

Original Research Article

Deficit Irrigation with Controlled Water Stress and its Effects on Physiology and Phenology of 'Navelate' Oranges in Brazil

ABSTRACT

Aims: The aim of this research was to study physiological responses and changes on phenology of 'Navelate' orange trees submitted to different intensities of water stress in greenhouse.

Study design: The experimental design was completely randomized, with three replications in each experimental unit. Values of each parameter was submitted to analysis of variance, compared by Tukey's test at 5.% significance and showed as average.

Place and Duration of Study: The experiment was carried out in a greenhouse (latitude 31°52'00 "S, longitude 52°21'24" W, 13 m above sea level), during 2014 and 2015.

Methodology: Stressed conditions were based on 50_% and 25_% of the field capacity. Gas exchange [photosynthesis (A), transpiration (E), stomatal conductance (gs), water use efficiency (WUE)] were analyzed using an infrared gas analyzer model Li-6400 (Portable Photosynthesis System LICOR, Nebraska, USA) in addition to growth parameters.

Results: It was observed reductions on photosynthetic rate (10.74% for T-50, and 20.66% for T-25, both compared to Control), indicating that CO₂ assimilation rate were affected by water stress conditions. Water stress affected all gas exchange parameters of the exposed orange trees, limiting growth in diameter and height. Fruit yield decreased with the amount of water (100%> 50%> 25%).

Conclusion: Navelate orange plants exposed to water deficit were tolerant in the initial phase of treatments and during the vegetative phase, being more sensitive in the reproductive period. Plants submitted to stress with 25.% of field capacity, presented limitations compared to control plants under full water availability, such as differences in height, diameter and fruit production. Water stress, at any level, reduced both plant growth and fruit production. Therefore, due to variations in phenological parameters among the treatments, it indicates that further studies should be performed on these variables to search for water deficit tolerant varieties and quality fruits production under these conditions.

Keywords: water stress; *Citrus sinensis*; gas exchange; photosynthesis; fruit production.

1. INTRODUCTION

Orange is a fruit of great importance in Brazil, the country is the world's largest orange producer with, producing 16,240,000 tons/yr., Other largest orange producing countries being show high orange production, such as China and India with respectively which has the second largest production 7,823,550 tons, and India which holds the third largest production and 7,313,610 tons/yr [1]. Approximately 70_% of orange production in Brazil is provided by belongs to São Paulo state, with which produces about 11,628,150 tons/yr. and Rio Grande do Sul is the fifth largest orange producing state with, state orange production is 399,296 tons/yr [2].

Water stress is one of the most frequent environmental factor which limits orange (*Citrus sinensis*) crop expansion in several places around the world. This water deficit can be resulted from by an excessive soil water deficit or by an excessive water loss by transpiration in relation to water absorption by root system. In trees, a high evaporative demand of atmosphere promotes enhances high transpiration rates, influencing water potential of leaves because of low hydraulic conductivity of root system [3].

Study of physiological parameters, such as photosynthetic rates, transpiration rates, and stomatal conductance are very important to evaluate drought tolerance in several plant species by elucidating changes on both production and quality of fruits. Citrus under several water stress close their stomata

in order to reduce water loss through transpiration. Those plants can also limit CO₂ diffusion to sub-stomatal cavity, resulting in reduction of photosynthetic rate and increase of foliar temperature [4]. Southern Brazil, as one of orange producing which is one of production areas of oranges is submitted to a, have subtropical climate with low temperatures during winter season and both warm and rainy during summer season [5]. Under these conditions, it seems to be necessary to study about citrus crop response to water stress, analyze how to choose a better water management during drought season and because of worldwide climate changes. Evaluation of gas exchange and water state of citrus plants can indicate the best conditions to keep both water and carbon balance during dryought season in this region.

The objective of this work was to analyze physiological responses and phenologically changes in 'Navelate' orange trees submitted to water stress conditions.

2. MATERIAL AND METHODS

The experiment was conducted in greenhouse of Fruit Crop Sector, Federal University of Pelotas, Brazil (Latitude 31°52'00" S; Longitude 52°21'24" W; altitude 13 m). The climate of this region is Cfa, according to Köppen-Geiger climate classification.

Evaluations were done between March 2014 and March 2015 in 'Navelate' orange trees. Young plants were obtained from commercial nurseries and cultivated in 26 L pots, and received same irrigation amount during acclimation period of 45 days. After this period, plants received distinct different water management treatments: control (substrate humidity corresponding 100% of field capacity), T-50 (substrate humidity corresponding 50% of field capacity), and T-25 (substrate humidity corresponding 25% of field capacity).

Gas exchange analyzes, growth measurement, and phenology evaluations were done after acclimation period, monthly during 210 days from August 2014 until March 2015.

Gas exchange analyzes were done according to following parameters: photosynthetic rate (A), transpiration rate (E), stomatal conductance (gs), and internal CO₂ concentration (Ci). Evaluations were done by using an infrared gas analyzer model Li-6400 (Portable Photosynthesis System LICOR, Nebraska, USA), with a photosynthetic active radiation intensity of 1200 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, measured in previously selected completely expanded leaves. The evaluations were recorded when the coefficient of variation (CV) was less than 0.5% and in temporal stability. Water use efficiency ($\text{WUE } \mu\text{mol mol}^{-1}$) and intrinsic water use efficiency ($\text{WUE}_{\text{intr}} \text{ mmol mol}^{-1}$) were calculated according to following equations: $\text{EUA } (\mu\text{mol CO}_2 \text{ mmol}^{-1} \text{ H}_2\text{O}) = \text{Photosynthesis} / \text{Transpiration}$, and $\text{WUE}_{\text{intr}} (\mu\text{mol CO}_2 \text{ mmol}^{-1} \text{ H}_2\text{O}) = \text{Photosynthesis} / \text{Stomatal Conductance}$, respectively.

The plant height (cm) was evaluated, adopting, as criterion, the graft distance until the terminal shoot of the main branch; the trunk diameter of the plants was determined 5 cm above the graft, using a scale and a digital caliper, respectively.

The experimental design was a randomized complete blockly randomized, with three replications in each experimental unit. Values of each parameter was submitted to analysis of variance, compared by Tukey's test at 5% significance and showed as average.

3. RESULTS AND DISCUSSION

During this experiment, it was not observed changes on gas exchange and plant phenology until 100 days after started treatments of controlled water stress (Figure 1A). After this period, it was observed reduction in this parameter according to the treatments: T-25 < T-50 < Control.

Changes were also observed in water use efficiency (Figure 1E), leaf temperature (Figure 1D), and vapor pressure deficit (Figure 1F) in plants submitted to controlled water deficit in comparison to control plants.

Internal CO₂ concentrations, in general, followed gas exchange, showing values lower than the control. Capacity to maintain physiological activity throughout reduction of water availability result in

some consequences, such as changes on gas exchange. In fact, it was observed changes on photosynthetic rate and reductions on stomatal conductance in plants submitted to higher deficit of atmospheric vapor pressure. This lower level of stomatal opening, which occurred in plants submitted to water stress, was a consequence of reduction of turgor pressure of cells, a higher deficit of atmospheric vapor pressure, or by chemical signals coming from root system [6,7].

Ramos and co-workers [8] observed that metabolism of orange plants were strongly affected by thermal regime, resulting in physiological changes related to photosynthesis, exportation of photoassimilates, and photosynthetic pigments, which changed both fruit development and composition. Therefore, exposition of orange plants to temperatures higher than optimal can result in reduction of both photosynthesis rate and carbohydrate metabolism. Reduction in CO₂ assimilation can be resulted as a consequence of closing the stomatal pores, and also because of possible photochemical damages in photosynthetic membranes [9]. Increase of air temperature, and consequently increase of leaf temperature, promoted a reduction on photosynthetic rate because of increase on respiration rate [10,11].

Results obtained from this work corroborated with findings of Pedroso and co-workers [12], related to which found substantial suppression on gas exchange in plants submitted to water stress. According to these authors, water deficit resulted in proline accumulation in leaves, reduction on water potential, stomatal conductance, respiration rate, CO₂ assimilation, and mass accumulation. This reduction on photosynthetic activity caused due to water stress occurred at the same time of as reduction on decrease of in turgor pressure [13].

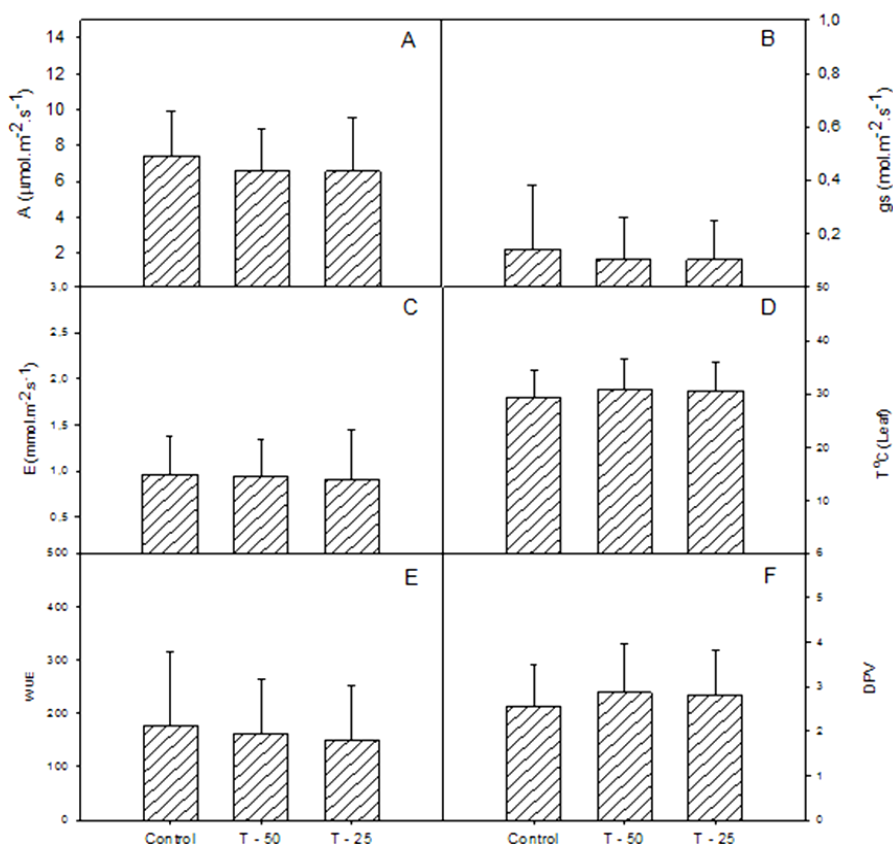


Figure 1. Photosynthetic rate (A), stomatal conductance (B), transpiration rate (C), leaf temperature (D), water use efficiency (E), and vapor pressure deficit (F), in 'Navelate' oranges submitted to different levels of irrigation [substrate humidity corresponding 100 % (Control), 50 % (T-50), and 25 % (T-25) of field capacity], evaluated monthly from August 2014 until March 2015.

One of the first reaction of orange plants grown under severe stress can be to close the stomatal pores, in order to minimize water loss [14]. The possible reduction tendency on transpiration rate observed in all treatments coincided with significant reduction on stomatal conductance throughout the experiment (Table 1). Direct interdependence between transpiration and stomatal conductance were expected because of vapor flux reduction on atmosphere caused by closing the stomatal pores. According to Lawlor and Tezara [15], during the periods of water shortage, plants keep their stomata closed in order to maintain favorable turgor pressures, an important characteristic for drought tolerance.

Water management affected gas exchange in plants submitted to water stress. It was observed variations in photosynthetic rate, stomatal conductance and transpiration rate (Table 1).

Table 1. Average values of photosynthetic rate (A), stomatal conductance (E), transpiration rate (gs), and intrinsic water use efficiency (WUE_{intr}) in 'Navelate' oranges submitted to different irrigation treatments and irrigation levels [substrate humidity corresponding 100% (Control), 50% (T-50), and 25% (T-25) of field capacity], evaluated monthly from March 2014 until August 2014.

	A	E	gs	WUE _{intr}
Treatments	($\mu\text{mol m}^{-2}\text{s}^{-1}$)	($\text{mmol m}^{-2}\text{s}^{-1}$)	($\text{mol m}^{-2}\text{s}^{-1}$)	($\text{mmol/mol}^{\dagger}$)
Control	6.05 ^a	3.06 ^a	0.06 ^a	1.98 ^a
T-50	5.40 ^a	2.64 ^b	0.05 ^a	2.01 ^a
T-25	4.80 ^{a*}	2.41 ^b	0.04 ^{a*}	1.99 ^a

* Values followed by same letter did not differ at the 5% probability level by Tukey's test.

* Means by comparison in a column and indicates differences among treatments in different times.

Ma and co-workers [16] concluded that photosynthetic rate associated with lower stomatal conductance and transpiration rate are typically observed in plants which tolerate lower water availability, but it was not clearly observed in this experiment.

It was observed reductions on photosynthetic rate (10.74 % for T-50, and 20.766 % for T-25, both compared to Control), indicating that CO₂ assimilation rate were affected by water stress conditions (Table 1). The intrinsic water efficiency levels did not differ significantly among treated plants and control. At this time, diffusion processes are promptly reduced, and the intrinsic water efficiency levels reaches the highest values. So, under severe water stress, mesophyll cells dehydration strongly inhibits plant metabolism and photosynthesis [14]. Variations in physiological factors were not accentuated in this period probably due to the winter period and the with low temperatures and days with a small solar radiation incidence, a fact that may have limited the stomata opening, generating less pressure on the plant.

Orange plants had morphological characteristics and physiological mechanisms which give considerably tolerance to water stress when compared to other perennial plants [17], but productivity are closely related to water availability. Since the photosynthetic rates are affected by water deficit, a reduction on both carbohydrate levels and fruit weight, will which can affect fruit quality [18,19].

The organic matter accumulated in a plant came from photosynthesis, and represented 95% of its dry matter [20, 21], and around 60% are in root system in orange seedlings [22]. In this

experiment, the highest growth rate (height and trunk diameter) occurred in plants with appropriate water supply (Control) and, which had higher photosynthetic rate, when compared to plants grown under water stress (T-50 and T-25). With water restriction, plants from both T-50 and T-25 treatments showed reduction on trunk growth (diameter) and leaf expansion. These responses to acclimation limited water consumption by different tissues, helping to keep maintain plant water status of those plants [6].

With water supply reduction, the plants of treatments T-50 and T-25 present stem growth, diameter and leaf expansion inhibitions. These acclimatization responses end up limiting the expenditure of water by the tissues, helping to maintain the plant water status [6]. Figure 2 shows differences in growth among control treatment plants and those submitted to controlled water deficit.

Following changes of trunk diameter and plant height, it was also observed reduction and changes in weight and diameter of fruits produced. T-25 plants had reduction on both fruit size (50 %) and weight (90 %) compared do Control. Some authors concluded that reduction on productivity occurred when water stress occurred was applied during both flowering and fruit set stages [23, 24]. In our experiment, water deficit were applied since vegetative growth stage, but reduction on fruit production was observed in plants grown under water deficit conditions (Figure 2).



Figure 2. A - treatment T-25 plants, B - treatment T-50 plants and C - control plants. The arrow points out that control plants already produce fruits. D - overview of the experiment and presence of fruits in the control, as indicated by the arrow.

Oliveira and colleagues et al [25] found significant differences in the size and yield of 'Cabula' orange fruits submitted to water deficit when compared to control plants. The plants exposed to extreme water shortages produced fruits, but without presenting commercial characteristics.

174 Torrecillas and co-workers [26] and Domingo and colleagues [et al](#) [27] studying lemon plants during
 175 one year, submitted to irrigations based on 100% of crop evapotranspiration (ETc) and irrigated at
 176 25% of ETc did not find changes in fruit growth and yield. However, for this result to be possible, [the](#)
 177 plants with 25% ETc were irrigated with 100% ETc during the period of rapid fruit development, after
 178 the june drop, indicating that a controlled deficit can improve the efficiency of water use from water.
 179 This fact does not apply when the deficit is continuous, as observed in [this our](#) experiment.

181 Velez and colleagues [28] mentioning different authors, among then Pérez-Pérez and co-workers
 182 (2009), Ginestar and Castel (1996) and Romero and colleagues (2006) report that in citrus plants
 183 under Mediterranean climate conditions, lack of water is a limiting factor for fruit growth and
 184 production. Maotani and co-workers [29] observed that in 'Satsuma' mandarins fruit and trunk growth
 185 were more sensitive to [water](#) stress than in other [plant](#) parts of the [plant](#).

186 In [this our](#) study, following the changes in diameter and height, reductions in fruit production were
 187 also observed, T-25 plants produced fruits with size and weight reduced up to 90% [in relationas](#)
 188 [compared](#) to [those from](#) the control [treatmentplants](#) (Figure 2C). [In addition,](#) [it](#) is important to note
 189 that, in case of fruit trees, [it is important to observe](#) that there is a significant decrease in plants
 190 productivity under water deficit. [In this experiment,](#) [although](#) [the](#) water deficit was applied
 191 from the beginning of plants vegetative phase, the results were similar, [being observedin terms of](#)
 192 reductions in fruit production [to that of in the](#) plants under controlled water deficit.

193 It was found no changes on plant growth rates and production in plants irrigated with both 25% and
 194 100% of crop evapotranspiration [30]. However, those plants were irrigated with 100% of crop
 195 evapotranspiration after 'june drop' phase until stage of rapid fruit growth. [Therefore,](#) [it](#) can be
 196 concluded that a controlled water deficit can improve water use efficiency.

197 Other parameters related to plant water status

198 [such as trunk sap flow, stem diameter shrinkage or reduction](#) [\[31\]. In this context,](#) leaf
 199 temperature is another indicator of [plant](#) water stress [in plants since as](#) transpiration [aids enhances](#)
 200 leaf cooling. With [decrease in soil](#) water content [decrease in soil,](#) the transpiration decreases
 201 [whereas and the](#) leaf temperature increases in relation to the air temperature [32]. Generally, plants
 202 submitted to [soil](#) water deficit [in the soil](#) present an increase in leaf temperature [and, as stress](#)
 203 [signs,with](#) stomatal closure [as physiological signals](#) is also observed in order [not to lose maintain](#)
 204 [their water statusdue to transpiration](#) [33]. [This factor could](#)Stomatal closure, [in when](#) combination
 205 [ed](#) with other parameters [such as trunk sap flow, stem diameter shrinkage or reduction,](#) [demonstrate](#)
 206 [regulates](#) plant water status as well as a potential indicator of [in irrigation time](#) scheduling [25].
 207 Table 2 shows the differences between the height and the diameter of 'Navelate' orange trees
 208 submitted to water deficit compared to those submitted to normal irrigation conditions (field capacity).

209 **Table 2. Plant height and trunk diameter of 'Navelate' orange plants, evaluated monthly from**
 210 **March 2014 until February 2015.**

Treatments	Height (cm)	Diameter (mm)	Number of leaves
Control	174 ^a	12,23 ^a	119 ^b
T-50	168 ^{ab}	9,74 ^b	123 ^{ab}
T-25	163 ^b	8,62 ^b	127 ^a

211 * Values followed by same letter did not differ at the 5% probability level by Tukey's test.

212
 213 [The variables presented in](#) Table 2 [correspond shows levels of](#)to the water deficit intensities
 214 [studied investigated](#) and the variations in plant height and stem diameter [asare](#)
 215 [suggestedrecommended as](#) indicators of [citrus](#) water status [in citrus](#) given their sensitivity to the

substrate moisture variation [34]. As a response to water stress, the plant development is inhibited, some of the first symptoms being ggin to appear, like: leaf withering, water potencialpotential reduction, decrease in stomatal conductance decrease, reduction in CO₂ assimilation reduction and depletion in hydraulic conductivity of the root depletion [35]. Water stress affects the plant's phenological stages in different ways and intensities, affecting flower formation, fertilization and even fruit abscission, besides causing plant growth and development reductions [36].

The waterWater extracted through the root system is transported by the xylem and, being distributed through across different plant parts until before reaching the atmosphere through the transpiration process that occurs in response to the energy gradient provided by solar radiation [32]. In fact, plant growth and development is influenced by environmental factors with among them and water availability since whichit plays a vital role asbecause it intervenes in practically almost physiological and biological processes.

Finally, a global climate change can be resulted in adverse conditions to plant growth. Moreover, under such conditions they should acclimate and adapt to surviveIn the context of global warming, it is crucial to select crops adapted to growing environmental stress conditions. Resistance to water deficit in citrus plants, for example, is based on tolerance (osmotic adjustment) and prevention (stomatal control) to of water stress through , and the stomatal control as a process being highly is very developed in this genus [22, 28].

4. CONCLUSION

Navelate orange plants exposed to water deficit were tolerant in the initial phase of treatments and during the vegetative phase, being more sensitive in the reproductive period. Water stress did not cause perceptible alterations in physiology, however, phenological parameters changes were observed. Plants submitted to stress with 25 % of field capacity, presented limitations compared to control plants under full water availability, such as differences in height, diameter and fruit production. Water stress, at any level, reduced both plant growth and fruit production. Therefore, due to variations in phenological parameters among the treatments, it indicates that further studies should be performed on these variables to search for water deficit tolerant varieties and quality fruits production under these conditions.

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