Ecophysiology of banana seedlings grown in different water regimes

Ecofisiologia de mudas de bananeira submetida a diferentes regimes hídricos

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ABSTRACT

Banana is one of the most cultivated fruits in tropical countries, however, the banana tree is susceptible to water deficit, with considerable physiological responses. Thus, the objective of this work was to evaluate ecophysiological parameters of seedlings of two banana cultivars grown in different water stress levels. The experiment was conducted at the State University of Maranhão in a completely randomized design with four replications, using a 2×3 factorial arrangement consisting of two banana cultivars (Pacovan-Ken, and Fhia-18) and three water regimes (0%, 67%, and 100% of the field capacity). The cultivar Pacovan Ken showed better adaptation to the water stress conditions, and presented less damages to the photosynthetic apparatus of the plants, which may be related to the higher canopy cooling capacity of plants of this cultivar.

Keywords: Musa spp., water deficit, chlorophyll, fluorescence.

RESUMO

A bananeira, uma das frutíferas tropicais mais cultivadas, é uma espécie suscetível ao déficit hídrico e apresenta considerável resposta fisiológica à escassez de água. Dessa forma, este estudo objetivou avaliar o comprometimento ecofisiológico de mudas de duas cultivares de banana sob diferentes níveis de estresse hídrico. O experimento foi conduzido na Universidade Estadual do Maranhão, em delineamento inteiramente casualizado, em esquema fatorial 2 x 3 com quatro repetições. Os tratamentos consistiram de duas cultivares de bananeira: Pacovan Ken e Fhia 18 e três regimes hídricos (0%, 67% e 100% CC), totalizando seis tratamentos. A cultivar Pacovan Ken mostrou ser melhor adaptada às condições do estresse hídrico aplicado, com danos mais tardios à integridade do aparato fotossintético das plantas, o que pode estar relacionado ao fato dessa cultivar apresentar maior capacidade de refrigeração do dossel.

Palavras-chave: Musa spp., déficit hídrico, clorofila, fluorescência

INTRODUCTION

The banana tree (Musa spp.) is one of the most cultivated perennial fruit species in tropical countries; its fruits have good organoleptic characteristics and are the fifth most consumed and traded product from agricultural crops (Singh et al., 2016). Banana farming has been important for the economy, generating direct and indirect jobs, and is a relevant source of income for both large and small farmers (Salomão et al., 2016).
According to Faostat (2014), 72% of world banana production is from India, followed by China, the Philippines, Ecuador, Indonesia, and Brazil. In Brazil, banana crops produce approximately 6.9 million Mg per year, in an area of 481 thousand hectares (yield of 14.35 Mg ha⁻¹). Banana is present all over Brazil, with a consumption per capita of approximately 25 kg per year (Gasparotto & Pereira, 2010; Mendonça et al. 2013).

Banana crops need high amount of water; their growth and productivity tend to increase proportionately with increasing transpiration, which depends on water availability. In environments with water deficits, the plant growth reduces due to reduced leaf area and stomatal conductance, which limits photosynthetic assimilation of CO₂ (Oliveira et al., 2013).

The amount of water transpired by leaves of banana, and most crops, in hot days with intense solar radiation is higher than the amount absorbed by the roots and transported by the xylem, causing a temporary water deficit, even when there is water available in the soil (Marenco and Lopes, 2007).

Partial closure of stomata avoids excessive dehydration and water imbalances in the epidermis of the leaves, reducing photosynthetic CO₂ assimilation (Levy, 1980; Medina and Machado, 1999; Machado et al., 2002; Ribeiro and Machado, 2007; Ribeiro et al., 2009).

According to Ravi et al. (2013), considering the forecasted increase in drought and thermal stresses, increasing banana production is feasible only through improvements in technology and cultivars for environments with limited water availability, using genotypes that are more efficient in water use and present improved physiological functions, such as osmotic adjustment.

Banana tolerance to abiotic stress, normally found in producing areas, is important when adopting genetic improvement and management strategies to increase crop productivity (Donato and Arantes, 2009). The use of cultivars that are more tolerant to water deficit is essential to reduce water and nutrient losses, considering the current agricultural production systems (Donato et al., 2015).

In this context, the objective of this work was to evaluate ecophysiological parameters of seedlings of two banana cultivars grown in different water stress levels, considering the plants’ photochemical efficiency and leaf greenness index responses.

**MATERIAL AND METHODS**

**Plant material and growing conditions**

The experiment was conducted in a greenhouse of the Agronomic Biotechnology Center of the State University of Maranhão (UEMA), in São Luís MA, Brazil, in July and August 2017. Seedlings of two banana (Musa spp.) cultivars (Pacovan-Ken, and Fhia-18) from a six-year old banana crop were used.

The seedlings were transplanted to 20-liter plastic pots, containing 15 kg of soil from the 0-20 cm layer of an arenic dystrophic Red Yellow Argissolo (Ultisol) of sandy-loam texture (Santos et al., 2013). The plants were irrigated daily, and the water regimes of 0%, 67%, and 100% of the field capacity (FC) were established using different water depths from 13 days after transplanting of the seedlings to each pot.

The water regimes were controlled by monitoring the weight of the pots (soil, plant, and pot) of the replication 1 of each treatment. Soil moisture was monitored using two moisture sensors connected to an automatic station (datalogggers).

The weights of the pots were uniformized after transplanting the seedlings to keep the soil at a constant field capacity. The seedlings were irrigated manually and the weights of the pots were adjusted daily to the gravimetric water content established as field capacity due to the growth of the plants. The pots were weighed daily and the soil moisture was reestablished on a weight basis to the established moisture.

The experiment was conducted in a completely randomized design with four replications, using a 2×3 factorial arrangement, consisting of two banana cultivars (Pacovan-Ken, and Fhia-18) and three water regimes (0%, 67% and 100% FC). Analyses were carried out with measurements repeated over time every seven days in a seven-week period.
The experimental plot consisted of one pot, totaling 24 plots in the experiment.

The data were subjected to analysis of variance by the F test. Means were compared by the Tukey’s test at 5% probability level, using the SAEG 9.1 program.

**Evaluation of Ecophysiological parameters**

The ecophysiological parameters in the intermediate region of fully expanded leaves grown in full sun were evaluated weekly for seven weeks.

Photochemical efficiency of three leaves per plant was evaluated three times a day (8:00 a.m., 12:00 p.m. and 4:00 p.m.). The photochemical efficiency was evaluated using a non-modulated Pocket-PEA Fluorometer (Hansatech Instruments Ltd, King’s Lynn, Norfolk, UK).

The saturation pulse method was used for measuring the initial ($F_0$) and maximum (Fm) fluorescence after a dark period; variable fluorescence ($F_v$), which is equal to Fm-$F_0$; and the potential quantum efficiency of photosystem II ($F_v/F_m$).

Simultaneously, the greenness index (SPAD value) of the leaves of the same plants was evaluated using a SPAD-502 chlorophyll meter (Minolta, 1989). Five points of each leaf were read, according to the method of Swiader and Moore (2002).

**RESULTS AND DISCUSSION**

The initial fluorescence ($F_0$) of the Fhia-18, and Pacovan-Ken cultivars presented no statistical difference, although it was high in both cultivars. According to Baker and Rosenqvist (2004), a high $F_0$ denotes destruction of the photosystem II (PSII) reaction center, or decrease in transfer capacity of the excitation energy from the antenna to the reaction center (Table 1).

High water stresses can be caused by nonstomatal factors, such as reduction of activity and concentration of the ribulose 1,5-bisphosphate carboxylase/oxygenase (RuBisCO) enzyme, photoinhibition, electron transfer rate, and reduction of the photochemical efficiency of PSII, which may decrease or inhibit photosynthesis (Flexas and Mendrano, 2002; Lawlor, 2002; Lawlor and Cornic, 2002; Grassi and Magnani, 2005).

The $F_0$ varied over time, however, with no significant effects of the different water regimes tested on either of the two cultivars (Table 1).

Plants of the Fhia-18 cultivar that were not irrigated had increasing $F_0$ over time, with a total increase of 70%, indicating a higher water stress when compared to those irrigated with 67% or 100% FC. The Pacovan-Ken cultivar was more tolerant to water stress than the Fhia-18 cultivar (Table 1).

### Table 1 - Initial fluorescence ($F_0$) as a function of water regimes of 0%, 67%, and 100% of the field capacity (%FC) for banana cultivars (Pacovan-Ken, and Fhia-18)

<table>
<thead>
<tr>
<th>Water Regime (%FC)</th>
<th>Weeks</th>
<th>$F_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fhia-18</td>
<td>0</td>
<td>6302 aC</td>
</tr>
<tr>
<td>67</td>
<td></td>
<td>6852 aA</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>6963 aA</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacovan-Ken</td>
<td>0</td>
<td>6742 aA</td>
</tr>
<tr>
<td>67</td>
<td></td>
<td>6028 aA</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>6488 aA</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same uppercase letter in the rows and lowercase letter in the columns do not differ statistically by the Tukey’s test at 5% probability.
Plants developed in soils of sandy texture, such as the arenic dystrophic Red Yellow Argisol (Ultisol) used, do not require low water potential to exhaust the soil available water, as shown by the Fhia-18 cultivar. Sandy soils may provide higher conductivity and soil moisture loss because water is less retained in larger capillaries (Hacke et al., 2000).

The Pacovan-Ken cultivar presented the highest mean maximum fluorescence (Fm) in the water regimes of 0% and 67% FC (Table 2). Strasser et al. (2010) evaluated the fluorescence of chlorophyll $a$ in plants under stress and found a decrease in Fm in plants subjected to UV-C radiation, indicating the weakness of the PSII in reducing plastoquinone A (QA), which is the primary electron acceptor.

The Fm results indicated that the two cultivars had different responses to the water regimes used (Table 2). The Fm of the Fhia-18 cultivar was more stable over time in the treatment with 100% FC, while the Pacovan-Ken cultivar had the best results in the treatment with 67% FC, statistically differing from the other treatments, which showed a decrease in Fm.

Plants subjected to water deficit presented reductions in Fm, which were more expressive in plants subjected to water regime of 0% FC (Table 2). Reductions in Fm indicate problems of the PSII in reducing QA (Strasser et al., 2004).

The Fm of the Fhia-18 cultivar in the treatment with 100% FC differed from the other treatments (0, and 67% FC) from the third day evaluated. The Fm of plants of the Pacovan-Ken cultivar in the treatment with 67% and 100% FC differed from that of plants in the treatment with 0% FC, and remained more constant, varying less over time, showing better adaptation to water stress conditions (Table 2).

According to Larcher (2004), the plant can undergo a repair period depending on its potential for response, and intensity and duration of stress, and can normalize even under continuous stress due to a better stability.

Fv/Fm was higher for the water regimes of 67% and 100% FC; plants in the water regimes of 0% FC presented Fv/Fm below 0.75 (Table 3), indicating damages in their photosynthetic apparatus due to stress caused by low water availability. Both banana cultivars presented Fv/Fm from 0.77 to 0.80 in the treatments with 67% and 100% FC (Table 3), denoting a good functioning of the photosynthetic apparatus.

According to Bolhár-Nordenkampf et al. (1989), when the photosynthetic apparatus of the plant is intact, the Fv/Fm ratio is 0.75 to 0.85. A decrease in this range means photoinhibition damage to PSII reaction centers.

According to Silva et al. (2007), the ability of a plant in maintaining a high Fv/Fm under water stress conditions indicates that it maintains high efficiency in using solar radiation and carbon assimilation, and a better water use efficiency.

### Table 2: Maximum fluorescence (Fm) as a function of water regimes of 0%, 67%, and 100% of the field capacity (%FC) for banana cultivars (Pacovan-Ken, and Fhia-18)

<table>
<thead>
<tr>
<th>Water regime (%FC)</th>
<th>Weeks</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fhia-18</td>
<td></td>
<td>0</td>
<td>35894 aA</td>
<td>33491 aB</td>
<td>32921 bBC</td>
<td>32250 aBC</td>
<td>32199 aBC</td>
<td>31999 bBC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>67</td>
<td>33955 bA</td>
<td>32859 aAB</td>
<td>32682 bAB</td>
<td>32046 bB</td>
<td>32390 aAB</td>
<td>32230 bAB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>35297 aAB</td>
<td>34157 aAB</td>
<td>34634 aAB</td>
<td>35396 aAB</td>
<td>35500 aB</td>
<td>34890 aAB</td>
</tr>
<tr>
<td></td>
<td>CV%</td>
<td>2.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacovan-Ken</td>
<td></td>
<td>0</td>
<td>38557 aA</td>
<td>37999 aAB</td>
<td>37250 aB</td>
<td>37293 aAB</td>
<td>36939 aBC</td>
<td>35718 aC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>67</td>
<td>35511 bA</td>
<td>35778 bA</td>
<td>35385 bAB</td>
<td>34114 bBC</td>
<td>34849 bABC</td>
<td>34681 bABC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>39347 aA</td>
<td>38248 aAB</td>
<td>37912 aB</td>
<td>37283 aAB</td>
<td>37274 aBC</td>
<td>36175 aCD</td>
</tr>
<tr>
<td></td>
<td>CV%</td>
<td>1.64</td>
<td></td>
<td></td>
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</tbody>
</table>

Means followed by the same uppercase letter in the rows and lowercase letter in the columns do not differ statistically by the Tukey’s test at 5% probability.
The treatments with 67% and 100% FC resulted in the highest Fv/Fm for both cultivars (Table 3), which were not affected by the water stress. When the PSII is not affected by water stress, the plant has in general high efficiency in solar radiation use due to carbon assimilation reactions (Silva et al., 2007).

Plants of the both cultivars in the treatments with 67% and 100% FC presented similar Fv/Fm (Table 3), with small reductions over time, which was probably due to their response to water stress. The photosynthetic apparatus of plants in the treatments with 0% FC was damaged by the water stress, presenting Fv/Fm below 0.75. These plants were possibly on oxidative stress.

Decreases in Fv/Fm indicate photoinhibition damage when plants are subjected to environmental stresses, including water deficit and cold (Baker et al., 1983; Ögren and Öquist, 1985; Campostrini, 2001). Variations in Fm denote variations in properties of PSII electron receptors due to stress-induced conformational changes in the main constituent of the protein complex that forms the PSII, the D1 protein (Bulkhov et al., 1999).

According to Krause and Weis (1991), environmental stresses decrease potential quantum efficiency of PSII, which can be detected by decreases in Fv/Fm due to the lower photochemical efficiency. This can cause reduction in the activity of some Calvin cycle enzymes, and changes in biochemical pathways, such as accumulation of amino acids and organic acids (Wright et al., 1995).

The Fhia-18, and Pacovan-Ken cultivars presented higher greenness index in the water regime of 100% FC; and the Fhia-18 cultivar had a greater chlorophyll degradation (Table 4). Chlorophyll degradation is a consequence of the water stress, which results in decreases in leaf greenness (Long et al., 1994).

The highest greenness index of the Pacovan-Ken, and Fhia-18 cultivars were found in plants subjected to the water regime of 100% FC (Table 4). Plants in the treatments with 0% and 67% FC had marked degradation of photosynthetic pigments, and possible mobilization of mobile nutrients, especially nitrogen, because of the lower water availability, since they are necessary to maintain the turgidity, and biochemical processes of the leaf. However, the Pacovan-Ken cultivar always presented higher mean greenness index when subjected water stress.

Plants under water deficit are usually characterized by loss of chlorophyll and a progressive decrease in photosynthetic capacity of plants. Thus, the analysis of photosynthetic pigments is important to evaluate the health and integrity of the internal apparatus of the plant cells responsible for the photosynthesis process (Rong-Hua et al., 2006).

Carvalho et al. (2005) evaluated the soil water availability and the growth of Tanacetum parthenium L. and found decreases in leaf chlorophyll contents (SPAD values) in plants subjected to water deficit over time, regardless of the water deficit level.

### Table 3 - Photochemical efficiency (Fv/Fm) as a function of water regimes of 0%, 67%, and 100% of the field capacity (%FC) for banana cultivars (Pacovan-Ken, and Fhia-18)

<table>
<thead>
<tr>
<th>Water regime (%FC)</th>
<th>Weeks</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fv/Fm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fhia-18</td>
<td>0</td>
<td>0.79 aA</td>
<td>0.79 aA</td>
<td>0.77 aAB</td>
<td>0.74 aABC</td>
<td>0.69 aBC</td>
<td>0.67 aBC</td>
<td>0.45 bD</td>
</tr>
<tr>
<td></td>
<td>67</td>
<td>0.80 aA</td>
<td>0.76 aA</td>
<td>0.76 aA</td>
<td>0.79 aA</td>
<td>0.76 aA</td>
<td>0.76 aA</td>
<td>0.73 aA</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.83 aA</td>
<td>0.80 aA</td>
<td>0.79 aA</td>
<td>0.77 aA</td>
<td>0.77 aA</td>
<td>0.76 aA</td>
<td>0.75 aA</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>6.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacovan-Ken</td>
<td>0</td>
<td>0.80 bA</td>
<td>0.78 bA</td>
<td>0.76 aA</td>
<td>0.68 bB</td>
<td>0.56 bC</td>
<td>0.60 bC</td>
<td>0.50 bD</td>
</tr>
<tr>
<td></td>
<td>67</td>
<td>0.80 bA</td>
<td>0.80 abA</td>
<td>0.79 aA</td>
<td>0.79 aA</td>
<td>0.78 aA</td>
<td>0.76 aA</td>
<td>0.74 aA</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.86 aA</td>
<td>0.83 aAB</td>
<td>0.81 aABC</td>
<td>0.78 aBC</td>
<td>0.79 aBC</td>
<td>0.76 aC</td>
<td>0.77 aBC</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>3.75</td>
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</table>

Means followed by the same uppercase letter in the rows and lowercase letter in the columns do not differ statistically by the Tukey’s test at 5% probability.
Similarly, Nautiyal et al. (1996) found rapid reductions in the chlorophyll content in *Pongamia pinnata* plants subjected to water stress caused by irrigation intervals equal to or greater than 30 days. Thus, longer periods of drought can cause degradation of chlorophyll in plants, even when they are under a moderate water stress.

Silva et al. (2014) evaluated responses of sugarcane cultivars subjected to different water deficit intensities and found that the SPAD value can be used to differentiate cultivars and select tolerant cultivars to water stress in breeding programs.

### Table 4 - Greenness index (SPAD value) as a function of water regimes of 0%, 67%, and 100% of the field capacity (%FC) for banana cultivars (Pacovan-Ken, and Fhia-18)

<table>
<thead>
<tr>
<th>Water regime (%CC)</th>
<th>Weeks</th>
<th>SPAD value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fhia-18</td>
<td>0</td>
<td>37.5 bA</td>
</tr>
<tr>
<td></td>
<td>67</td>
<td>38.4 bA</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>42.4 aA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacovan-Ken</td>
<td>0</td>
<td>39.9 cA</td>
</tr>
<tr>
<td></td>
<td>67</td>
<td>42.8 bA</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>47.4 aA</td>
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</table>

Means followed by the same uppercase letter in the rows and lowercase letter in the columns do not differ statistically by the Tukey’s test at 5% probability.

### CONCLUSIONS

Photochemical efficiency parameters, and greenness index are efficient for differentiating cultivars and selecting the more tolerant ones to a specific water stress.

Photochemical efficiency parameters, and greenness index are affected by water regimes.

Plants of the Pacovan-Ken cultivar are better adapted and more tolerant to water stress, maintaining longer the integrity of their photosynthetic apparatus.

### REFERENCES


