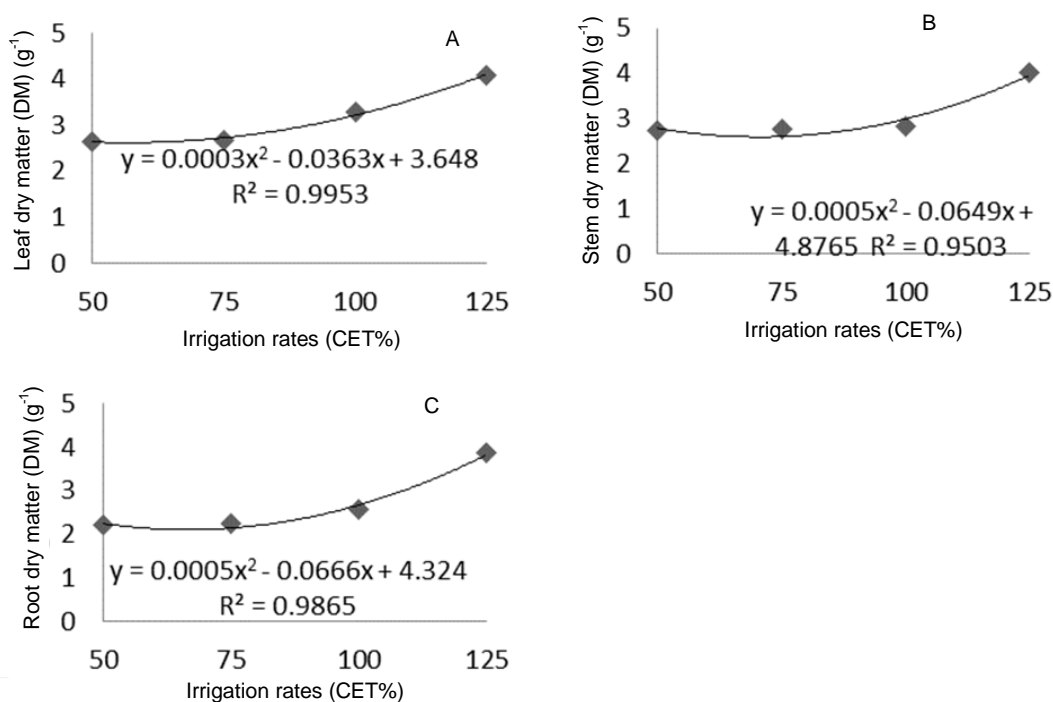

Figure 9. A) Change in leaf dry matter according to irrigation rates (crop evapotranspiration: CET), B) change in stem dry matter with different irrigation rates (CET), C) change in root dry matter with the different irrigation rates (CET). Juazeiro, Bahia State, UNEB, 2017.

The results of the present study are also in line with the studies by Pereira-Filho et al. (2015), Ferraz et al. (2011), and Tomaz, Porto Filho, Medeiros, Dutra, and Queiroz (2008), who studied melon and found that reductions in leaf dry matter contents were caused by water stress.

Conclusion

'Piel de Sapo' showed a higher photosynthetic adjustment than 'Amarelo' melon due to its gas exchange behaviour under water stress, and the dry matter content decreased with the water deficit, showing its best behaviour at the 125% rate.

Acknowledgements

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