Research Article

Leaf water potential of papaya subjected to irrigation depths under semi-arid climate[1]

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ABSTRACT

Water scarcity and high evapotranspiration rates in the Brazilian Northeast region, especially due to climate change, are major limiting factors to the papaya crop. This study aimed to evaluate the leaf water potential in papaya plants at different dates, times of the day (6:00, 8:00, 10:00, 12:00, 14:00, 16:00 and 18:00) and irrigation depths to indicate the crop water deficit. The experiment followed a randomized block design, with four treatments (50, 75, 100 and 125 % of the irrigation depth required to reach the field capacity). The leaf water potential measurements between 12:00 and 14:00 showed the greatest differences among the applied irrigation depths, thus being the most suitable interval for assessing the water status. The water potential of -2.5 MPa can be used as a critical limit for 'Sunrise Solo' papaya plants.

KEYWORDS: *Carica papaya* L., psychrometrics, water deficit.

RESUMO

Potencial hídrico foliar de mamoeiro submetido a lâminas de irrigação na região semiárida

A escassez de recursos hídricos e as altas demandas evapotranpiratórias na região Nordeste do Brasil, sobretudo em função das mudanças climáticas, são fatores limitantes à cultura do mamoeiro. Objetivou-se avaliar o potencial hídrico foliar do mamoeiro, em diferentes datas, horários (6:00, 8:00, 10:00, 12:00, 14:00, 16:00 e 18:00) e lâminas de irrigação, como indicador de déficit hídrico da cultura. O delineamento experimental foi em blocos aleatorizados, com quatro tratamentos (50; 75; 100; e 125 % da lâmina de reposição de água até a condição de capacidade de campo). A medida do potencial hídrico foliar entre 12:00 e 14:00 evidenciou as maiores diferenças entre as lâminas de irrigação aplicadas, sendo, portanto, o intervalo mais indicado para a avaliação do estado hídrico. O potencial hídrico de -2,5 MPa pode ser utilizado como limite crítico para plantas de mamoeiro 'Sunrise Solo'.

PALAVRAS-CHAVE: *Carica papaya* L., psicrometria, déficit hídrico.

INTRODUCTION

Papaya (*Carica papaya* L.) is widely cultivated and consumed in tropical and subtropical regions for its high nutritional value, pleasant flavor and aroma (Viana et al. 2015). Brazil is one of the leading global producers, reaching 1,138,343 t in 2023 (IBGE 2023). Bahia accounts for 31.14 % of the country's production, primarily in the western and southern regions of the state (IBGE 2023). The crop is also highly significant in semi-arid regions. In 2023, Bahia produced 354,525 t from a planted area of 9,410 ha, with an average yield of 37,675 kg ha^{-1}, making it the first-largest papaya producer in Brazil (IBGE 2023).

Northeast Brazil is a region marked by low annual rainfall, leading to significant water loss through evaporation. Over 60 % of the region faces semi-arid conditions (Medeiros et al. 2012). Water scarcity is concentrated within the Drought Polygon, which includes the semi-arid regions of eight northeastern states (Bahia, Alagoas, Ceará, Paraíba, Pernambuco, Piauí, Rio Grande do Norte and Sergipe), as well as northern Minas Gerais (Marengo et al. 2016).

As water resources become scarce and irrigated areas expand, new technologies and irrigation management strategies are gaining prominence, driving numerous research efforts (Lima et al. 2015,

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Lamaoui et al. 2018, Coelho et al. 2019). Therefore, understanding the water-use efficiency is essential for optimizing water resources in crops, particularly in semi-arid regions. This includes cultivar selection, crop spacing, soil and orchard management, and irrigation (Libardi et al. 2015, Nascimento et al. 2022).

Water availability for papaya plants may affect fruit yield and quality. The crop is highly adaptable to regions with rainfall ranging from 1,500 to 2,000 mm. It has low tolerance to prolonged water deficits, particularly during the reproductive phase, leading to temporary flower abortion (Ramalho et al. 2011). Studies on papaya crops have shown high stomatal sensitivity to soil water deficit, particularly under high evapotranspiration demands (Campostrini et al. 2010, Lima et al. 2016).

Leaf water potential is a reliable indicator of plant water status under various field conditions, including soil treatments (with and without mulch), irrigation depths (Medeiros et al. 2024) and potassium deficiency (Yang et al. 2022). Water deficit affects respiratory and photosynthetic rates and stomatal movement differently across species, with reductions observed at leaf water potential values of -0.6, -0.5 and -1.6 MPa, respectively (Lopes & Lima 2015). Accordingly, quantitative methods to assess leaf water conditions can help to detect the physiological state of plants and provide valuable information for plant production (Junttila et al. 2019, Zhu et al. 2019). This culminates in a direct influence on crop yield; therefore, developing methods for evaluating it is essential.

Psychrometers or pressure chambers are commonly used to measure plant water potential, but their use is typically limited to laboratory settings (Taiz et al. 2017). Among the instruments for measuring leaf water potential, the WP4-C (dew point meter) offers a quick and accurate method for assessing water potential in soils, leaves and plant materials, both in the field and laboratory (Decagon Devices 2017). In this regard, the leaf water potential can be measured by placing the sample in a closed environment, allowing it to equilibrate, and then measuring the partial water pressure in the atmosphere of that environment. However, few studies have used the WP4-C to estimate leaf water potential in papaya.

Given the limited studies on soil-plant-atmosphere interaction in papaya crops, this study aimed to evaluate the leaf water potential in papaya at different dates, times and irrigation levels under the agroecological conditions of the semi-arid region.

MATERIAL AND METHODS

The study was conducted in Guanambi, Bahia state, Brazil (14º21'05.87''S, 42º42'40.85''W and 600 m of altitude, with average rainfall of 663.69 mm and mean temperature of 26 ºC). The soil in the experimental area is classified as Eutrophic Red-Yellow Latosol (Eutrophic Red-Yellow Oxisol) (Oliveira 2021). The experiment followed a randomized block design, with four irrigation depth treatments: 50, 75, 100 and 125 % of the amount required to reach the field capacity. Five replicates were used, and each plot consisted of four rows with four plants, totaling 16 plants per unit.

During the soil preparation, mechanical scarification was performed in the 0-0.15 m depth layer, followed by the opening of planting holes measuring 0.5 m in diameter and 0.5 m in deep. Then, 20 L of cured cattle manure and 150 g of single super-phosphate were applied to each planting hole. For planting, direct sowing at the final location was tested, as used in citrus cultivation by Brito et al. (2006) and Silveira et al. (2022).

Seeds of the 'Sunrise Solo' cultivar, from the 'Solo' group, were used. The crop was established in a single-row system, with 1.8 m spacing between plants within the row and 2.5 m between rows, resulting in a plant density of 2,222 plants ha^{-1}. Planting was carried out in May 2019. The orchard was established through direct sowing in the final location, with 15 seeds per hole arranged in three groups of five seeds, planted in a triangular formation with 0.5 m spacing between seeds.

Topdressings were applied using soil starting at 30 days after planting (DAP). The following amounts were applied per plant at 30, 60, 90 and 120 DAP, respectively: 23 g of NPK (20:00:20); 23 g of NPK (20:00:20) + 18 g of monoammonium phosphate; 23 g of NPK (20:00:20) + 10 g of urea; and 23 g of NPK (20:00:20) + 18 g of monoammonium phosphate + 10 g of urea.

At 30 DAP, thinning was performed, leaving three plants per hole. After 140 DAP, sexing was conducted, retaining one plant with hermaphrodite flowers per hole. From 140 to 480 DAP, topdressings were applied through fertigation. A mixed mineral fertilizer was used, containing 15 % of N, 5 % of P_2O_5, 23 % of K_2O, 2.5 % of Mg, 3.5 % of S, 0.2 % of B, 0.01 % of Mo and 0.1 % of Zn, at a rate of 2.82 kg per application.

Localized irrigation using a drip system with self-compensating emitters, with nominal flow rate of 7.80 L h^{-1} and working pressure of 196.13 kPa, was employed. From planting to 140 DAP, one emitter was placed at the center of each planting hole. After 140 DAP (sexing), two emitters were used per plant, spaced 0.5 m apart.

A fixed Bourdon-type pressure gauge with a reading range of 0-10 bars was installed at the beginning of the derivation line to monitor and maintain the operating pressure of 2.0 bars during the daily irrigation management. This pressure accounted for the emitter service pressure and lateral line pressure variations.

Until 140 DAP, irrigation was applied daily and uniformly across all plots. After this period, four irrigation depths were implemented. Irrigation depth control was managed by adjusting the application time for each treatment, achieved by closing the valves corresponding to each irrigation level. Valves were closed in ascending order of irrigation depth: 50, 75, 100 and 125 % of the water replacement depth to reach the field capacity.

Irrigation management, including the calculation of irrigation depths and application time, was based on soil monitoring, using the soil water retention curve at a depth of 0.2 m. Rainfall events were subtracted from the irrigation depth to adjust the irrigation time accordingly. The total applied gross irrigation depths were 441.58, 662.36, 877.86 and 1,103.94 mm for the 50, 75, 100 and 125 % treatments, respectively. During the experimental period, the total rainfall reached 778.7 mm.

Samples were collected from the upper third of the plants (3 to 4 leaves from the top of the canopy), selecting undamaged leaves. These were cleaned with deionized water and lightly sanded with 600-grit sandpaper to remove the leaf cuticle (Campbell & McInnes 1999). Using an extractor, a 32-mm diameter circular sample was taken from each plant and stored in a plastic bag inside a styrofoam box at 11 ºC for transport. The samples were then placed in Petri dishes and stored in a Biological Oxygen Demand (BOD) chamber at 7 ºC, until the leaf water potential was measured (Figure 1).

Three leaf samplings were conducted to assess the water potential on rain-free days: November 8, 2019; December 3, 2019; and January 22, 2020. On November 8, 2019, the first collection was made, with samples taken at 2-hour intervals (6:00, 8:00, 10:00, 12:00, 14:00, 16:00 and 18:00) to assess the influence of different irrigation depths and leaf collection times on the leaf water potential of papaya trees. On December 3, 2019, and January 22, 2020 (second and third collections, respectively), the samples were taken only at 08:00 and 14:00 (representing low and high temperatures, respectively) to assess the influence of collection date and time on the leaf water potential.

After extraction, the samples were hermetically sealed in a plastic container, stored in an iced styrofoam thermal box and kept at approximately 11 ºC. The material was transported to the laboratory and stored in a BOD incubator (Figure 1B) at approximately 7 ºC, until the leaf water potential readings were taken.

The water potential was determined by correlating the sample's water potential reading with the vapor pressure of the air in equilibrium with the

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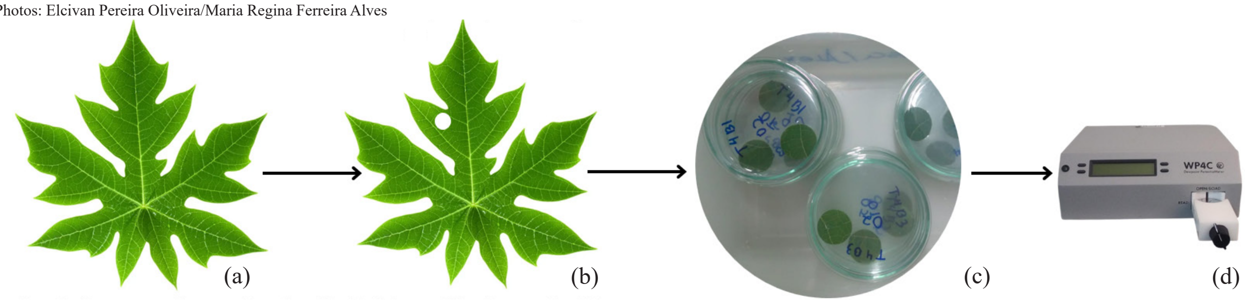

Figure 1. Workflow for analyzing the leaf water potential in papaya: a) leaf selection and asepsis of the picking host; b) sample collection (diameter of 32 mm) and packaging in a sterile plastic bag, followed by packaging in a polystyrene box with ice (11 ºC) to transport; c) transfer to Petri dishes and storage in a BOD chamber (7 ºC); d) leaf water potential measurement using a WP4-C device.

sample. The relationship between the sample's water potential (Ψ) and the vapor pressure of the air is as follows: $\Psi = (RT/M) \times (\ln p/p_0)$, where p is the vapor pressure of the air (measured using a chilled mirror), p_0 the condensation pressure at a given temperature (calculated from the sample temperature), R the gas constant (8.31 J/mol K), T the Kelvin temperature of the sample and M the molecular mass of water (WP4-C dew-point potentiometer, Meter group). The WP4-C measures the total water potential, which is the sum of the osmotic and matrix potentials.

Data were tabulated in an electronic spreadsheet and analyzed in R (R Development Core Team 2024) to check for outliers and normal distribution of residuals using the MASS package (Venables & Ripley 2002), along with the Shapiro-Wilk normality test. Analysis of variance, regression and Tukey test were then performed using the Expdes.pt package (Ferreira et al. 2018).

RESULTS AND DISCUSSION

The analysis of variance for the leaf water potential of the 'Sunrise Solo' papaya under different irrigation depths (50, 75, 100 and 125 %) showed a statistically significant effect. However, the regression analysis of the papaya leaf water potential as a function of irrigation depths was not significant.

The leaf water potential increased with higher irrigation depths, rising from -2.45 MPa (50 %) to -2.28 MPa (125 %), an increase of 7.23 %. However, when comparing the mean leaf water potentials of -2.45, -2.43, -2.41 and -2.28 MPa, respectively, no statistical difference was observed among the 75, 100 and 125 % treatments, although a significant difference was found between the 50 and 125 % treatments. The leaf water potential was noticeably lower in plants receiving lower irrigation depths, indicating its potential as an indicator of water deficit in papaya (Figure 2).

Water deficiency typically affects plant growth by causing stomatal closure, leaf wilting, reduced photosynthetic activity, seed germination failure, increased root elongation, flower and fruit abortion, and petiole elongation (Campos et al. 2021). Souza et al. (2021), however, applied brassinosteroids (a plant hormone) to papaya plants and observed a reduction in leaf moisture with increasing irrigation depths.

Considering the mean leaf water potential regardless of irrigation depth, significant differences were observed across the collection times: 6:00, 8:00, 10:00, 12:00, 14:00, 16:00 and 18:00 (Figure 3A). The highest leaf water potential was recorded at 18:00 (-2.17 MPa), while the lowest occurred at 12:00 (-2.60 MPa). Average leaf water potentials were higher during cooler periods, reaching -2.18 MPa at 6:00 and -2.17 MPa at 18:00, and lower during the hottest hours, with values of -2.52 MPa at 10:00, -2.60 MPa at 12:00 and -2.57 MPa at 14:00.

Overall, the water potential increased until midday (~12:00 to 13:00) and decreased in the afternoon. This likely reflects the plant's physiological response to water balance throughout the day, influenced by solar radiation, temperature and vapor pressure deficit.

The 100 and 75 % treatments showed the highest water potential values, peaking near -2.60 MPa, indicating better water status and less stress. In contrast, the 50 % treatment consistently showed more negative values, especially in the early morning and late afternoon, suggesting a higher water stress. However, the 125 % treatment displayed an atypical response, with a significant drop at the end of the day, what may indicate excess of water in the soil, impairing absorption or causing root hypoxia.

The plants experienced the water potential effects most during hours of highest evaporative demand (midday). The 50 % treatment irrigation depth limited the water supply, causing stress in the plants, while the 75 and 100 % treatments promoted water homeostasis, potentially benefiting processes like stomatal conductance and photosynthesis. Regarding the 125 % treatment, the excess of water

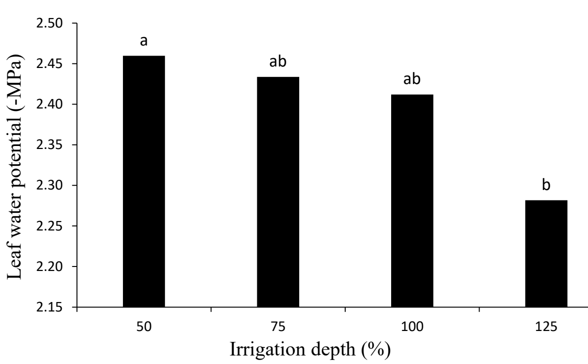

Figure 2. Leaf water potential of the 'Sunrise Solo' papaya tree at different irrigation levels. Means followed by the same letter do not differ significantly from each other by the Tukey test at 5 % of significance.

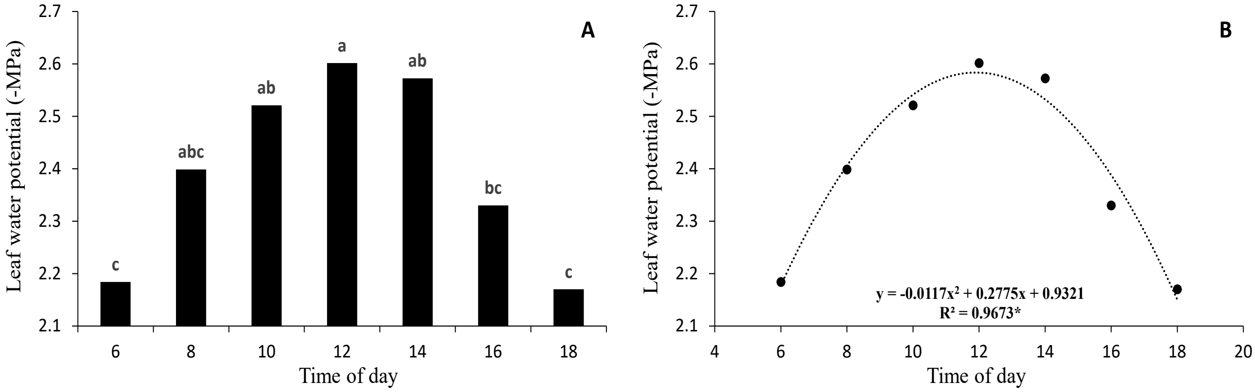

Figure 3. Tukey test at 5 % of significance (A) and regression analysis (B) of the mean leaf water potential of the 'Sunrise Solo' papaya at different times of the day. * Significant at $p < 0.01$.

may not be advantageous, highlighting the need for proper irrigation management to conserve water.

Throughout the day, the leaf water potential varied from -0.41 MPa (6:00 to 12:00) and -0.4315 MPa (12:00 to 18:00), indicating a greater water replacement after noon (Figure 3B). However, when comparing the average leaf water potentials of -2.18, -2.39, -2.521, -2.60, -2.57, -2.33 and -2.17 MPa at the different measurement times, no statistical difference was found between the leaf water potentials at 8:00, 10:00, 12:00 and 14:00. The leaf water potentials at 6:00 and 18:00 were statistically similar, but differed significantly from those recorded between 10:00 and 14:00, with the lowest value observed at 11:51 (Figure 3).

Considering the irrigation depth treatments (50, 75, 100 and 125 % of the water required to reach the field capacity), the lowest leaf water potentials were recorded at different times: -2.687 MPa at 12:37 for 50 %; -2.579 MPa at 12:08 for 75 %; -2.52 MPa at 11:21 for 100 %; and -2.55 MPa at 11:19 for 125 %. Between 08:30 and 09:00, the leaf water potentials were similar across the treatments; from that point onward, differences emerged, with 50 % showing the lowest values (Figure 4).

Two relevant findings stand out: the difference in the leaf water potential between the 50 and both 75 and 100 % treatments increased after 08:30, reaching peak values between 13:30 and 14:30, with average differences of -0.116 MPa (50-75 %) and -0.188 MPa (50-100 %); and in the 50 and 75 % treatments, the leaf water potential at 18:00 was lower than at 6:00, particularly for 50 %. In contrast, the opposite trend occurred in the other treatments, especially for 125 %, which showed a substantial increase in the water potential by 18:00. Thus, papaya is sensitive to water stress, what triggers prolonged physiological responses that can reduce fruit yield and quality.

Papaya plants maintain a higher stomatal conductance under mild water stress, when compared to severe stress conditions, resulting in greater carbon assimilation (Campostrini & Glenn 2007). Yet, moderate water stress, driven by atmospheric vapor pressure deficits during the hottest part of the day (around noon), should be mitigated. Reis & Campostrini (2011) demonstrated that micro-sprinkler irrigation can reduce leaf temperature and improve gas exchange, whereas plants under natural conditions experienced a 13 % decline in photosynthetic carbon assimilation at midday.

This midday depression in photosynthesis is associated with increased photon flux density on

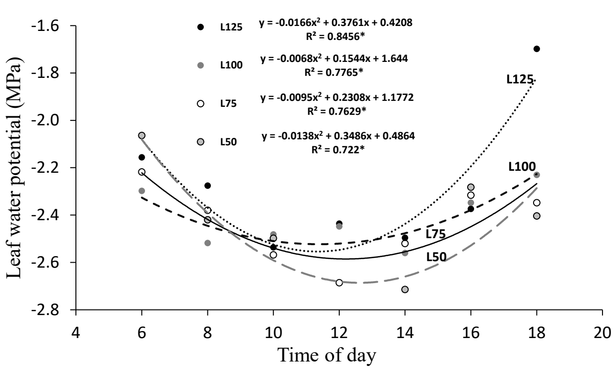

Figure 4. Leaf water potential of the 'Sunrise Solo' papaya as a function of irrigation depths [50 (L50); 75 (L75), 100 (L100) and 125 % (L125) of the depth required to reach the field capacity] and measurement times.

upper leaves and elevated air temperatures, leading to higher vapor pressure deficits at the leaf-air interface and, consequently, reduced stomatal conductance (Campostrini & Glenn 2007). However, papaya plants under water stress (50 % irrigation depth) began to exhibit stress symptoms as early as 08:30, as indicated by the leaf water potential. At 09:33, the values for the 100 and 125 % treatments were equal, while the difference between 50 (-2.557 MPa) and 100 % (-2.498 MPa) reached approximately -0.06 MPa. Leaf water potentials below -2.5 MPa at this time may serve as a reliable indicator of water stress.

Papaya exhibits anisohydric behavior, showing wide daily fluctuations in the leaf water potential driven by variations in stomatal conductance, maintaining low tissue water potential during peak temperature periods. In a study of physiological traits and water relations in two juvenile papaya genotypes, water stress reduced the leaf water potential, relative water content and stomatal conductance in both varieties, thus confirming the anisohydric behavior (Torres Netto 2005).

Pre-dawn measurements of leaf water potential typically show higher values across various cropping systems. In contrast, the lowest midday water potentials observed in coffee plants grown under full sun were significantly lower than pre-dawn values and reaching approximately -3.0 MPa (Oliveira et al. 2006).

Significant differences in papaya leaf water potential were observed across the different dates and times: November 8, 2019; December 3, 2019; and January 22, 2020, at 08:00 (Figure 5A) and 14:00 (Figure 5B). On November 8, 2019, the lowest average values were -2.39 MPa at 08:00 and -2.57 MPa at 14:00. However, no statistical difference was detected, when compared to November 3, 2019, at 14:00. These findings suggest that the high evaporative demand in November negatively impacted the leaf water potential, resulting in lower values than those recorded in December and January.

Martins et al. (2010) evaluated the leaf water potential in corn under water deficit and reported that variations across the assessed days were likely driven by atmospheric evaporative demand, influenced by the vapor pressure deficit.

The leaf water potential on January 22, 2020, differed statistically from the other dates, showing the highest averages of -1.27 and -0.89 MPa at 8:00 and 14:00, respectively. The leaf water potential increased significantly over the months: from -2.39 to -1.27 MPa at 8:00 h, and from -2.5725 to -0.89 MPa at 2:00, between November 03, 2019, and January 22, 2020, respectively. These findings suggest that the rainfall in January increased the papaya leaf water potential at different times of the day.

Papaya trees are highly sensitive to soil moisture deficits, with water availability being a key factor influencing their growth (Martins & Costa 2003). Rainfall events during the experiment directly influenced the leaf water potential in the region. Rainfall months significantly reduced the ambient temperature and increased the soil water availability, lowering evapotranspiration demands and increasing the leaf water potential, which was overestimated during rainfall periods; therefore, it should not be used as an indicator of water deficit in papaya plants during these times. For instance, Rezende et al. (2009) observed that, in the absence of rainfall, non-irrigated coffee plants (*Coffea arabica* L.)

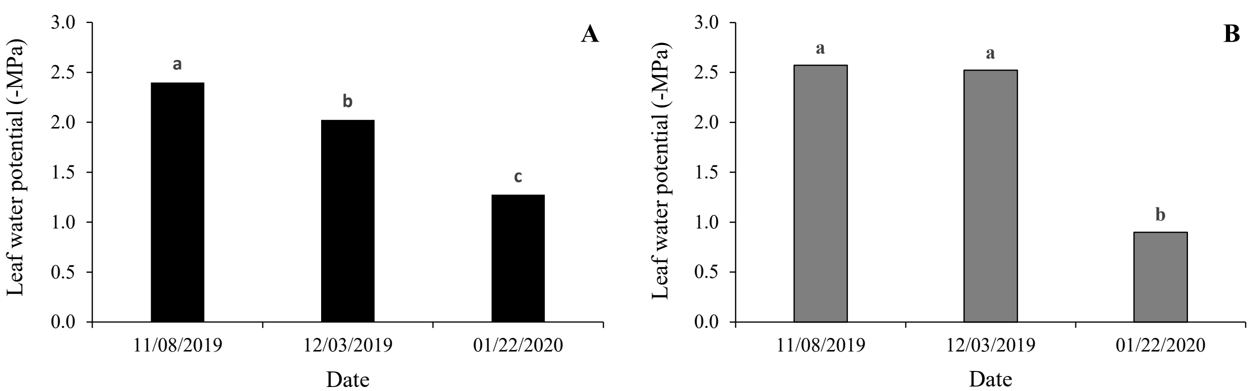

Figure 5. Leaf water potential the ‘Sunrise Solo’ papaya on different days at 8:00 (A) and 14:00 (B). Means followed by the same letter do not differ from each other by the Tukey test at 5 % of significance.

experienced a reduction in the leaf water potential, what negatively impacted flowering induction and coffee production.

CONCLUSIONS

1. The leaf water potential increased by 7.23 % from 6:00 to 18:00 with higher irrigation levels for the 'Sunrise Solo' papaya;
2. The greatest differences in leaf water potential occurred between 12:00 and 14:00, making this the optimal period for assessing water status. A threshold of -2.5 MPa can be used as a critical limit for 'Sunrise Solo' papaya;
3. The 125 % treatment showed an atypical behavior, with a sharp increase in the leaf water potential after 13:00, suggesting excess of water in the soil and highlighting the need for proper irrigation management to prevent water waste and physiological damage to the plant.

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REFERENCES

BRITO, A. S.; NEVES, P. M.; REZENDE, J. O.; MAGALHÃES, A. F. J.; SHIBATA, R. T.; COSTA, J. A. Lima da Pérsia com porta-enxerto semeado no local definitivo. *Bahia Agrícola*, v. 7, n. 1, p. 61-71, 2006.

CAMPBELL, C. S.; MCINNES, K. J. Response of *in situ* leaf psychrometer to cuticle removal by abrasion. *Agronomy Journal*, v. 91, n. 5, p. 859-862, 1999.

CAMPOS, A. J. M.; SANTOS, S. M.; NACARATH, I. R. F. F. Water stress in plants: a review. *Research, Society and Development*, v. 10, n. 15, e311101523155, 2021.

CAMPOSTRINI, E.; GLENN, D. M. Ecophysiology of papaya: a review. *Brazilian Journal of Plant Physiology*, v. 9, n. 4, p. 413-424, 2007.

CAMPOSTRINI, E.; GLENN, D. M.; YAMANISHI, O. K. Papaya: ecophysiology of growth and production. *In*: DAMATTA, F. *Ecophysiology of tropical tree crops*. Hauppauge: Nova Science, 2010. p. 287-307.

COELHO, E. F.; SANTOS, M. R.; DONATO, S. L. R.; CRUZ, J. L.; OLIVEIRA, P. M.; CASTRICINI, A. Soil-water-plant relationship and fruit yield under partial root-zone drying irrigation on banana crop. *Scientia Agricola*, v. 76, n. 5, p. 362-367, 2019.

DECAGON DEVICES. *WP4 dewpoint potentiometer operator's manual*. Pullman: Decagon Devices Inc., 2017.

FERREIRA, E. B.; CAVALCANTI, P. P.; NOGUEIRA, D. A. *ExpDes.pt*: experimental designs. R package version 1.2.0. 2018. Available at: https://CRAN.R-project.org/package=ExpDes.pt. Access on: Jan. 29, 2021.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). *Levantamento sistemático da produção agrícola*. 2023. Available at: http://www.ibge.gov.br. Access on: May. 27, 2025.

JUNTTILA, S.; HOLOPAINEN, M.; VASTARANTA, M.; LYYTIKÄINEN-SAARENMAA, P.; KAARTINEN, H.; HYYPPÄ, J.; HYYPPÄ, H. The potential of dual-wavelength terrestrial lidar in early detection of *Ips typographus* (L.) infestation: leaf water content as a proxy. *Remote Sensing of Environment*, v. 231, e111264, 2019.

LAMAOUI, M.; CHAKHCHAR, A.; KHARRASSI, Y.; WAHBI, S.; MODAFAR, C. Morphological, physiological, and biochemical responses to water stress in melon (*Cucumis melo*) subjected to regulated deficit irrigation (RDI) and partial rootzone drying (PRD). *Journal of Crop Science Biotechnology*, v. 21, n. 4, p. 407-416, 2018.

LIBARDI, P. L.; MOTA, J. C. A.; ASSIS JÚNIOR, R. N.; BRITO, A. S.; AMARO FILHO, J. Water balance components in covered and uncovered soil growing irrigated muskmelon. *Revista Brasileira de Ciência do Solo*, v. 39, n. 5, p. 1322-1334, 2015.

LIMA, R. S. N.; FIGUEIREDO, F. A. M. M.; MARTINS, A. O.; DEUS, B. C. S.; FERRAZ, T. M.; GOMES, M. M. A.; SOUSA, E. F.; GLENN, D. M.; CAMPOSTRINI, E. Partial rootzone drying (PRD) and regulated deficit irrigation (RDI) effects on stomatal conductance, growth, photosynthetic capacity, and water-use efficiency of papaya. *Scientia Horticulturae*, v. 183, n. 1, p. 13-22, 2015.

LIMA, R. S. N.; GARCÍA-TEJERO, I.; LOPES, T. S.; COSTA, J. M.; VAZ, M.; DURÁNZUAZO, V. H.; CHAVES, M.; GLENN, D. M.; CAMPOSTRINI, E. Linking thermal imaging to physiological indicators in *Carica papaya* L. under different watering regimes. *Agricultural Water Management*, v. 164, n. 1, p. 148-157, 2016.

LOPES, N. F.; LIMA, M. G. S. *Fisiologia da produção*. Viçosa: Ed. UFV, 2015.

MARENGO, J. A.; CUNHA, A. P.; ALVES, L. M. A seca de 2012-15 no semiárido do Nordeste do Brasil no contexto histórico. *Revista Climanálise*, v. 3, n. 1, p. 49-54, 2016.

MARTINS, D. S.; COSTA, A. F. S. *A cultura do mamoeiro*: tecnologias da produção. Vitória: Encaper, 2003.

MARTINS, J. D.; CARLESSO, R.; KNIES, A. E.; OLIVEIRA, Z. B.; BROETTO, T.; RODRIGUES, G. J. Potencial hídrico foliar em milho submetido ao déficit hídrico. *Irriga*, v. 15, n. 3, p. 324-334, 2010.

MEDEIROS, R. L. S.; NUNES, J. A.; LEAL, L. Y. D.; SANTOS, M. A.; MONTENEGRO, A. A. D.; SOUZA, E. R. Gas exchange dynamics and leaf water potential in sorghum intercropped with prickly pear and irrigated with reused water. *Pesquisa Agropecuária Tropical*, v. 54, e79527, 2024.

MEDEIROS, S. S.; CAVALCANTE, A. M. B.; MARIN, A. M. P.; TINÔCO, L. B. M.; SALCEDO, I. H.; PINTO, T. F. *Sinopse do censo demográfico para o semiárido brasileiro*. Campina Grande: INSA, 2012.

NASCIMENTO, D. A.; BRITO, A. S.; SILVA, L. M. N.; PEIXOUTO, L. S.; COTRIM, V. F. Water use efficiency of castor bean under semi-arid conditions of Brazil. *Agricutural Water Management*, v. 260, n. 9, p. 107278-107287, 2022.

OLIVEIRA, C. P. *Desempenho do mamoeiro com semeadura direta submetido a lâminas de irrigação no semiárido baiano*. 2021. Dissertação (Mestrado em Produção Vegetal) - Instituto Federal de Educação, Ciência e Tecnologia Baiano, Guanambi, 2021.

OLIVEIRA, C. R. M.; BARBOSA, J. P. R. A. D.; SOARES, A. M.; OLIVEIRA, L. E. M.; MACEDO, R. L. G. Trocas gasosas de cafeeiros (*Coffea arabica* L.) e seringueiras (*Hevea brasiliensis* Muell. Arg.) em diferentes sistemas de cultivo na região de Lavras, MG. *Revista Árvore*, v. 30, n. 2, p. 197-206, 2006.

R DEVELOPMENT CORE TEAM. *R*: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2024.

RAMALHO, A. R.; SOUZA, V. F.; SILVA, M. J. G.; VIEIRA JÚNIOR, J. R.; CASSARO, J. D. *Condicionantes agroclimáticas e riscos tecnológicos para cultura do mamoeiro em Rondônia*. Porto Velho: Embrapa, 2011. (Comunicado técnico, 9).

REIS, F. O.; CAMPOSTRINI, E. Microaspersão de água sobre a copa: um estudo relacionado às trocas gasosas e à eficiência fotoquímica em plantas de mamoeiro. *Revista Brasileira de Agrociência*, v. 17, n. 3-4, p. 284-295, 2011.

REZENDE, F. C.; FARIA, M. A.; MIRANDA, W. L. Efeitos do potencial de água da folha na indução da floração e produção do cafeeiro (*Coffea arabica*, L.). *Coffee Science*, v. 4, n. 2, p. 126-135, 2009.

SILVEIRA, F. G. F.; SOUZA JÚNIOR, J. O.; SOUZA, L. S.; BRITO, A. S.; PAIVA, A. Q.; PEREIRA, B. L. S.; SANTOS, E. B.; SILVA, E. F.; LIMA, J. C. Fruit quality and nutritional analysis in 'Pêra' orange as affected by soil available water and different rootstocks. *International Journal of Environmental Science and Technology*, v. 19, n. 8, p. 7387-7398, 2022.

SOUZA, J. M. S.; SOUSA, V. F. O.; SANTOS, G. L.; SILVA, J. A.; MAIA, J. M.; BARBOZA, J. B.; COSTA, J. E. Crescimento de mamoeiro sob diferentes lâminas de irrigação e aplicação de brassinosteroide. *Diversitas Journal*, v. 6, n. 4, p. 3724-3728, 2021.

TAIZ, L.; ZEIGER, E.; MOLLER, I.; MURPHY, A. *Fisiologia e desenvolvimento vegetal*. 6. ed. Porto Alegre: Artmed, 2017.

TORRES NETTO, A. *Atributos fisiológicos e relações hídricas em genótipos de mamoeiro (Carica papaya L.) na fase juvenil*. 2005. Tese (Doutorado em Produção Vegetal) - Universidade Estadual do Norte Fluminense, Campos dos Goytacazes, 2005.

VENABLES, W. N.; RIPLEY, B. D. *Modern applied statistics with S*. New York: Springer, 2002.

VIANA, E. D. S.; REIS, R. C.; SILVA, S. C. S. da; NEVES, T. T. das; JESUS, J. L. de. Avaliação físico-química e sensorial de frutos de genótipos melhorados de mamoeiro. *Pesquisa Agropecuária Tropical*, v. 45, n. 3, p. 297-303, 2015.

YANG, C.; ZHANG, J. L.; ZHANG, G.; LU, J. W.; REN, T.; CONG, R. H.; LU, Z. F.; ZHANG, Y. Y.; LIAO, S. P.; LI, X. K. Potassium deficiency limits water deficit tolerance of rice by reducing leaf water potential and stomatal area. *Agricultural Water Management*, v. 271, e107744, 2022.

ZHU, X.; SKIDMORE, A. K.; DARVISHZADEH, R.; WANG, T. Estimation of forest leaf water content through inversion of a radiative transfer model from lidar and hyperspectral data. *International Journal of Applied Earth Observation and Geoinformation*, v. 74, suppl. 1, p. 120-129, 2019.