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Artigo/Article

Seasonal variation in leaf gas exchange of young citrus trees

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SUMMARY

The physiological responses of plants exposed to environmental conditions allow us to infer information about the adaptive capacity in a certain region. This study aimed to evaluate the behavior of gas exchange in orange, mandarin, and hybrids in the following cultivars: Clemenules, Okitsu, Ortanique, Navelina, Navelate, and Lanelate in the first 2 years of cultivation. The experiments were conducted in a randomized block design with treatments that resulted from the factorial combination of 3 cultivars (4 evaluations in each of the seasons over 2 years). The physiological evaluations were performed using CO_2 assimilation rate, stomatal conductance, and transpiration and relation between the internal and external concentrations of CO_2. Statistical calculations were performed using univariate and canonical analysis. In autumn and winter, all orange cultivars demonstrated higher water use efficiency and lower vapor pressure deficit values, signaling an enhanced performance in low rainy seasons. In the first year of the study, the Okitsu cultivar distinguished itself as it presented variations in conductance values and internal and external carbon relationships in the summer and spring. In the second year, there was a reduction in the transpiration of all tangerine cultivars in the winter, which contributed to water efficiency in this season. The gas exchange relationships in citrus plants are lower in periods of low temperature and precipitation.

Index terms: *Citrus sp.*, photosynthesis, water use efficiency.

Variação estacional de troca de gás em folhas de plantas jovens árvores de citros

RESUMO

As respostas fisiológicas das plantas expostas às condições ambientais nos permitem inferir informações sobre a capacidade de adaptação em uma determinada região. Este estudo teve como objetivo avaliar o comportamento da troca de gás em laranja, tangerian e híbridos nas seguintes cultivares: Clemenules, Okitsu, Ortanique, Navelina, Navelate e Lanelate nos primeiros dois anos de cultivo. Os experimentos foram realizados em um delineamento em blocos ao acaso com tratamentos que resultaram da combinação fatorial de três variedades (quatro avaliações em cada uma das estações ao longo de dois anos). As avaliações fisiológicas foram realizadas com taxa de assimilação de CO_2, condutância estomática e transpiração e relação entre as concentrações internas e externas de CO_2. Os cálculos estatísticos foram realizados utilizando análise univariada e canônica. No outono e no inverno, todas as cultivares de laranjeira demonstraram maior eficiência no uso da água e menores valores de déficit de pressão de vapor, sinalizando um desempenho aprimorado em

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estações de baixa chuva. No primeiro ano do estudo, a cultivar Okitsu se distinguiu, pois apresentou variações nos valores de condutância e nas relações de carbono interno e externo no verão e na primavera. No segundo ano, houve uma redução na transpiração de todas as cultivares de tangerina no inverno, o que contribuiu para a eficiência da água nesta temporada. As relações de troca de gás em plantas cítricas são menores em períodos de baixa temperatura e precipitação.

Termos de indexação: *Citru*s sp., fotossíntese, eficiência de uso da água.

INTRODUCTION

The implantation of citrus orchards in non-irrigated areas is common in some countries. Under these conditions, plants are subject to climatic conditions and rainfall variations which, together with climatic changes and frequent periods of drought, cause inadequate water supply by limiting the growth and development of plants. Although most commercially grown citrus species adapt to various climatic conditions (Spiegel-Roy & Goldschmidt, 1996; Sentelhas, 2005), some cultivars (both scion and rootstock) are more sensitive to climatic oscillations than others (Dzikiti et al., 2011; Johnson et al., 2013).

In the early years of citrus plants organized in the orchard formation, quality plant development and the subsequent canopy formation will safeguard the sustainability of the productive period. This is one of the most critical phases in the process; it is where the climatic conditions and the peculiar characteristics of each season influence the physiological metabolism reflecting on growth and development (Machado et al., 2010).

In this sense, the physiological parameters of gas exchange have been used to evaluate the response of plants to climatic variations, mainly through CO_2 assimilation rate, transpiration, stomatal conductance, and internal concentration of CO_2. These parameters provide useful information about the vital processes of vegetable metabolism (Taiz & Zeiger, 2013). These parameters were also used in a study regarding the vegetative growth of citrus species throughout the year in association with seasons by Ribeiro & Machado (2007) and Ramos et al. (2010).

Knowing the physiological behavior of plants in response to environmental factors allows inferences about their development and their ability to adapt to surrounding climatic conditions. Thus, in the process of identifying promising cultivars for the southern conditions of state of Minas Gerais, Brazil; this work aimed to evaluate the climatic effects on gas exchanges in selected citrus cultivars during the early years of cultivation.

MATERIAL AND METHODS

The experiment was carried out in an experimental area located at 21° 14 43 S and 44° 59 59 W of Greenwich longitude. According to Köppen climatic classification, the climate is Cwa and is characterized by a dry winter and a rainy summer, with an annual average temperature of 22 °C and 1530 mm of annual rainfall. The soil type of the experimental area was latosol, and soil pH was corrected and fertilized following chemical analysis according to Mattos Júnior et al. (2005) prior to planting.

The following cultivars were evaluated: Clemenules (*C. reticulata* Blanco), satsuma Okitsu (*C. unshiu* Marcovitch), tangor Ortanique (*C. sinensis* (L.) Osbeck x *C. reticulata* Blanco) and the oranges Navelina, Navelate and Lanelate (*Citrus sinensis* (L.) Osbeck). All cultivars were grafted onto *Poncirus trifoliata* (L.) Raf and planted in September of 2011 in a 6 m by 4 m area. A randomized block experimental design was utilized, with 4 replications and 4 plants per plot in a factorial scheme with 6 cultivars x 2 years (2012 and 2013) x 4 seasons (spring, summer, autumn and winter). The environmental parameters of maximum and minimum air temperatures and precipitation totals are presented in Figure 1.

The evaluations were carried out using the following physiological variables of gas exchange: CO_2 assimilation rate (*A*), transpiration (E), stomatal conductance (gs), internal carbon (Ci), deficit of water vapor pressure (Vpda), relation between internal carbon dioxide and atmospheric pressure (CiPa), ratio of internal and external carbon concentration (CiCa), water efficiency use (WEU), and instantaneous carboxylation efficiency (A/Ci). These measurements were obtained from 8 fully expanded leaves, similar in size and age and located at the top of the branch of each cultivar studied. The evaluations were performed between 9:00 AM and 10:30 AM with a portable infrared gas analyzer (IRGA) (Li-6400, LI-COR, Nebraska, USA) following the procedure described by Vu et al. (1986). The irradiance used inside the IRGA chamber at the time of reading was standardized to

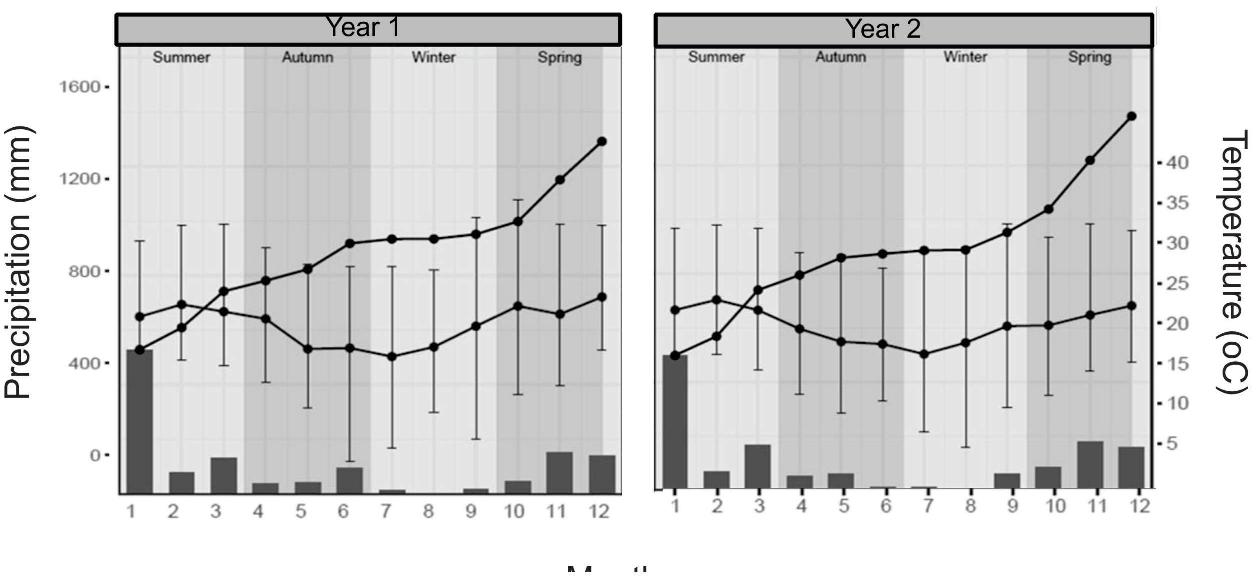

Figure 1. Precipitation and temperature data observed during the 2 years of evaluation by season.

1800 µmol photon m^{-2} s^{-1} to prevent the temporary effects of variation on the ecophysiological responses in response to detrimental cloud-induced shading. The applied irradiance value, 1800 µmol photon m^{-2} s^{-1}, was calibrated admitted after observing the irradiance incident at experiment. Readings of incident irradiance were made at different points within the experiment in areas completely exposed to radiation and at full sun.

All the data obtained were evaluated by univariate analysis and by canonical evaluation using software R (R Development Core Team, 2015).

RESULTS AND DISCUSSION

The mean values obtained in the univariate analysis results for all the parameters evaluated in this study are presented in Tables 1 and 2 for oranges and tangerines, respectively. These results indicated no statistically significant differences in the gas exchange parameters to separate the orange trees belonging to the genus *Citrus sinensis.* Differences among the cultivars were found only in the years and seasons studied (Table 1). For tangerines and hybrids, the distinction occurred only in *A* and Vpda for cultivar Okitsu, which presented higher values compared to the others (Table 2), possibly due to its genetic constitution.

In all studied cultivars, the average values of *A* were lowest during the winter and highest in the summer when compared to the other seasons. The low water availability due to the decreased rainfall over the study period, as well as the low temperatures common to winter in the region (Figure 1), explain this behavior, which was similar to that reported by Ribeiro et al. (2009) and Machado et al. (2010).

According to Taiz & Zeiger (2013), *A* values for citrus plants vary from 10 to 20 µmol m^{-2} s^{-1}. In the present study, this range was recorded for all cultivars only in the second year of evaluation. This may be indicative of photosynthetic apparatus organization that had not yet occurred in the first year when there was variation of this parameter and predominated values lower than 10 µmol m^{-2} s^{-1}. In this case, the results corroborate with those reported by Machado et al. (2002) and Jifon & Syvertsen (2003) and Magalhães, 2008; and are associated to the adaptive process.

The gs values showed patterns similar to *A* (Table 1), which suggests that the fluctuations in this variable are related to partial stomata closure (Konrad et al., 2005), which was also demonstrated by Medina et al. (1999) for the Valencia orange. The seasonal variation of *A* and gs for tree species is related to water vapor pressure conditions and soil moisture, which are characteristic of each season (Silva et al., 2004).

According to Lisar et al. (2012), Ci values for citrus generally vary from 200 to 250 µmol mol^{-1}. When values fall below this range, which is typical of the seasons with low precipitation, damages may occur in the photosynthetic

Table 1. Mean values of CO_2 assimilation rate *(A)* (µmol m^{-2} s^{-1}); stomatal conductance (gs) (mmol m^{-2} s^{-1}); internal carbon (Ci) (mmol m^{-2} s^{-1}); transpiration (E) (mol); vapor pressure deficit (Vpda); ratio of internal carbon and atmospheric pressure (CiPa); ratio of carbon internal and external concentration (CiCa), water efficiency use (WEU), and carboxylation efficiency (A/Ci)

Parameters/	Cultivars	Sweet oranges First year				Second year			
		Summer	Autunm	Winter	Spring	Summer	Autunm	Winter	Spring
A	Lanelate	14.12Aaa	9.28Abb	6.79Abb	7.47Abb	15.05Aaa	10.09Aba	11.27Aba	10.86Aba
	Navelate	11.28Aaa	9.78Aba	7.33Aba	7.90Abb	14.60Aaa	11.18Aba	10.60Aba	10.15Aba
	Navelina	11.88Aaa	9.17Aba	7.72Abb	7.77Abb	14.84Aaa	11.39Aba	12.24Aba	12.30Aba
gs	Lanelate	0.20Aaa	0.09Aba	0.20Aab	0.07Aba	0.16Aaa	0.18Aaa	0.05Aaa	0.12Aaa
	Navelate	0.20Aba	0.11Aaa	0.17Aaa	0.08Aaa	0.20Aaa	0.10Aaa	0.06Aaa	0.09Aaa
	Navelina	0.22Aaa	0.09Aba	0.21Aaa	0.09Aba	0.20Aaa	0.17Aaa	0.07Aab	0.15Aaa
Ci	Lanelate	240.61Aba	185.37Aaa	198.45Aaa	236.17Aaa	280.46Aaa	191.85Aaa	154.35Aaa	235.05Aaa
	Navelate	246.87Aaa	205.20Aaa	203.20Aaa	220.78Aaa	256.24Aaa	183.51Aaa	174.79Aaa	249.98Aaa
	Navelina	241.79Aaa	197.98Aaa	216.42Aaa	242.45Aaa	286.81Aaa	216.94Aaa	189.81Aaa	256.20Aaa
E	Lanelate	4.42Aaa	1.33Aba	2.39Aba	2.09Abb	3.96Aaa	2.63Aaa	0.95Abb	3.05Aaa
	Navelate	4.49Aaa	1.55Aba	2.19Aba	2.38Aba	4.67Aaa	1.63Aba	1.12Aba	2.50Aba
	Navelina	4.80Aaa	1.31Aba	2.50Aba	2.59Aba	4.73Aaa	2.25Aca	1.16Adb	3.38Aba
Vpda	Lanelate	2.00Aaa	1.29Aba	1.00Aba	2.34Aaa	2.26Aaa	1.36Aba	1.42Aba	2.33Aaa
	Navelate	2.00Aaa	1.27Aba	1.06Aba	2.32Aaa	2.11Aaa	1.36Aba	1.45Aba	2.37Aaa
	Navelina	1.93Aaa	1.25Aba	1.04Aba	2.24Aaa	2.11Aaa	1.28Aba	1.39Aba	2.18Aaa
CiPa	Lanelate	22.12Aaa	17.11Aaa	21.72Aaa	18.17Aaa	25.73Aaa	21.58Aaa	14.25Aaa	17.65Aaa
	Navelate	22.70Aaa	22.70Aaa	18.94Aaa	20.20Aaa	22.96Aaa	23.51Aaa	16.14Aaa	16.88Aaa
	Navelina	22.23Aaa	18.28Aaa	22.29Aaa	19.82Aaa	23.16Aaa	26.31Aaa	17.52Aaa	19.96Aaa
CiCa	Lanelate	0.69Aaa	0.51Aaa	0.65Aaa	0.55Aaa	0.65Aaa	0.63Aaa	0.40Aab	0.50Aaa
	Navelate	0.71Aaa	0.57Aaa	0.60Aaa	0.56Aaa	0.70Aaa	0.56Aaa	0.46Aab	0.48Aaa
	Navelina	0.70Aaa	0.55Aaa	0.66Aaa	0.59Aaa	0.70Aaa	0.62Aaa	0.50Aaa	0.57Aaa
WEU	Lanelate	2.57Aca	7.52Aaa	6.35Abb	3.25Aca	3.89Aca	7.07Aba	8.01Abb	3.89Aaa
	Navelate	2.57Aca	7.52Aaa	6.35Abb	3.25Aca	2.43Aca	5.65Baa	7.10Baa	4.08Abb
	Navelina	2.59Aca	7.16Aaa	5.95Abb	3.11Aca	2.43Ada	5.92Bbb	6.86Baa	3.68Aca
A/Ci	Lanelate	0.046Aba	0.049Aba	0.063Aaa	0.034Acb	0.046Aba	0.053Aaa	0.048Abb	0.061Aaa
	Navelate	0.043Aba	0.045Aba	0.066Aaa	0.036Abb	0.045Aba	0.047Aba	0.045Abb	0.057Aaa
	Navelina	0.050Aba	0.046Aba	0.061Aaa	0.035Acb	0.045Aba	0.050Aaa	0.040Abb	0.057Aaa

Capital letters in column compares cultivars in same season and same year; Lowercase letters in same row compares seasons in same year and same cultivar; Lowercase letters underlined in same row compares seasons in different years and same cultivar.

apparatus due to water stress (Lisar et al., 2012). The lowest values of Ci were recorded for Lanelate in autumn and winter and reflected negatively on the *A* of this cultivar, which differs from the other cultivars in this experiment as it does not belong to Navel orange group.

The orange cultivars presented similar behavior for WEU in the period of low precipitation, and Lanelate stood out with higher values for this variable in the second year of cultivation (Table 1). Considering that gas exchange is regulated by the stomatal opening and regulates water loss at same time, these results may indicate a greater efficiency in water extraction from the soil of this cultivar and, consequently, a potential adaptation. This can be confirmed by an optimum standard of WEU that demonstrated reduced water loss with maximum CO_2 absorption, which was also demonstrated by Shimazaki et al. (2007), Lisar et al. (2012), and Taiz & Zeiger (2013). In this context, the importance of optimal root system development for the process of water absorption is highlighted by the influence of the rootstock and its interaction with the scion and the metabolism and development of plants (Brito et al., 2012).

Table 2. Mean values of CO_2 assimilation rate *(A)* (μmol m^{-2} s^{-1}); stomatal conductance (gs) (mmol m^{-2} s^{-1}); internal carbon (Ci) (mmol m^{-2} s^{-1}); transpiration (E) (mol); vapor pressure deficit (Vpda); ratio of internal carbon and atmospheric pressure (CiPa); ratio of carbon internal and external concentration (CiCa); water efficiency use (WEU); and carboxylation efficiency (A/Ci)

TANGERINES									
Parameters/ Cultivars		First year				Second year			
		Summer	Autunm	Winter	Spring	Summer	Autunm	Winter	Spring
A	Clemenules	12.65Aaa	10.77Aaa	8.58Aaa	7.40Aaa	8.62Aaa	9.72Aaa	7.24Aab	7.32Aaa
	Okitsu	13.79Aaa	9.17Aaa	4.77Bbb	11.42Aaa	10.34Aaa	10.248Aaa	8.32Aab	9.71Aaa
	Ortanique	14.54Aaa	9.56Aba	8.94Aba	8.35Aba	10.99Aaa	10.50Aaa	6.81Abb	8.15Aaa
gs	Clemenules	0.14Aaa	0.12Aaa	0.17Aaa	0.08Aba	0.12Aaa	0.11Aaa	0.05Aaa	0.04Aaa
	Okitsu	0.07Aba	0.11Aba	0.24Aaa	0.17Aaa	0.17Aaa	0.15Aaa	0.08Aaa	0.08Aaa
	Ortanique	0.15Aaa	0.11Aba	0.25Aaa	0.10Aba	0.17Aaa	0.12Aaa	0.05Aab	0.05Aaa
Ci	Clemenules	231.54Aaa	210.41Aaa	229.77Aaa	191.69Aaa	232.57Aaa	222.59Aaa	159.43Aba	110.02Aba
	Okitsu	223.06Aaa	214.48Aaa	255.29Aaa	229.73Aaa	243.64Aaa	249.60Aaa	193.12Aaa	168.99Aaa
	Ortanique	237.92Aaa	217.74Aaa	238.45Aaa	192.85Aaa	237.48Aaa	214.35Aaa	162.71Aaa	125.38Aba
E	Clemenules	4.20Aaa	2.00Aba	2.35Aba	2.47Aba	3.83Aaa	2.77Aaa	0.98Abb	1.47Aba
	Okitsu	2.42Bba	1.84Aba	3.07Aba	4.32Aaa	4.60Aaa	3.18aaA	1.31bbA	2.50bbA
	Ortanique	4.24Aaa	1.85Aba	2.82Aba	2.81Aba	4.83Aaa	2.99baA	0.94cbA	1.78caA
Vpda	Clemenules	2.67Baa	1.48Abb	1.14Aba	2.55Aaa	2.62Aaa	2.18aaA	1.50baA	2.66aaA
	Okitsu	3.03Aaa	1.51Acb	1.11Aaa	2.21Aba	2.43Aaa	2.04baA	1.45baA	2.56aaA
	Ortanique	2.48Baa	1.47Abb	1.06Aba	2.50Aaa	2.51Aaa	2.29baA	1.51baA	2.68aaA
CiPa	Clemenules	21.30Aaa	19.42Aaa	21.14Aaa	17.56Aaa	21.37Aaa	20.43aaA	14.73baA	10.13bbA
	Okitsu	20.52Aaa	19.80Aaa	23.49Aaa	21.05Aaa	22.39Aaa	22.92aaA	17.84aaA	15.56aaA
	Ortanique	21.88Aaa	20.10Aaa	21.94Aaa	17.67Aaa	21.82Aaa	19.67aaA	15.03bbA	11.54baA
CiCa	Clemenules	0.67Aaa	0.59Aaa	0.64Aaa	0.54Aaa	0.64Aaa	0.57aaA	0.42bbA	0.28bbA
	Okitsu	0.63Aaa	0.59Aaa	0.71Aaa	0.65Aaa	0.67Aaa	0.63aaA	0.51bbA	0.44bbA
	Ortanique	0.68Aaa	0.60Aaa	0.67Aaa	0.54Aaa	0.66Aaa	0.55aaA	0.43baA	0.33bbA
WEU	Clemenules	2.00Aaa	5.38Aaa	5.48Aab	3.02Aab	2.28Aaa	3.69Aab	7.51Aba	5.14Aaa
	Okitsu	1.94Baa	5.15Aaa	4.49Bbb	2.66Bab	2.26Aaa	3.33Aab	6.53Baa	4.08Bba
	Ortanique	2.07Aca	5.20Aaa	5.29Aab	3.01Aab	2.32Aaa	3.63Aab	7.28Aba	4.69Baa
A/Ci	Clemenules	0.037Aaa	0.051Aaa	0.045Aaa	0.038Bab	0.037Aaa	0.043Aaa	0.045Aaa	0.068Aaa
	Okitsu	0.021Abb	0.043Aaa	0.044Aaa	0.050Aaa	0.042Aaa	0.040Aaa	0.042Aab	0.057Aaa
	Ortanique	0.037Aaa	0.043Aaa	0.042Aaa	0.044Baa	0.046Aaa	0.048Aaa	0.042Aab	0.071Aab

Capital letters in column compares cultivars in same season and same year; Lowercase letters in same row compares seasons in same year and same cultivar; Lowercase letters underlined in same row compares seasons in different years and same cultivar.

The results of the canonical analysis for orange trees in the first year demonstrated that 98.33% of the total variance was explained by the first two canonicals (77.81% and 20.53% for the first and second canonical, respectively) (Figure 2). In the 2 canonical variables evaluating the physiological parameters in the first year of evaluation, the WEU obtained a high score with a positive value, which negatively correlated with the Vpda. This may be associated with the humidity variation that acts as a mechanism to prevent water loss. When analyzing the treatment scores, it was observed that in the winter and autumn seasons the 3 orange cultivars presented WEU higher values and lower Vpda values. On the contrary, spring and summer presented a higher positive correlation with reduced WEU and increased Vpda (Figure 2B). This indicates that the 3 orange cultivars studied in this assay probably have the ability to increase WUE in low rainfall periods despite having lower values of Vpda and a subsequent reduction of availability water for the plants.

In the second year, the total variance explained by the first 2 canonical variables was 95.84%. The first and second canonical variances were 83.81% and 12.03%,

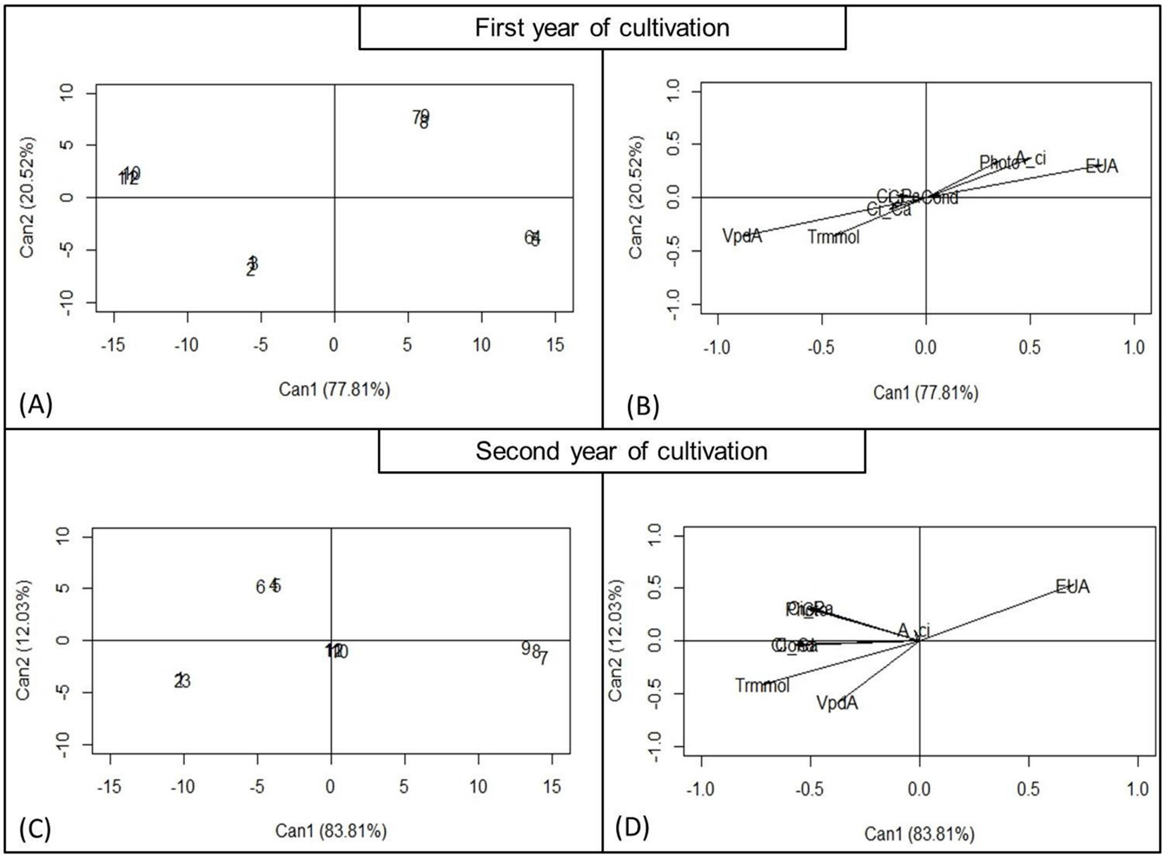

Figure 2. Biplot showing first 2 axes of canonical analysis for cultivar data (A and C) and ecophysiological parameters (B and D) evaluated in 2 years of tangerine tree cultivation. Numeric representation refers to the cultivars Navelina, Navelate, and Lanelate in the following seasons: 1, 2, and 3 in summer; 4, 5, and 6 in autumn; 7, 8, and 9 in winter; and 10, 11, and 12 in spring. Description of ecophysiological parameters presented on (B) and (D): *A*, photosynthesis; gs, stomatal conductance; Ci, internal carbon; R, transpiration; Vpda, vapor pressure deficit; CiPa, ratio of internal carbon and atmospheric pressure; CiCa, ratio of carbon internal and external concentration; WEU, water efficiency use; and A/Ci, carboxylation efficiency.

respectively (Figure 2C). In this situation, the WEU also presented a high score with a positive value, but negatively correlated with E. After analysis of the results, it was observed that all the orange cultivars presented higher WEU values and lower E values primarily during the winter. In the summer, these cultivars were allocated to the left, indicating contrary behavior. In this case, the Vpda was an important variable to compose the second canonical, where the cultivars stood out in the fall season presenting lower values of this variable (Figure 2D).

For the group of mandarins and hybrids, the total variance explained by the first 2 canonical variables is presented in Figure 3. In the first year of cultivation, Vpda indicated a high score with a positive value, while negatively correlating with WUE. All cultivars presented higher values of WEU and lower values of Vpda and the opposite was observed in the summer, where the cultivars were allocated to the left (Figure 3). Considering canonical 2, the parameters gs and CiCa presented negative values, which was important in differentiating the Okitsu behavior of Clemenules and Ortanique in the spring and summer seasons. This may indicate that Okitsu had increased gs and CiCa values in the summer and decreased values in spring (Figure 3B).

The differences observed between cultivars in the first year of tangerine cultivation did not persist in the second year (Figure 3C). The canonical variable scores of the measured ecophysiological parameters in the second year presented a high score with a positive value for Vpda, while negatively correlating with the WEU (Table 3). The treatment scores and seasonal comparisons

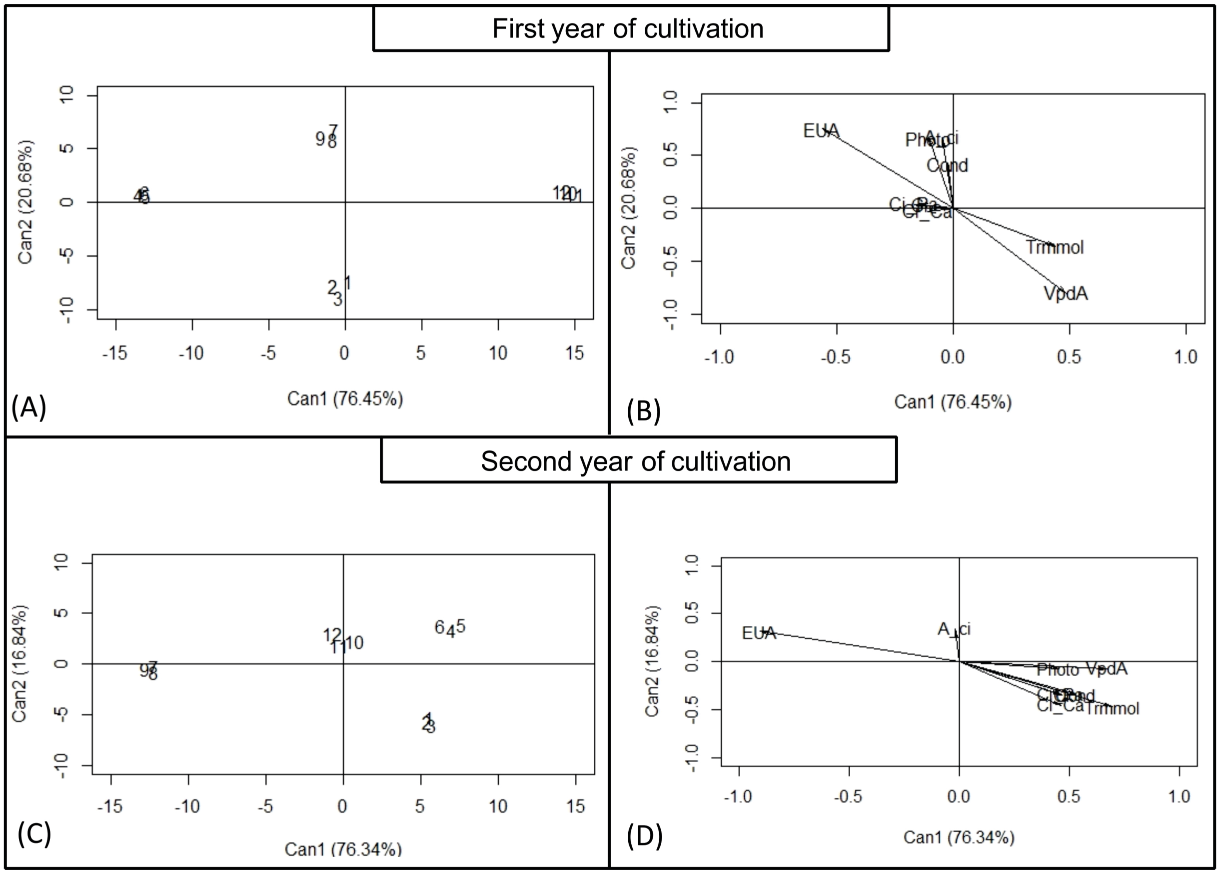

Figure 3. Biplot showing first 2 axes of canonical analysis for cultivars data (A and C) and ecophysiological parameters (B and D) evaluated in 2 years of tangerine tree cultivation. Numeric representation refer to the cultivars Ortanique, Okitsu, and Clemenules in the following seasons: 1, 2, and 3 in summer; 4, 5, and 6 in autumn; 7, 8, and 9 in winter and 10, 11, and 12 in spring. Description of ecophysiological parameters presented on (B) and (D): *A*, photosynthesis; gs, stomatal conductance; Ci, internal carbon; R, transpiration; Vpda, vapor pressure deficit; CiPa, ratio of internal carbon and atmospheric pressure; CiCa, ratio of carbon internal and external concentration; EUA, water efficiency use; and A/Ci, carboxylation efficiency.

Table 3. Correlation matrices of the first 2 canonical variables (Can 1 and Can 2) of ecophysiological characteristics observed in first and second year of orange tree cultivation

Physiological parameters	Sweet oranges			
	First year		Second year	
	Can 1	Can 2	Can 1	Can 2
A	0.3577	0.3490	-0.517	0.3132
gs	0.0641	0.0205	-0.5738	-0.0278
Ci	-0.1456	0.0261	-0.5007	0.3154
E	-0.4411	-0.3504	-0.7215	-0.4052
Vpda	-0.8805	-0.3548	-0.3791	-0.5830
Ci_Pa	-0.1274	0.0187	-0.4966	0.3135
Ci_Ca	-0.1780	-0.1015	-0.5712	-0.0445
WEU	0.8457	0.3108	0.7050	0.5327
A/Ci	0.5014	0.3786	-0.0241	0.1

Table 4. Correlation matrices of first 2 canonical variables (Can 1 and Can 2) of ecophysiological characteristics observed in first and second year of tangerine group tree cultivation

Physiological parameters	Tangerines group			
	First year		Second year	
	Can 1	Can 2	Can 1	Can 2
A	-0.6293	-0.5819	0.3950	0.1370
gs	-0.3816	-0.7262	0.3726	0.3953
Ci	-0.1061	-0.6573	0.2387	0.3497
E	0.5242	-0.6286	0.5494	0.5716
Vpda	0.9318	0.2597	0.7811	0.2678
Ci-Ca	-0.025	-0.6959	0.2255	0.4641
WUE	-0.9333	0.0762	-0.8177	-0.4798
A/Ci	-0.6078	-0.3495	0.2190	-0.2562

demonstrated that in the winter, the 3 cultivars presented higher values of WEU and lower values of Vpda, and the inverse was observed in the other seasons. Considering canonical 2, both the *E* and the WEU efficiency parameters were negatively correlated (Table 4), indicating the lower values of *E* contributed to the increase in WEU in the winter for all cultivars.

CONCLUSIONS

During periods of low rainfall and reduced water availability, all orange cultivars had increased WEU values and reduced Vpda values, indicating higher water use efficiency. The cultivar Lanelate showed higher WEU values in the second year of cultivation. The Okitsu cultivar differed from the other tangerines studied in the conductance and internal and external carbon concentration parameters in summer and spring.

REFERENCES

Brito MEB, Soares LAA, Fernandes PD, Lima GS, Sá FVS & Melo AS (2012) Comportamento fisiológico de combinações copa/porta-enxerto de citros sob estresse hídrico. Agrária 7(Suppl): 857-865. http://dx.doi.org/10.5039/agraria.v7isa1941.

Dzikiti S, Verreynne SJ, Stuckens J, Strever A, Verstraeten WW, Swennen R, Theron KI & Coppin P (2011) Seasonal variation in canopy reflectance and its application to determine the water status and water use by citrus trees in the Western Cape, South Africa. Agricultural and Forest Meteorology 151(8): 1035-1044. http://dx.doi.org/10.1016/j.agrformet.2011.03.007.

Jifon JL & Syvertsen JP (2003) Moderate shade can increase net gas exchange and reduce photoinhibition in citrus leaves. Tree Physiology 23(2): 119-127. PMid:12533306. http://dx.doi.org/10.1093/treephys/23.2.119.

Johnson K, Sankaran S & Ehsani R (2013) Identification of water stress in citrus leaves using sensing technologies. Agronomy 3(4): 747-756. http://dx.doi.org/10.3390/agronomy3040747.

Konrad MLF, Silva JAB, Furlani PR & Machado EC (2005) Trocas gasosas e fluorescência da clorofila em seis cultivares de cafeeiro sob estresse de alumínio. Bragantia 64(3): 339-347. http://dx.doi.org/10.1590/S0006-87052005000300004.

Lisar SYS, Motafakkerazad R, Hossain MM & Rahman IMM (2012) Water stress in plants: causes, effects and responses. In: Rahman M & Hasegawa H (Eds). Water stress. Rijeka: Tech, p. 1-14.

Machado DFSP, Machado EC, Machado RS & Ribeiro RV (2010) Efeito da baixa temperatura noturna e do porta-enxerto na variação diurna das trocas gasosas e na atividade fotoquímica de laranjeira Valência. Revista Brasileira de Fruticultura 32(2): 351-359. http://dx.doi.org/10.1590/S0100-29452010005000064.

Machado EC, Medina CL, Gomes MMA & Habermann G (2002) Variação sazonal da fotossíntese, condutância estomática e potencial da água na folha de laranjeira Valência. Scientia Agrícola 59(1): 53-58. http://dx.doi.org/10.1590/S0103-90162002000100007.

Mattos Júnior D, Bataglia O & Quaggio JÁ (2005) Nutrição dos citros. In: Mattos Júnior D, JD Negri, RM Pio & J Pompeu Junior (Eds). Citros. Campinas: Instituto Agronômico: Fundag, p. 198-219.

Medina CL, Machado EC & Gomes MMA (1999) Condutância estomática, transpiração e fotossíntese em laranjeira Valência sob deficiência hídrica. Revista Brasileira de Fisiologia Vegetal 11(1): 29-34.

R Development Core Team (2015). R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. Available from: <http://www.R-project.org/>. Accessed: 5 Jan. 2017.

Ramos RA, Ribeiro RVR, Machado EC & Machado RS (2010) Variação sazonal do crescimento vegetativo de laranjeiras Hamlin enxertadas em citrumeleiro Swingle no município de Limeira. Estado de São Paulo Acta Scientiarum Agronomy 32(3): 539-545.

Ribeiro RV & Machado EC (2007) Some aspects of citrus ecophysiology in subtropical climates: revisiting photosynthesis under natural conditions. Brazilian Journal of Plant Physiology 19(4): 393- 411. http://dx.doi.org/10.1590/S1677-04202007000400009.

Ribeiro RV, Machado EC, Santos MG & Oliveira RF (2009) Photosynthesis and water relations of well-watered orange plants as affected by winter and summer conditions. Photosynthetica 47(2): 215-222. http://dx.doi.org/10.1007/s11099-009-0035-2.

Sentelhas PC (2005) Agrometeorologia dos citros. In: Mattos Júnior D, JD Negri, RM Pio & J Pompeu Junior (Eds). Citros. Campinas: Instituto Agronomico, Fundag p. 319-344.

Shimazaki KI, Doi M, Assmann SM & Kinoshita T (2007) Light regulation of stomatal movement. Annual Review of Plant Biology 58(1): 219-247. PMid:17209798. http://dx.doi.org/10.1146/annurev.arplant.57.032905.105434.

Silva EA, Matta FM, Ducatti C, Regazzi AJ & Barros RS (2004) Seasonal changes in vegetative growth and photosynthesis of *arabica coffee* trees. Field Crops Research 89(2-3): 349-357. http://dx.doi.org/10.1016/j.fcr.2004.02.010.

Spiegel-Roy P & Goldschmidt EE (1996) Biology of citrus. Cambrigde: Cambridge University Press. 230 p.

Taiz L & Zeiger E (2013) Fisiologia vegetal. 5. ed. Porto Alegre: ArtMed. 959 p.

Vu JCV, Yelenosky G & Bausher MG (1986) CO2 exchange rate, stomatal condutance, and transpirationin attached leaves of Valência orange. HortScience 21(1): 143-144.

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